A PALEOECOLOGICAL INTERPRETATION FOR THE OSTRACODES AND AGGLUTINATED FORAMINIFERA FROM THE EARLIEST CARBONIFEROUS MARGINAL MARINE HORTON BLUFF FORMATION (BLUE BEACH MEMBER), NOVA SCOTIA, CANADA

by

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*To Dylan, Chloë, Lisa, and Yellow Dog. Without their support
and understanding this thesis would never have been.*

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Abstract

The shales, siltstones and dololutites of the Blue Beach Member (Horton Bluff Formation) contain a rich assemblage of ostracodes, agglutinated foraminifera, serpulid worms, palaeoniscid fish, crossopterygian fish, tetrapod trackways, and fossil macrophytes. The ostracodes from Blue Beach were previously interpreted as nonmarine. A re-evaluation of the taxa, however, indicates that most had brackish/marine affinities. This paleoecological information combined with the first reported occurrence of glaucony grains suggest a marine influence on the depositional system.

The shallowing upward sedimentary cycles contain five faunal assemblages as follows: 1. the profundal lagoon dominated by the euryhaline marine *Copelandella novascotica* associated with glauconitic shale and primary pyrite; 2. the restricted nearshore dominated by opportunistic paraparchitaceans (*Shemonaella scotoburdigalensis*, *Shemonaella tatei*, and *Chamishaella sp.*), *Cavellina lovatica?*, and post mortem *Carbonita scalpellus* all associated with hummocky cross-stratified siltstone and shale; 3. the upper estuary dominated by *C. scalpellus* and *Carbonita rankiniana* associated with pedoturbated calcareous mudstones; 4. the distal lagoon dominated by paraparchitaceans, *Bairdia pruniseminata*, *Geisina sp.*, and *Youngiella sp.* all associated with silty glauconitic shale; and 5. the infringing marsh dominated by the agglutinated foraminifera *Trochammina sp.* associated with calcareous mudstones and in situ plants.

Low diversity, large populations, and dominance characterise the microfossil assemblages resembling recent stressed ecosystems where physical and chemical conditions are unstable. Deposition of these marginal marine sediments occurred during a Tournaisian transgressive pulse in the earliest stages of the Maritimes Basin.

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CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

The Blue Beach Member (BBM) (Martel and Gibling, 1996) of the Horton Bluff Formation (HBF) contains abundant fossil macrophytes (plants), palaeoniscid fish, and scarce invertebrate macrofossils previously interpreted as a fresh water assemblage. The 250 m of BBM strata from the coastal outcrop at Blue Beach near Hantsport Nova Scotia (Figs. 1.1 and 1.2) differ both lithologically and paleontologically from the other three members. Researchers have attempted to explain these differences using all the information available and some have even suggested a marine connection. The lack of well-known marine macrofossils and the presence of fresh water plant fossils makes a saline interpretation difficult to justify. A paleoecological study using updated ostracode taxa and recently discovered foraminiferal assemblages, all with marine/brackish water affinities, will help test the hypothesis that the Blue Beach Member of the Horton Bluff Formation was deposited in a marginal marine environment.

1.2 BASIN SETTING

The Horton Group (Fig. 1.1), the basal stratigraphic unit of the Maritimes Basin, is a siliciclastic unit containing conglomerates, sandstones, and shales. The Horton strata in the Minas Basin area rest both unconformably upon the Cambrian-Ordovician Meguma Group (Meguma Terrane) and nonconformably over Late Devonian intrusive granites (Figs. 1.1, 1.2, and 1.3). The northern margin of the Windsor Subbasin is bounded by the Chedabucto-Cobequid Fault where the Horton Group is juxtaposed against rocks of the Avalon Terrane. Schenk (1991) suggested the Meguma and Avalon Terranes were in close proximity during Early to Middle Devonian times. Deep crustal

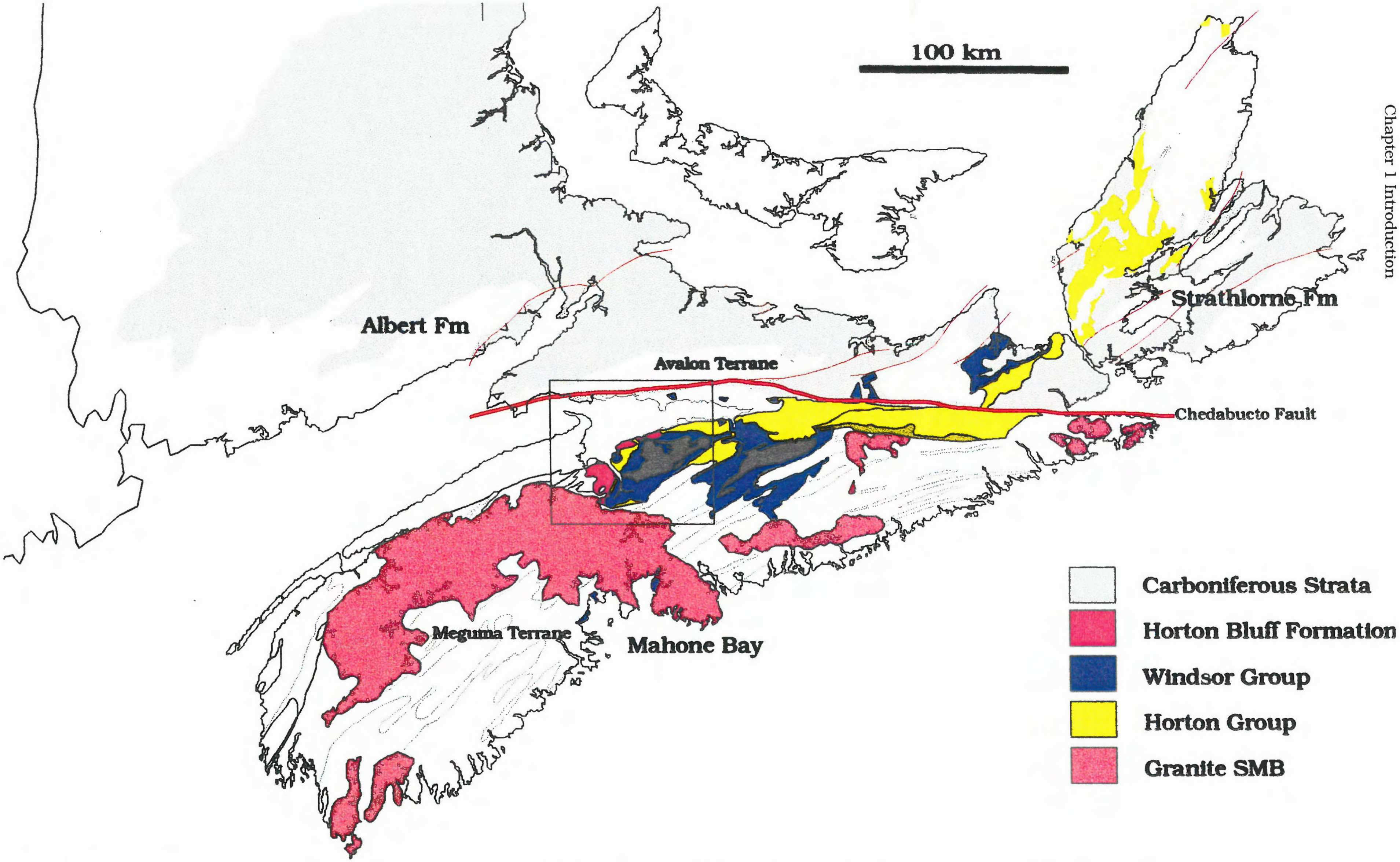


Figure 1.1 The regional geology of Nova Scotia showing the South Mountain Batholith granitic intrusion, the Horton Group, the Windsor Group, and the Horton Bluff Formation (after Keppie, 1979).

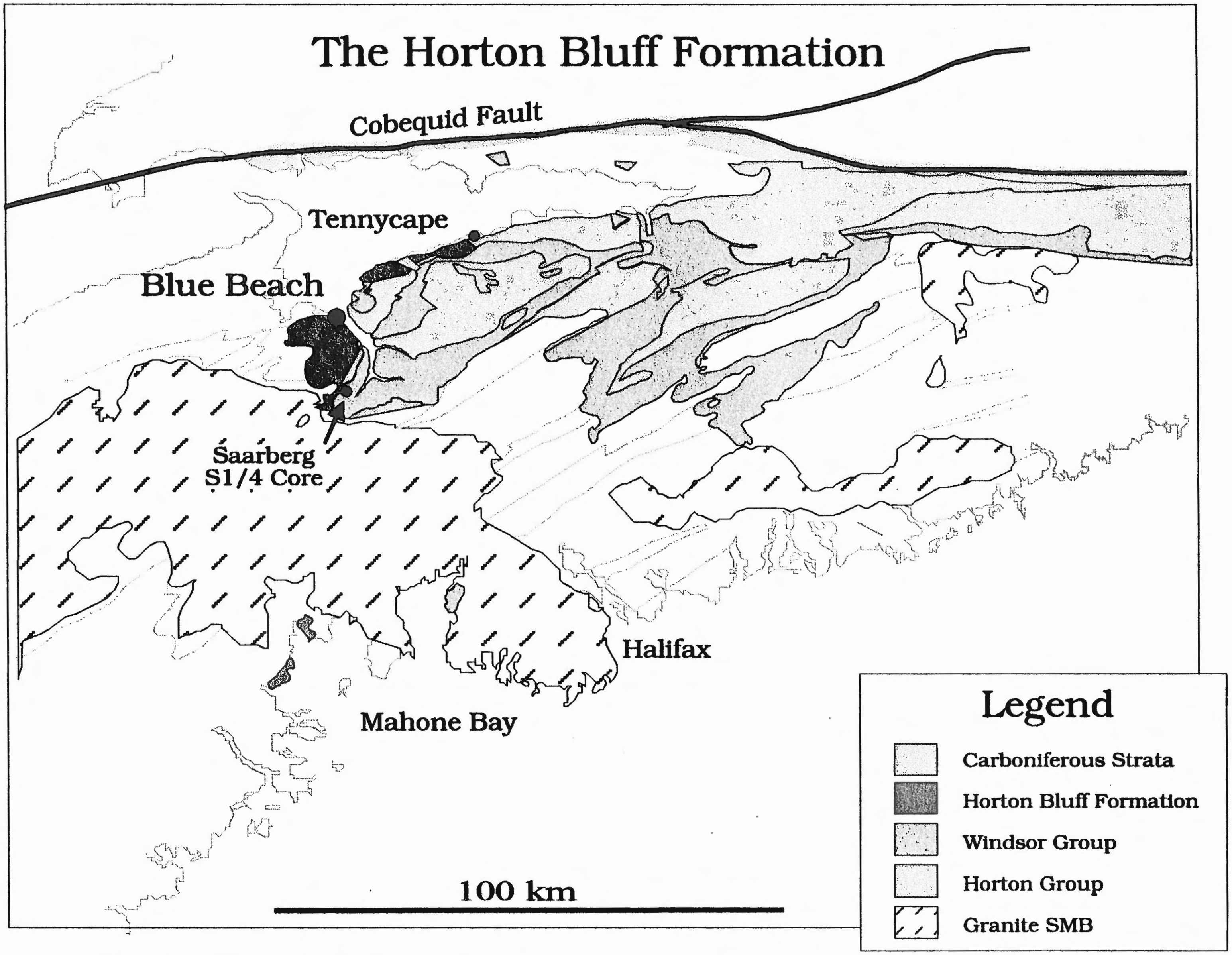


Figure 1.2 The Windsor Subbasin showing the extent of the Horton Bluff Formation. Note north of the HBF is the pre-cursor to the Cobequid Fault which was active during deposition of the Horton Group sediments. Note also the Windsor Gp sediments near Mahone Bay.

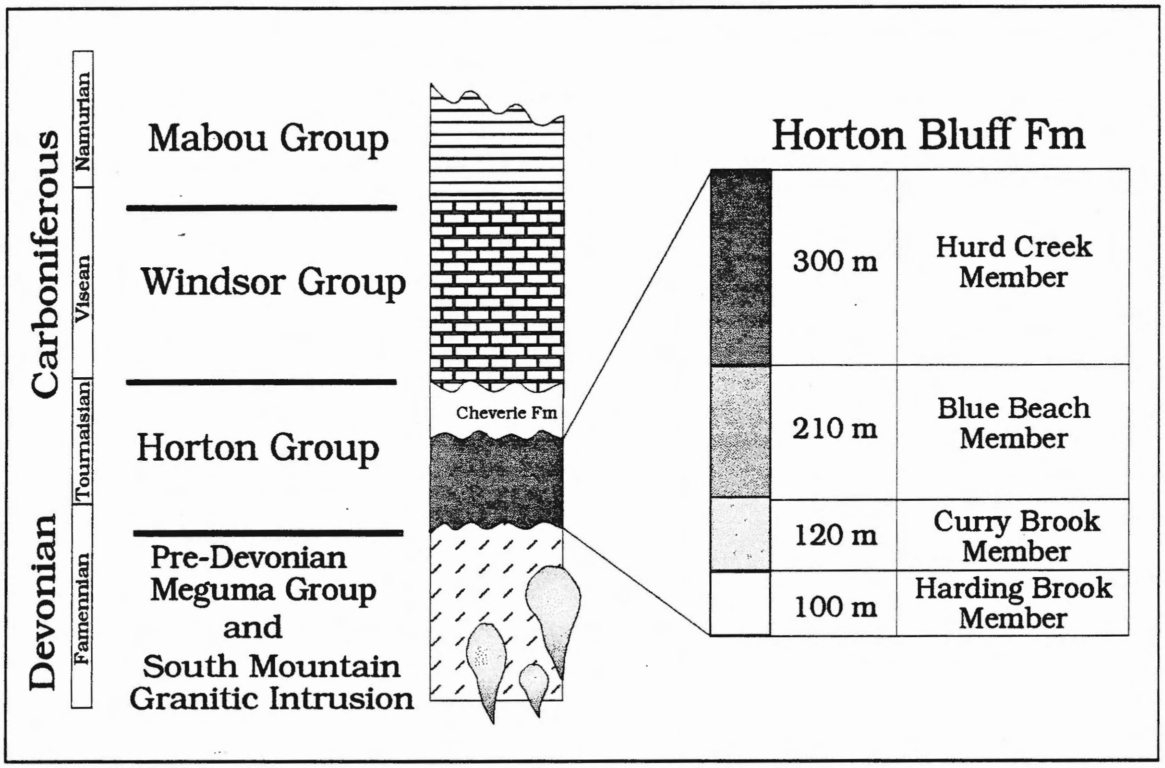


Figure 1.3 The stratigraphy of the Windsor Subbasin (after Martel et al., 1993). Miospores of the Blue Beach Member include the *Spelaeotriletes cabotii* zone dated at approximately 350 Ma (TN2 and TN3 of the Tournaisian Series).

seismic data from the Bay of Fundy (Keen et al., 1991) and geochemical data from the intrusive granites (Tate and Clarke, 1993) provide evidence for subduction of the Meguma terrane under the Avalon Terrane during the late stages of the Acadian Orogeny. By Late Devonian times the high relief of the Cobequid highlands to the north and both the fold and thrust belt of the Meguma and the igneous rocks south of the basin provided the sediment source for the rapidly infilling alluvial depocentre. In general, the Horton sediments in the Minas Basin area thicken northward towards the Cobequid fault suggesting the Windsor Subbasin was a tectonically subsiding, fault-bounded half-graben by Early Carboniferous times (Martel, 1990; Martel and Gibling, 1991, 1996). Palynological data suggest a moderately humid climate corresponding to similar Tournaisian zonations in southwest Ireland, northwest England, and the Visean strata of Nova Scotia (Van Der Zwan et al., 1985).

The Horton Bluff Formation, of the Windsor Subbasin, comprises 730 m of lacustrine strata and is overlain by fluvial strata of the Cheverie Formation (Bell, 1960; Murray, 1960; Martel, 1990; Martel and Gibling, 1991). Murray (1960) correlated the HBF with the Strathlorne Formation in western Cape Breton and the Albert Formation (economic oil shales) in south-eastern New Brunswick. Miospore assemblages suggest a Tournaisian age for the HBF with deposition beginning in the Famennian (Late Strunian) at about 355 Ma (Martel et al., 1993).

Bell (1929, 1960) divided the formation into the Lower Member (fluvial), Middle Member (lower fluvial/upper lacustrine), and Upper Member (lacustrine/deltaic) based on both lithologies and fossil assemblages. Martel (1990) and Martel and Gibling (1996), however, proposed 4 informal members similar to Bell's (1929, 1960) stratigraphic units based on lithological differences only: the Harding Brook Member: the Curry Brook Member: the Blue Beach Member; and the Hurd Creek Member. Table 1.1 provides a description and interpretation for each Member. The study area of this project is the 250 m of coastal section of the Blue Beach Member (BBM) (corresponding

Table 1.1 The four Members of the Horton Bluff Formation and their characteristic features and interpretations (Martel, 1990; Martel and Gibling, 1991, 1994, and 1996).

Member Name	**Sedimentary Features**	**Depositional Interpretation**
Harding Brook Base of HBF (100 m)	cross-bedded sandstone and conglomerate with coarsening-up minor siltstone and mudstone; large sub-angular quartz clasts; unconformably overlies Meguma Terrane	coarser lithologies are fluvial channel while finer coarsening upward siltstones capped by mudstone represent distributary channel deposits
Curry Brook (120 m)	1-4 m thick coarsening-up cycles of bioturbated mudstone prograding upward into ripple and planar laminated sandstone; abundant plant detritus, organic rich horizons, and siderite nodules	distributary channel and interdistributary bayfills; siderite suggests predominantly freshwater influx
Blue Beach (210)	4-15 cycles of locally pyritic and glauconitic fossiliferous shale, hummocky cross-stratified siltstone and sandstones penecontemporaneous dololutite, and minor green mudstones; basal strata contain sparse insitu plant fossils but rich in ostracode, foraminifera, and fish	progradational cycles deposited in wave dominant lakes periodically connected to a marine source (lagoonal); low oxygen in the shale low in the cycles while tops contain shallow sometime subaerial exposure
Hurd Creek (300 m)	coarsening-up cycles of both ripple cross-laminated sandstone and planar/lenticular siltstone dominated; sandstones are up to 8 m in thickness and well sorted with dolomitic nodule and mudstone horizons; lower strata contain insitu tree horizons and tetrapod trackways	wave influenced standing water body with prograding coarser lithologies during periods of increased fluvial recharge

to Bell's upper lacustrine Middle Member) near Hantsport, Nova Scotia (Figs. 1.3 and 1.4).

1.3 SEDIMENTOLOGY

Bell (1929, 1960), Murray (1960), and Hesse and Reading (1978) provided descriptions of the lithologies with fluvial/lacustrine interpretations for the HBF. The sediments occur in coarsening-up packages ranging from approximately 5-20 m in thickness. Cycles of the BBM differ from the other Members as they contain thick sequences of black shale , minor siltstone lenses, and tabular dololutites. Also in-situ plants in the basal cycles are rare and there is a definite absence of siderite nodules common in the other three Members (Martel, 1990). The BBM was interpreted as a lacustrine stage when increased tectonic subsidence, during the Hercynian/Variscan orogeny, caused water to pond on the alluvial plain (Martel, 1990; Martel and Gibling, 1991; Martel and Gibling, 1994).

1.4 PALEONTOLOGY

1.4.1 Overview

Previous work by Bell (1929, 1960) demonstrated an abundance of fresh water plant fossils within the HBF. These plants are usually abundant in the tops of the coarsening-up packages of sediment and represent a fresh-water-dominated depositional phase. The problem is that all the sediments have had a fresh water interpretation based on the plant fossil assemblages in the tops of the cycles. Curiously enough, sampling reveals most of the brackish/marine ostracodes and foraminifera occur mainly within the black shales low in the sedimentary cycles, and commonly occur with petroliferous palaeoniscid fish horizons. This section will provide a brief review of the literature pertaining to the fossil assemblages found in the BBM.

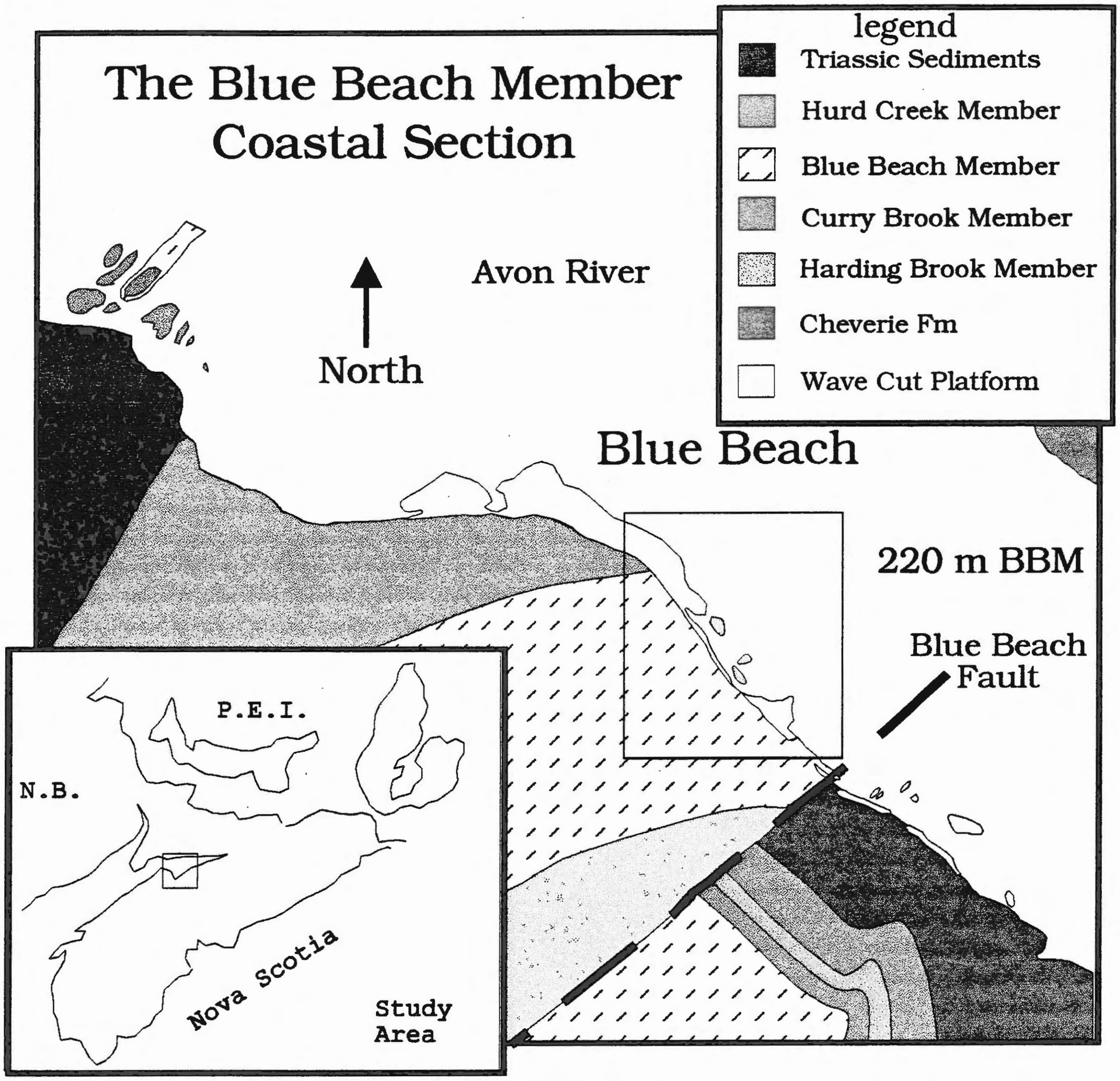


Figure 1.4 The location of the Blue Beach Member (BBM) of the Horton Bluff Formation near Hantsport, Nova Scotia (after Martel, 1990).

1.4.2 Foraminifera and Arcellacea

Foraminifera and Arcellacea are orders of unicellular Protists. There are over 25,000 species identified occupying all marine habitats. The Protists are fairly simple organisms and the shallow water foraminifera appear to have evolved very little since the first forms in the early Paleozoic. Foraminifera and Arcellacea secrete a test, either siliceous, calcareous or tectinous. Most brackish forms of the upper estuarine/marsh areas have an agglutinated test of foreign particles that allow them to withstand low pH/oxygen levels that accompany rapidly changing conditions (Scott and Medioli, 1980). Most estuarine/marsh species have well-known ecological tolerances defined from studies on living specimens.

Recent studies demonstrate that extant Carboniferous agglutinated foraminifera and Arcellacea from the Late Carboniferous Sydney Basin are useful for determining paleoenvironments in coal bearing strata (Thibaudeau, 1993; Wightman, 1993; and Wightman et al., 1993, 1994). Because the genera of foraminifera and Arcellacea from the Carboniferous have living representatives they provide excellent paleoecological indicators.

1.4.3 Ostracoda

Ostracodes are a subclass of sub-ovate bivalved crustaceans, most less than 3 mm in length. The basic morphological characteristic is a bivalved carapace, either calcareous or chitinous, that hinges along the dorsal region of the body (Fig. 1.5). Generally, the shell is ovate in shape and possesses a ventral margin, dorsal margin, and an anterial and posterial zone.

Paleoenvironmental Applications

Ostracodes have many features that make them useful for paleoenvironmental reconstructions (Whatley 1983, 1988). Ostracodes are ubiquitous and occupy all

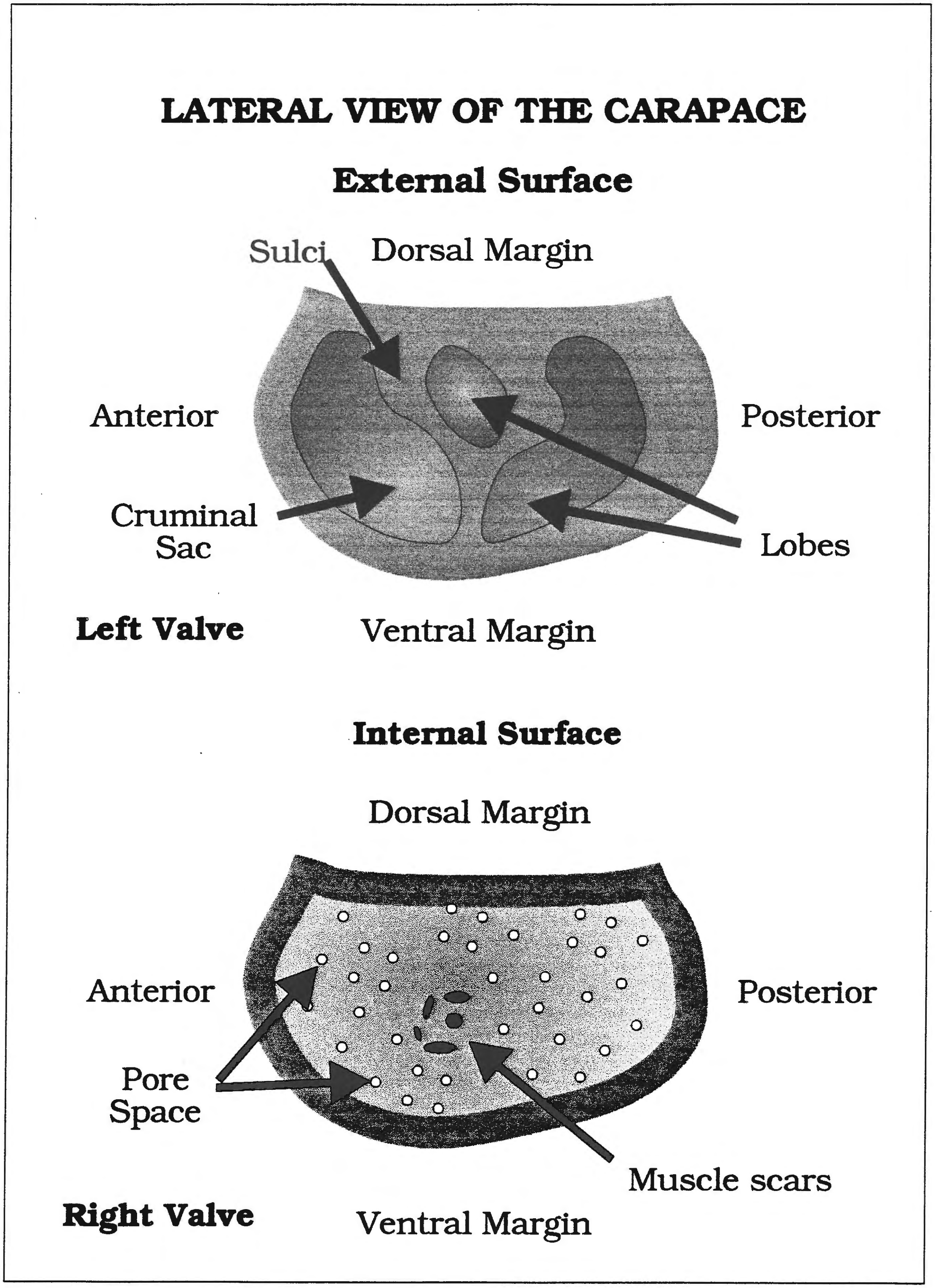


Figure 1.5 The morphological characteristics of the ostracode shell.

aquatic habitats including freshwater, marginal marine, marine, and inland saline water bodies, thus ancient fossil assemblages lend themselves to comparison with modern analogues. In the past 20 years there have been numerous studies on living species. Subsequently, a well-documented and detailed ecological data base of their life-cycles, breeding strategies, and functional morphologies exists. For example: a typical ostracode life span is approximately 60 days (they usually have only 1 generation per year), during which they usually molt 8 or 9 times before the organism reaches maturity (Schweitzer and Lohmann, 1990). This information is important to the paleoecologist as it is possible to distinguish whether or not an assemblage is transported (thanatocoenosis) or in situ (biocoenosis) by observing the proportion of adults to juveniles (see below for detailed discussion). Also, because ostracodes are dimorphic, it is often possible to distinguish between heteromorphs (females) and tecnomorphs (males and juveniles) by the shape and size of the carapace (Scott and Wainwright *cited in* Benson et al., 1961). Not only does this information provide excellent taxonomic criteria but allows inferences to be made as to the breeding strategy of a stressed population. Finally, simple population dynamics such as species diversity and relative distributions, in addition to the above information, make ostracodes invaluable for paleoenvironmental problem solving.

Previous Ostracode Work

The ostracodes of the HBF, which occur almost exclusively in the Blue Beach Member, have long posed a paleoecological problem because of their association with marine macrofossils in other Carboniferous basins. Jones and Kirkby (1884), Bell (1929, 1960), and Bless and Jordan (1971) worked specifically on the ostracodes from Blue Beach (See Chapter 7 Systematic Paleontology). A list of the previously identified and new ostracode taxa are given in Chapter 3 (Table 3.5).

1.4.4 Other Fossils

Palaeoniscid Fish

Much attention at the turn of the century was given to the fossil fish found both at Blue Beach and in the equivalent aged petroliferous shales of the Albert Formation, New Brunswick (Lambe, 1910). The fish comprise three species: *Rhadinichthys alberti* (Jackson) and *Canobius modulus* (Dawson) from the Order Palaeoniscida; and *Streposodus hardingi* (Dawson) allied to the genus *Rhizodus* from the Order Rhyzodontida. One well-preserved jaw was found that is nearly identical to the crossopterygian fish from Dinantian strata in Scotland (Conlan and Hitchcock, pers. comm. 1994; Andrews, 1985).

Tetrapods

Some of the more interesting trace fossils at Blue Beach are the tetrapod trackways. Sarjeant and Mossman (1978) identified *Baropezia sp.*, an amphibian form, and *Anticheiropus bishopi* ichnogen from the class Reptilia. Little information exists on the life styles or paleoecology of these primitive terrestrial/aquatic vertebrates and this study will contribute paleoenvironmental information as to the habitat these animals occupied.

1.5 OBJECTIVES

To interpret the paleoenvironment of the Blue Beach Member a detailed taxonomic and paleoecological study of all the microfossil groups is necessary. To attain this goal there are three primary objectives.

1. Ostracode Taxonomic Review: Most of the previous taxonomic designations and paleoecological interpretations of the ostracodes from the HBF are outdated and inadequate for comparisons with current literature. Therefore, a complete taxonomic and paleoecological revision of the ostracodes at Blue Beach is essential.

2. Foraminifera Identification: The second objective is to provide a detailed taxonomic study of the previously undocumented genera of extant agglutinated foraminifera identified by the author. Because these Protists have living representatives in modern brackish/marine ecosystems and their environmental tolerances are well-documented, they serve as excellent paleoecological indicators (Thibaudeau, 1993; Wightman, 1993; Wightman et al., 1993, 1994).

3. Distribution of Species and the Depositional Environment: The third objective is to relate the distribution of the microfossil assemblages to the lithological changes within the sedimentary record. Trends for the distribution of each microfossil form, with known paleoecological tolerances, will test the hypothesis that the HBF experienced increases in salinity during deposition of the shales.

1.6 SIGNIFICANCE

For the long term, this project will serve to help future researchers on the following:

1. Because the HBF unconformably overlies the Cambrian/Ordovician Meguma Group, it represents one of the first phases of sedimentation in the Maritimes Basin following the Acadian Orogeny (Martel, 1990). Also, recent studies demonstrate a marine influence during deposition of the Late Carboniferous Maritimes Basin. The results from this study contribute significant environmental information pertaining to the evolution of the Maritimes Basin during its earliest stages.

2. The coeval and younger strata in the Maritimes Basin contain similar ostracode assemblages. This updated taxonomic description of the Blue Beach ostracodes will make them useful as paleoenvironmental indicators for future researchers studying in the Maritimes Basin.

3. The trackways of primitive amphibians and reptiles (tetrapods) and palaeoniscid fish remains documented at Blue Beach represent the transitional phase of vertebrate evolution toward an exclusively terrestrial habitat (Ahlberg and Milner, 1994: Carroll et al., 1972; Sarjeant and Mossman, 1978). The paleoecology of these early vertebrates, however, is poorly understood. This paleoecological study may help researchers better understand the environment of these primitive aquatic tetrapods.

CHAPTER 2 METHODS

2.1 SAMPLING

Achieving the above objectives necessitated the acquisition of shale and siltstone samples from the Blue Beach Member near Hantsport, Nova Scotia. Because Martel (1990) had already completed a sedimentologic and stratigraphic study, samples could be taken from coastal outcrop and pinpointed stratigraphically within the Windsor Subbasin. Microfossil samples and field observations were taken on 6 separate field excursions: 1. May 10, 1994 (13 samples); 2. October 1994 (17 samples); 3. February 18, 1995 (9 samples); 4. May 17, 1995 (28 samples); 5. June 5, 1995 (20 samples); and 6. August 24, 1995 (5 samples). The bulk of the samples came from the basal 50 meters at a sampling interval at approximately 1 m. Random samples were taken from each cycle up to 215 m. If the ostracodes could be identified easily at outcrop, single bedding planes were sampled. However, most samples were time averaged to approximately 25-50 cm above and below the sampling point to improve the probability of finding specimens not detectable in the field. All of the sedimentary facies (see Table 3.1) were sampled with the majority coming from the organic rich shales low in the cycles. All sample locations were recorded on both a stratigraphic log (Martel, 1990) and when possible directly from a chained baseline on the beach (Fig. 2.1). This was necessary as mass-wasting between sampling sessions often covered key marker beds. A total of ninety-two samples were taken for ostracodes, foraminifera, Arcellacea, palaeoniscid fish remains, and petrographic thin sections (77 for microfossils and 15 for thin sections).

In addition to coastal outcrop, 22 samples were taken for both micopaleontological and petrographical data from the Saarberg Series core S1/4 (Fig. 1.2). The Saarberg core was drilled near Falmouth, Nova Scotia in 1979 and is

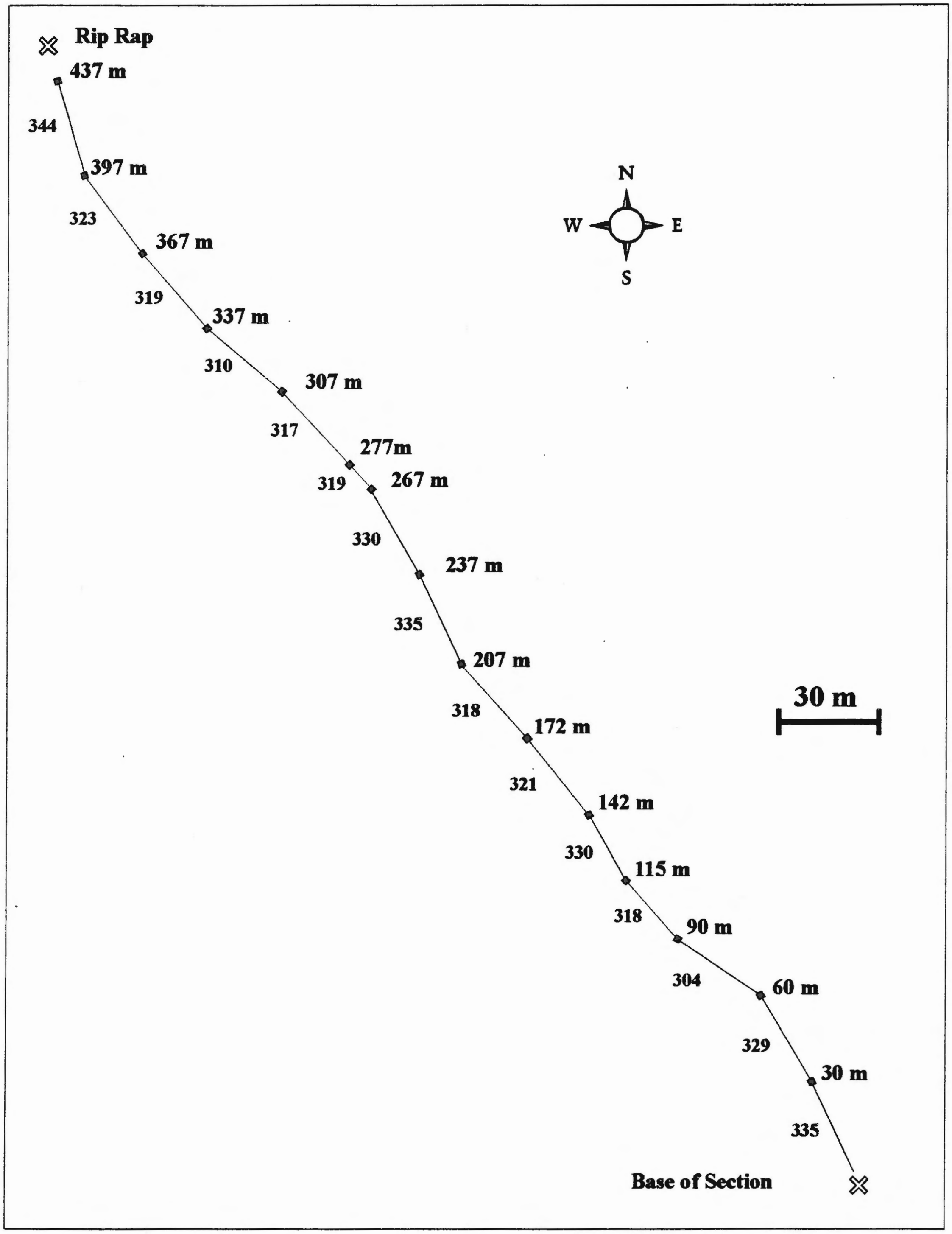


Figure 2.1 Baseline for sampling May 17 and June 5, 1995 at Blue Beach. Numbers above and below the baseline indicate the distance and direction respectively.

significant to this project as it contains the lower 70 meters of the Blue Beach Member strata not exposed at coastal outcrop. Overall, 114 samples were taken from both the coastal section and the drill core, the majority of which were processed and picked for microfossils.

2.2 PROCESSING

Microfossils could not be identified at coastal outcrop, with the exception of a few larger ostracode specimens, and had to be separated from the siliciclastic matrix using chemical dissolution methods at Dalhousie University. The techniques used for separating the microfossils, outlined by Wightman (1993) are as follows: 1. dry a small portion of the shales at 100 degrees; 2. make up a stock solution of 3:1 Versa Clean (brand of industrial strength detergent Na_2CO_3) to water; 3. add 100 ml of this solution to 200 ml of boiling water and the dried sample; and 4. boil on a hot plate for several hours stirring occasionally. If the sample does not break down immediately, it may have to soak for several days or even weeks as is the case for well-indurated siltstones. When the sample was completely broken down it was washed over a 63 micron mesh sieve to remove clay-sized particles. The dried samples were sieved through 2.0, 1.0, 0.5, 0.25, 0.125. and 0.063 mm size fractions. Each size fraction was examined using a binocular microscope and the microfossils picked out using a sable-hair artists' paint brush.

2.3 IDENTIFICATION

The foraminifera were identified by morphological shape and if present, the aperture. The ostracodes are better preserved than the protists and were distinguished by morphologic characteristics and muscle scar patterns. The identification of both Protists and ostracodes in 350 Ma samples is often difficult. Therefore, the finer details of the test were observed using the Scanning Electron Microscope. While picking the samples, careful attention was paid to the other microfossils such as fish (identified by scales, teeth, and bone fragments), serpulid worms, and any other fossil material. All taxonomic designations were made using both current and previous references to the literature (see Chapter 7). Following the identification of the taxa, the paleoecological limits for each species were defined (Chapter 5).

2.4 PALEOECOLOGY

Recent studies show that the dominant hydrochemical parameter that limits ostracode species is salinity (Forester and Brouwers, 1985). Also, Becker and Bless (1990) used ostracode biotypes to indicate different hydrologic energy zones within ancient nearshore-marine stratigraphic sequences. Foraminifera also respond to chemical and physical parameters on the benthic substrate by changing the composition of their tests (Scott and Medioli, 1980). Once the paleoecological tolerances for all of the different microfossil types were known, their distribution was related to lithologic, physical, and chemical changes within the sedimentary record based on both previous (Martel, 1990) and new field observations.

CHAPTER 3 RESULTS

3.1 SEDIMENTOLOGY

3.1.1 Introduction

The Horton Bluff Formation Blue Beach stratotype is the basal 146 m of the coastal section (Fig 1.4). This section contains strata attributed by Martel and Gibling (1996) to four stratigraphic members and this project will concentrate on the Blue Beach Member (BBM) and the lower units of the overlying Hurd Creek Member (Table 1.1). The upper boundary of the BBM, with the Hurd Creek Member, is marked by an increase in cross-bedded sandstone and green mudstone that lies several metres below the uppermost ostracod bearing bed (Fig. 3.1: see Table 3.1 for Legend). The lower contact with the Curry Brook Member is not observable at coastal outcrop but can be seen in the Saarberg core as a relatively sharp transition from coarsening-up siltstone and sandstone into thick shale sequences (Fig 3.2). The strata occur in packages that comprise basal dark fossiliferous shale with minor siltstone lenses, siltstone with interbeds of fine sandstone, disrupted grey to olive grey mudstone, and massive, laterally continuous, tabular beds of dolomite [magnesium carbonate $CaMg(CO_3)_2$].

3.1.2 Sedimentary Facies

A recent evaluation of the Blue Beach Member demonstrated six facies that occur in asymmetrical cyclic packages (Martel, 1990; Martel and Gibling, 1991) (Table 3.2). This section describes the facies of the Blue Beach Member using data obtained by Martel (1990) and original observations by the author during field work, thin section descriptions, and analyses of microfossil residues from both the Blue Beach coastal outcrop and Saarberg drillcore S1/4 near Falmouth, Nova Scotia (Fig. 1.2).

Table 3.1 Legend for the lithologic logs.

	Agglutinated Foraminifera		Insitu Lycopsid Trees
	Paraparchitacean Ostracodes		Disarticulated Plant Matter
	Copelandella novascotica		Root Traces (pedoturbation)
⬭	Bairdiacean Ostracodes		Hummocky Strata
	Carbonita sp.		Bioclastic Ggl Scours
	Bivalves		Trough Cross-beds
	Serpulid Worms		Ripple Laminae
U	Worm Burrows	✡	Dessication Cracks
	Palaeoniscid Fish	□ ❁	Pyrite (euhedral and Framboidal)
○	Coprolites	■ ●	Glauconite (euhedral and pelloidal)
✹	Algal Bodies	K	Nodular Dolomite
▲	Megaspores	▩	Micaceous
	Tetrapod Trackways	$	Slickenside Structures
▓	Dolomite Horizons	░	Green Calcarous Mudstone

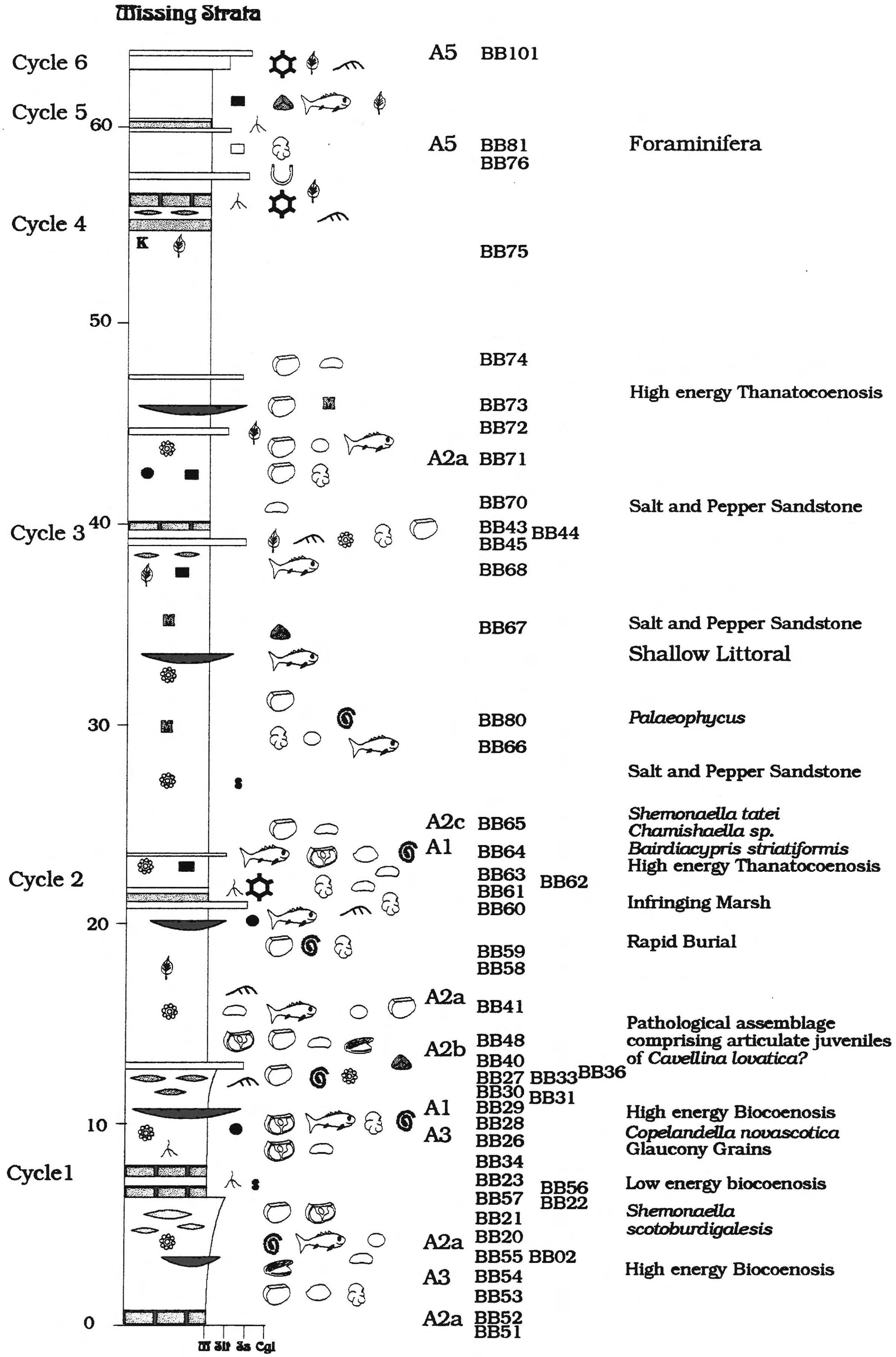


Figure 3.1 Stratigraphic log of the Blue Beach coastal outcrop.

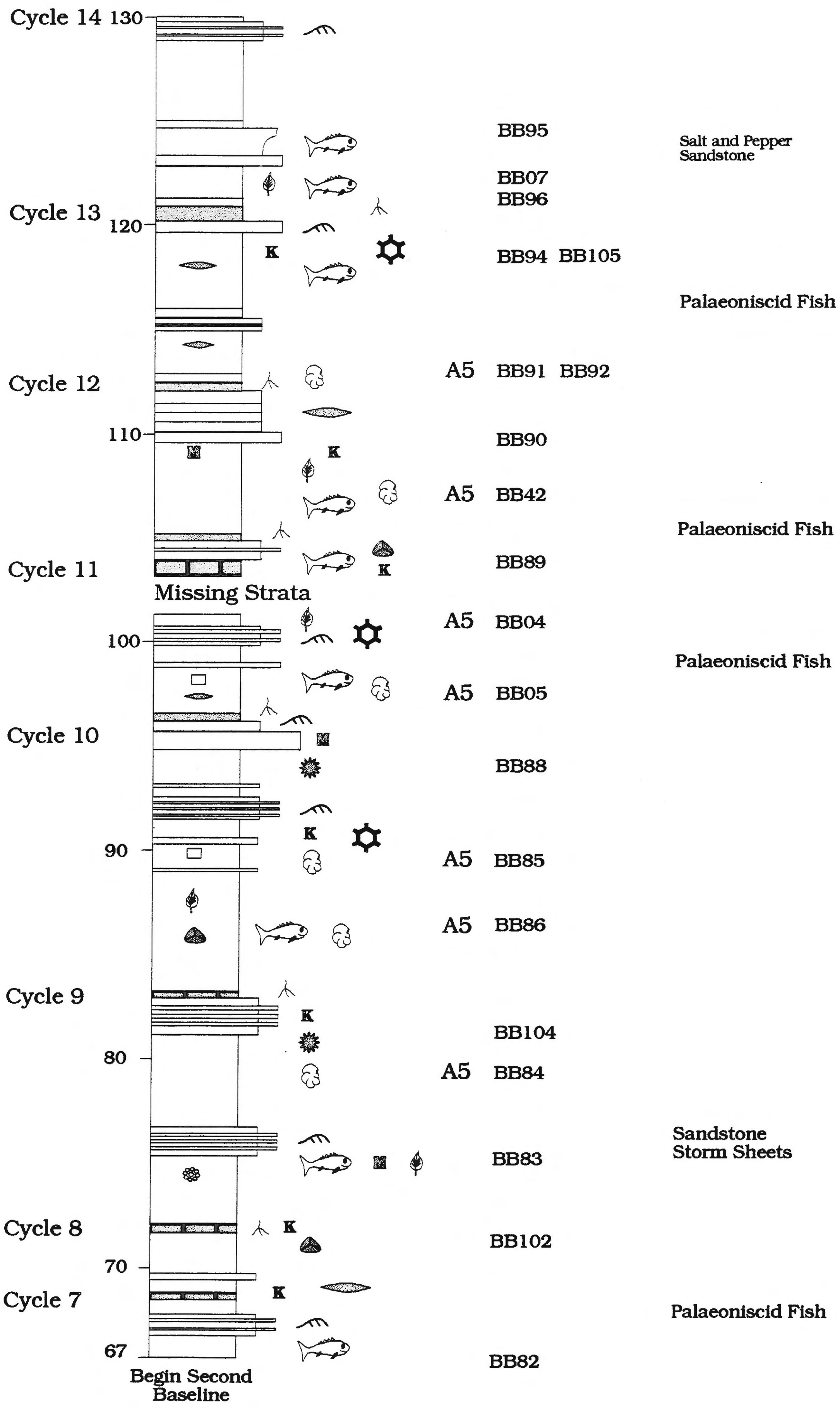


Figure 3.1 continued...

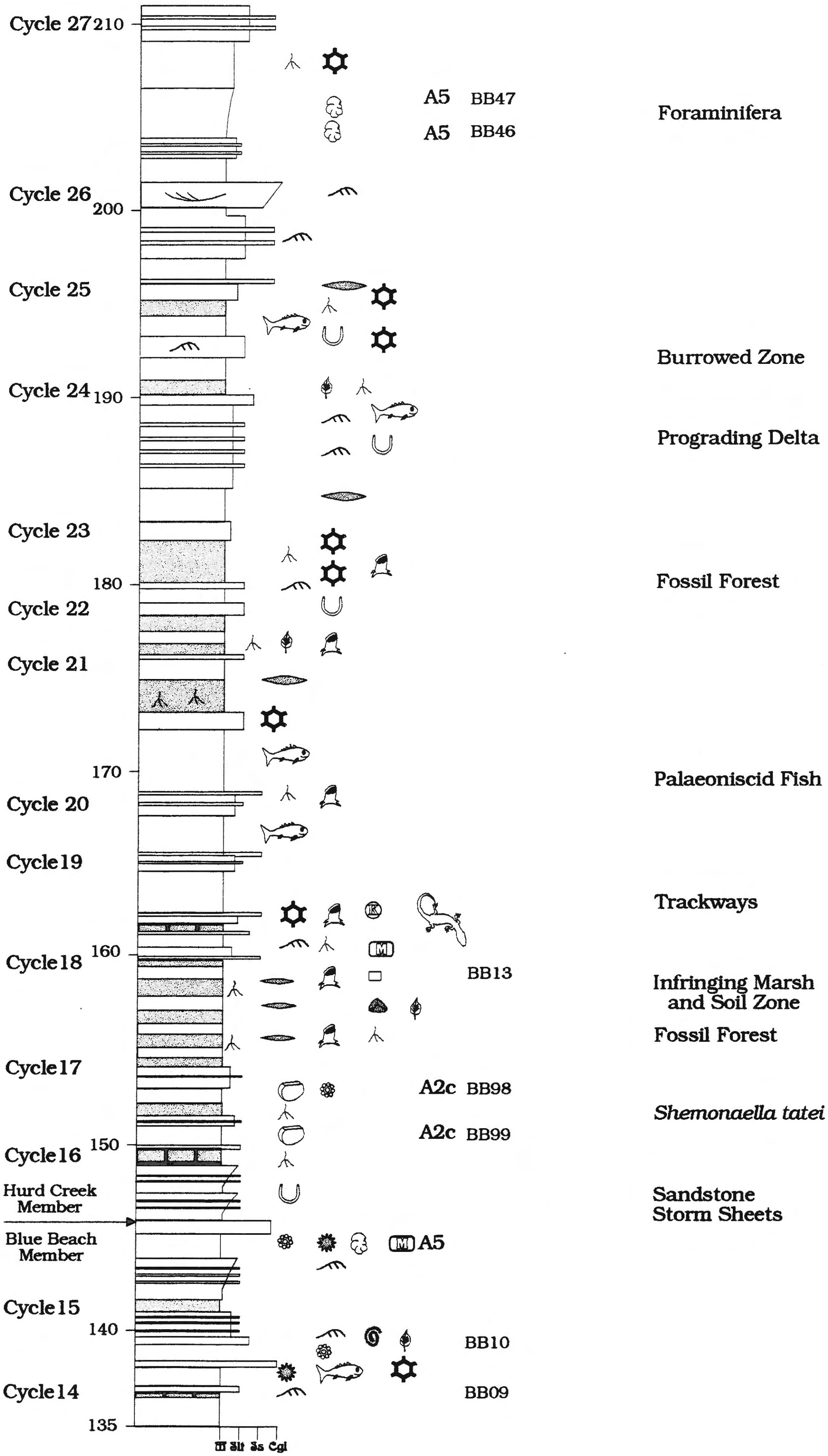


Figure 3.1 continued...

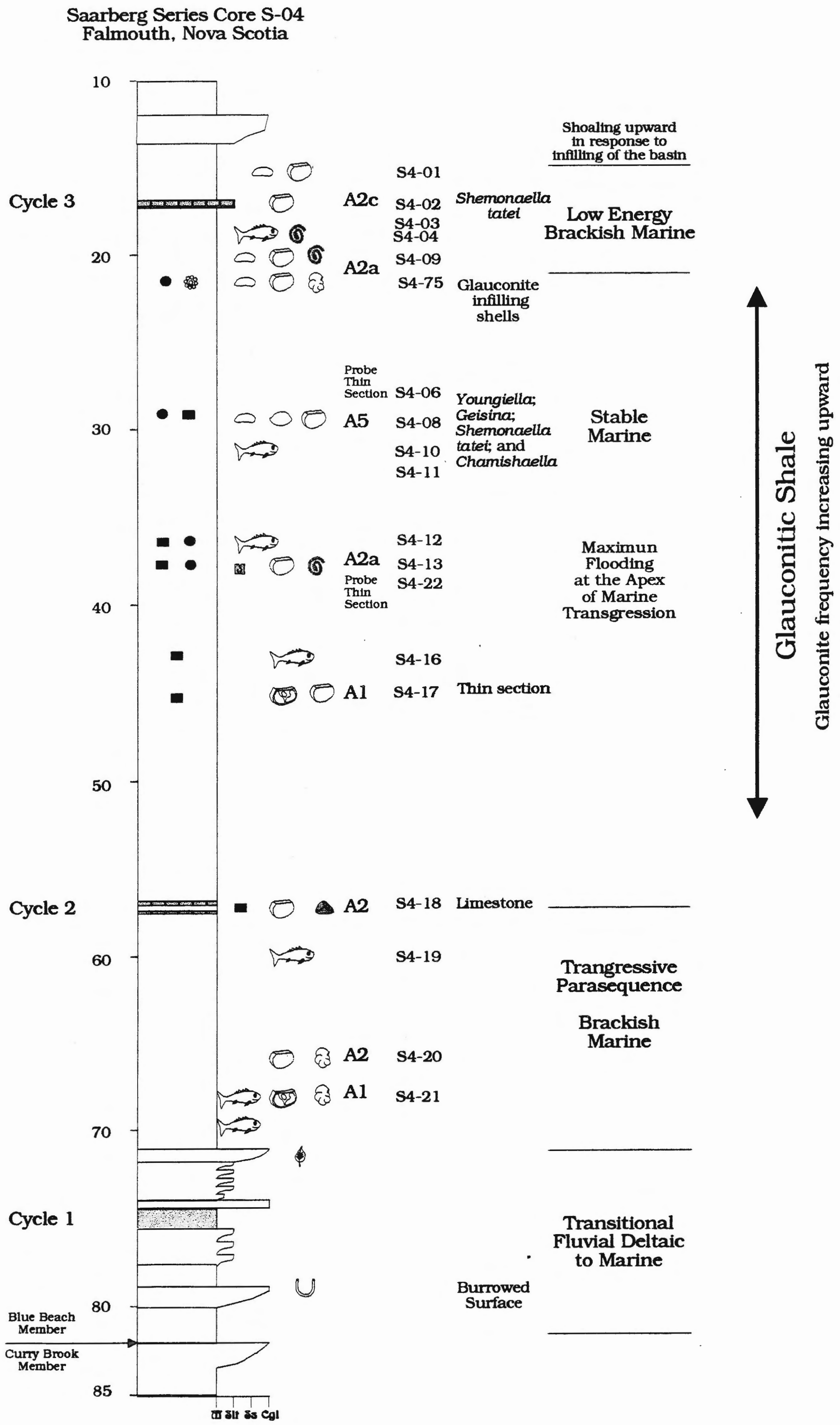


Figure 3.2. Stratigraphic log from the Saarberg core near Falmouth.

Table 3.2 The sedimentary facies from the Blue Beach Member and new microfossil data (after Martel, 1990).

Facies	**Sedimentary Features**	**Fossils**	**Hydrologic Interpretation**
Mudstone	pedoturbated; carbonate cement	root traces; plant detritus	infringing marsh
Dolostone (Dololutite)	microcrystalline dolomite (tabular beds with vertical fractures and discontinuous nodules)	fish scales in nodules	hard duricrust formed diagenetically soon after deposition of fine sediments (penecontemporaneous)
Black Shale	medium grey to black; high organic content <1.o% (Smith and Naylor, 1990); glauconite and framboidal pyrite	fish; ostracodes; serpulid worms; foraminifera	suspension deposition in a quiescent kenoxic zone below wave base (profundal)
Hummocky and Planar Siltstone and Sandstone	siltstone; low angle scours (2-40 cm thick); hummocky cross-stratification	ostracodes (reworked?)	traction/suspension during wave interaction with bottom in near shore zone
Wave Rippled Sandstone	5-20 cm bidirectional ripple laminations; carbonate cement	worm burrows; foraminifera?	waning episodes of a wave attenuated shoreline

Black clayshale and claystone (Fc)

This facies varies from grey to black in colour and has an organic content of approximately 1.0 % (McMahon, 1988 *cited in* Smith and Naylor, 1990). The shale occurs in cycles ranging in thickness from 1m to as much as 50 m in the Saarberg core. Shale sequences become progressively thinner up section with a 5-10 m average thickness (Fig. 3.1). The basal portions usually comprise a bioturbated medium to coarse grained lag containing sandstone grains, fish debris, reworked nodules and fragments of duricrust. The shale is clay rich and contains thin sandstone and siltstone lenses (Fig. 3.5) that often contain convolute structures. Thin sections of the shale show a high proportion of carbonate cement associated with the fossiliferous layers.

The black shales contain locally abundant glauconitic detrital grains, pellets, and ostracode fossil casts. Most of the glaucony grains have a distinct dark green to greenish blue color and display cracks and fractures. The subround flattened pellets resemble coprolites of mud-eating filter feeders. The detrital grains are most common in the core and have a light green to dark green color (Fig. 3.6). Thin sections from the core reveal greenish-blue grains with moderate relief and slighlty dissolved grain margins. Under cross-polars the detrital glaucony grains demonstrate second order birefringent colors and a thin marginal calcite replacement of deteriorated margins. The chemical composition of two polished thin sections from the Saarberg Core correspond with those expected from chemical analysis (Table 3.3). The stable K_2O, MgO, combined FeO, and high SiO_2 values most closely resemble glauconitized mica (Deer et al, 1989).

Abundant micro-crystalline pyrite ["raspberry"] framboids occur in the basal organic-rich shales of both the coastal section and core (Plate XI, Fig. 8) whereas the upper cycles contain octahedral crystalline pyrite. Some of the euhedral grains form

Figure 3.5 The black shale facies from the coastal section Blue Beach. Note the shales coarsen upward into siltstone with hummocky cross-strata and discontinuous dolostone horizons midway in the unit.

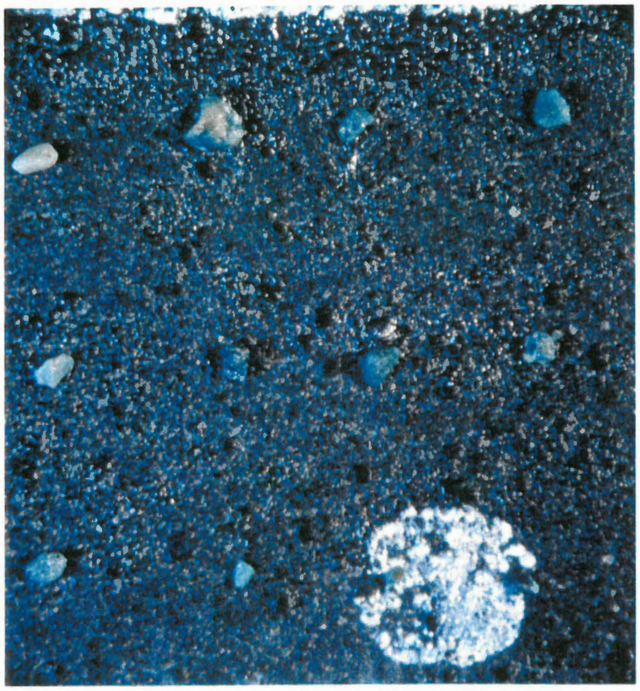


Figure 3.6 Glaucony grains from the Blue Beach coastal section.

Table 3.3 The chemical composition of glaucony from the Saarberg Core. All values are percent oxide. The slightly higher values for aluminum are probably due to contamination of the porous feldspathic grains (anomalous values are common when analyses are obtained using the electron microprobe). Note that S4-06 contained minor glaucony grains isolated in a arenaceous siltstone and demonstrates the highest SiO2 and Al_2O_3 values. Fe_2O_3 and FeO are not distinguishable and therefore represent a rough estimate for percentages. The S4-22 values were obtained from a glauconitic layer containing abundant faecal pellets, foraminiferal casts, and a potential hardground. The most diagnostic feature are the stable values obtained for potassium and magnesium indicative for most glaucony grains. The typical values expected from XRF and XRD chemical analyses from various localities and habits (Odin and Fullagar, 1988). The K_2O percentages of approximately 5-6% indicate that the glaucony grains are moderately to highly evolved (Amorosi, 1995).

Oxide	**S4-22a**	**S4-22b**	**S4-22c**	**S4-06**	**Expected Values**
SiO_2	52.437	51.848	52.792	53.151	48 to 50%
Al_2O_3	17.474	17.561	16.979	21.608	4 to 11%
FeO	13.326	13.337	13.827	11.005	1 to 25%
MgO	3.604	3.636	3.579	3.271	2 to 5%
CaO	0.484	0.458	0.649	0.305	
Na_2O			0.155		
K_2O	6.768	6.358	6.933	5.584	3 to 9%
Cl		0.067	0.095	0.075	
P_2O_5			0.407		
SrO			0.269		
Total %	94.093	93.265	95.684	94.999	

agglomerations that resemble the shape of trochospiral foraminiferal tests (Plate I, Fig. 4). Other pyrite crystals demonstrate perfect octahedral shapes. Both the octahedral and framboidal pyrite mineral habits range from approximately 125 to 250 µm in diameter with the exception of larger pyritized faecal pellets and plant material.

Interpretation: The lack of sedimentary structures, abundant organic rich layers, and abundant pyrite indicate a quiescent low oxygen environment. Disarticulated fish remains and ostracodes in thin beds suggest periods of increased hydraulic energy which would restrict extended periods of anoxia to the deeper parts of the basin. Deposition probably occurred during storm events when the organic remains were transported and accumulated into concentrated beds.

Alternating Siltstone, Sandstone, and Claystone assemblages:

Three sub-facies comprise this facies: hummocky cross-stratified siltstone, wave rippled sandstone, and planar bedded siltstone (Fig. 3.7).

Hummocky cross-stratified siltstone

The dominant lithology is siltstone with rare thin sandstone interbeds deposited in low angle scours (Fig. 3.8). The sandstone bedsets range from approximately 2-20 cm thick with widths ranging from 30-150 cm. The basal units contain first order scours with tool marks, load casts, minor lags of fossil material, and rare gutter casts. The orientation of the gutter and groove casts is parallel to paleocurrent direction as defined by ripple marks (discussed in the next sub-facies). The siltstone grades into thick lenticular scours. This is the hummocky cross-stratified zone that commonly has thin micaceous horizons separating the ripple cross-laminated layers. The base of the HCS zone usually has minor tool markings and is rarely bioturbated. The upper BBM contains clastic dykes 1 cm wide by 5 cm in depth.

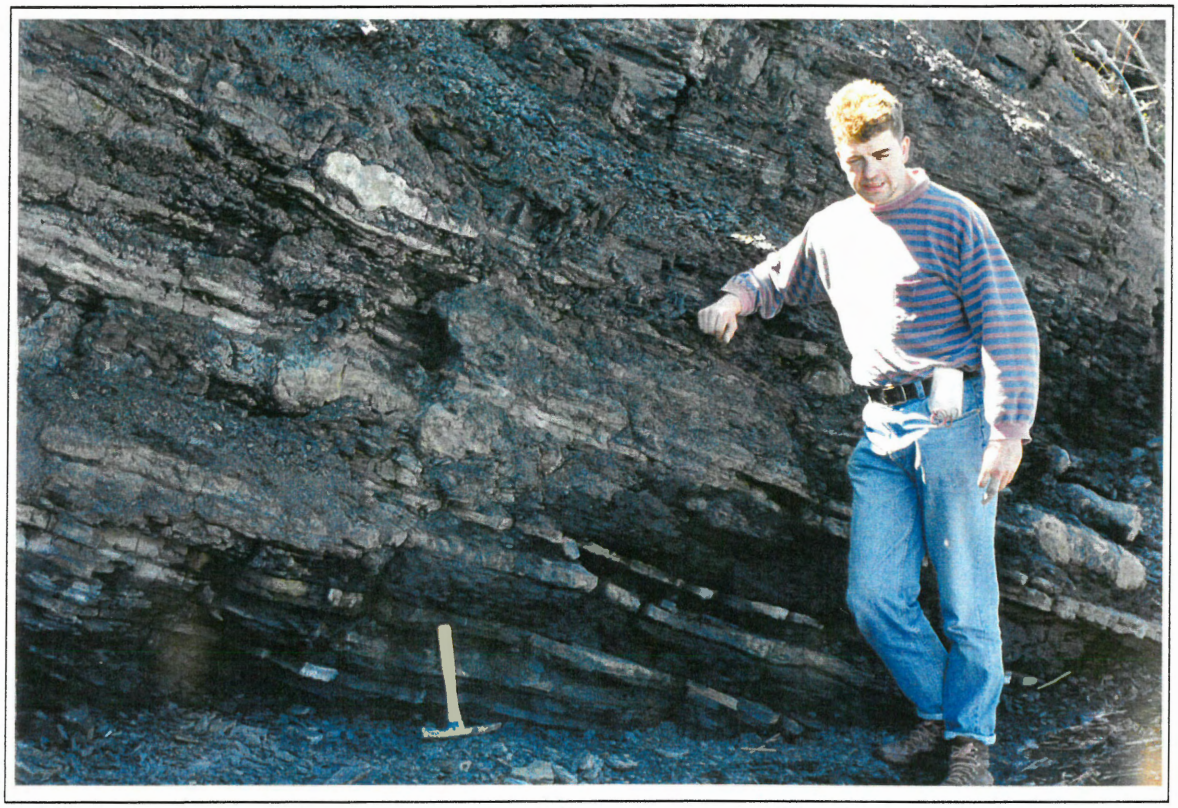


Figure 3.7 Interbedded sandstone and shale facies. Note the lower units of the BBM are characterised by dolostone horizons in the top strata of the incomplete cycles.

Figure 3.8 Hummocky cross-bedded sandstone at the top of a cycle (centre of photo). Note the thick storm associated sandstone sheet above capped by a nodular dolostone. The hammer is 30 cm in length.

Interpretation: The abundance of hummocks associated with tool marks on scour bases indicates high energy flow where storm-wave base interacts with the bottom sediments. Deposition was probably rapid as indicated by load casts and convolute bedding. The absence of plants and roots indicates deposition at depths below periodic lowstands in the standing water body. The presence of clastic dykes oriented with flow direction suggest that cyclic wave loading caused sediment to be injected downward (Martel and Gibling, 1993).

Wave Rippled Sandstone

This facies varies laterally and consists of very-fine to fine sandstone with siltstone bedsets ranging from 5-20 cm in thickness. The beds range from 1-5 cm thick, are wavy to lenticular in form, display moderate discontinuity, and they often are separated by thin clay-shale bedsets. Pedoturbation and bioturbation generally increases upwards in the bedsets. The sandstone and siltstone beds contain symmetrical wave ripples with wave lengths ranging from 1.5-11 cm and averaging approximately 5.7 cm. The ripples are bidirectional with one predominant direction (Fig. 3.9). The ripple cross-laminated beds and bedsets fine upwards. V-shaped casts, prod marks, and grooves occur on the basal beds. Thin mud cracks infrequently cap unit tops (Fig. 3.10). Trace fossils include: *Margaritichnus* (stuffed burrows); *Pelecypodichnus*; *Isopodichnus*; *Palaeophycus*; and *Planolites*.

Interpretation: Bedload deposition occurred during waning episodes of storms. The presence of tool marks indicate moderately high energy waves. Mud cracks indicate periodic subaerial exposure. The ripple marks associated with thin muddy drapes and wavy/lenticular bedding suggest a shallow water depositional environment.

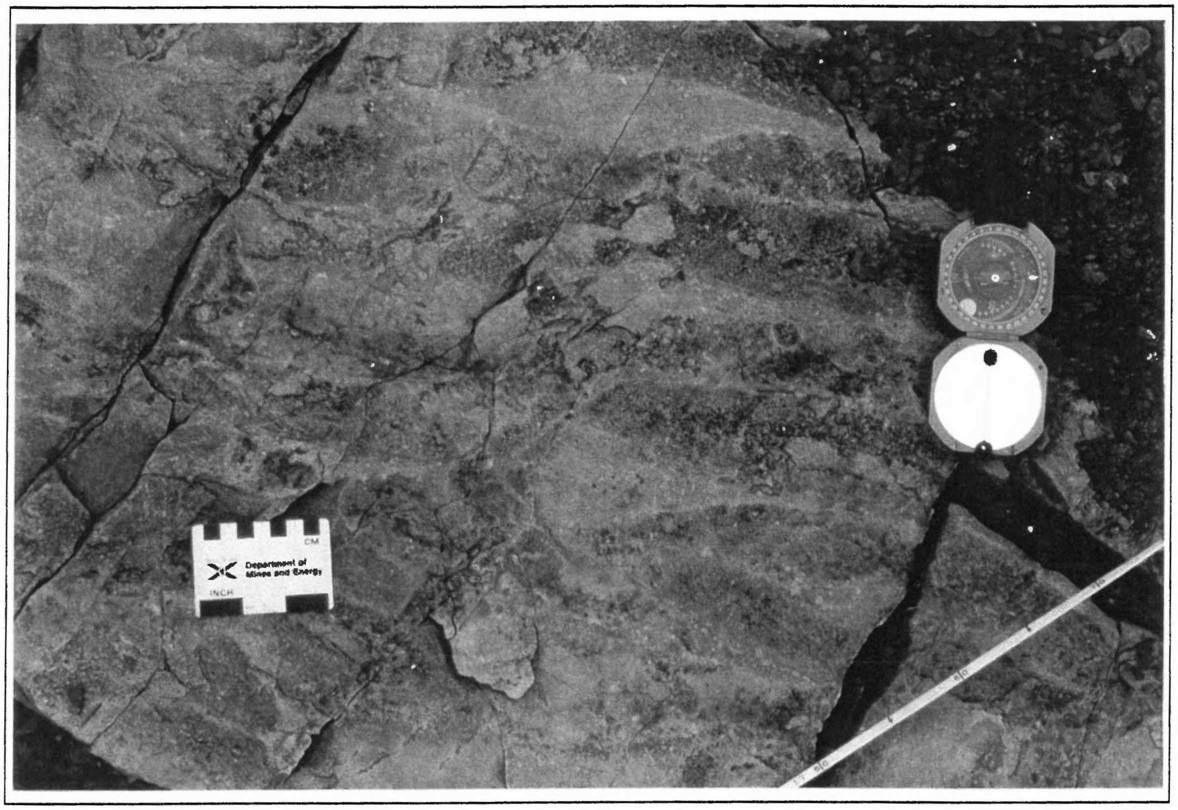


Figure 3.9 Sinous asymetrical ripples indicating west-northwest/east southeast paleocurrent directions (bidirectional). Note the clay drapes (black bands) in the troughs of the ripples. The Brunton compass is oriented with paleoflow.

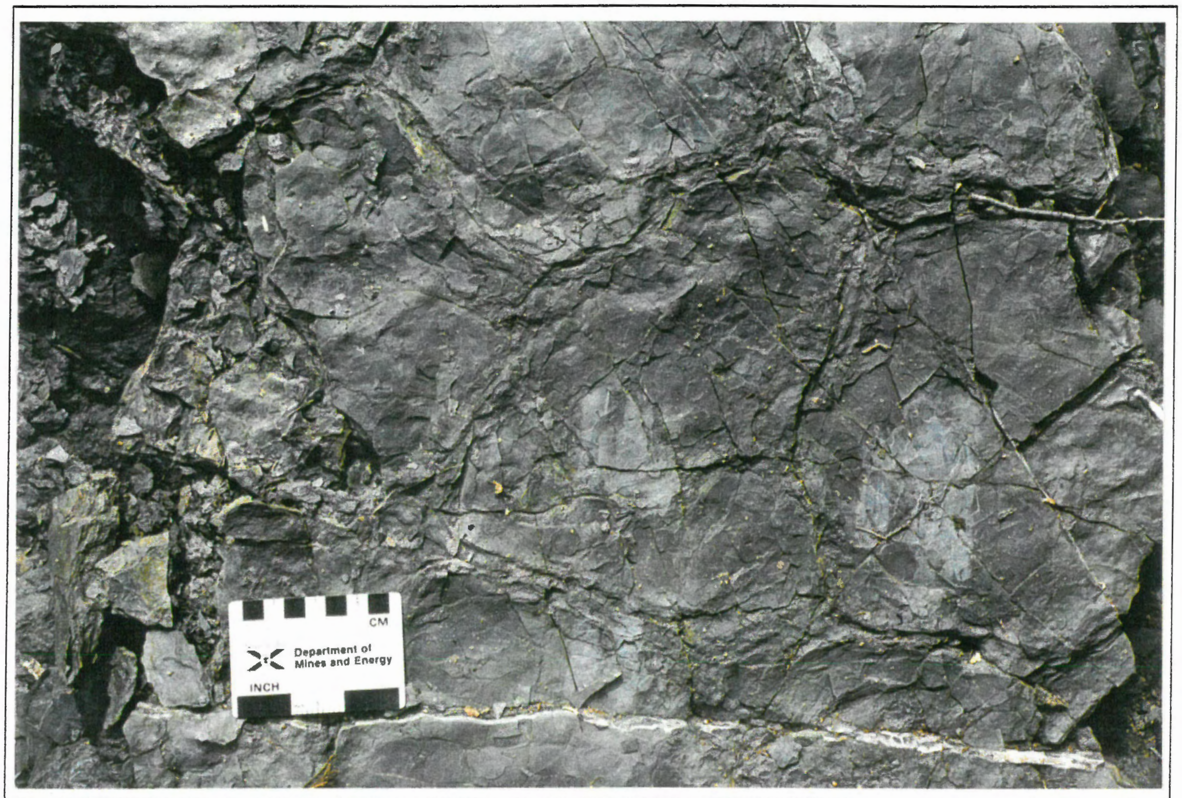


Figure 3.10 Mudcracks at the top of a cycle. These beds are thin (approx. 1-3 cm) and contain a large proportion of silt and sandstone quartz grains. This photo can be seen in profile in Figure 3.12 in the uppermost bed.

Planar Bedded Siltstone

This facies consists of tabular siltstone and sandstone beds ranging in thickness from 1-15 cm and bedsets 10-60 cm. The beds thicken locally into scours and are laterally continuous for hundreds of meters. Clay-shale beds ranging from 2-5 cm thick separate the siltstone and sandstone bedsets. The base of the units are usually ripple cross-laminated sandstone fining upwards into massive siltstone. The massive siltstone contains planar laminae in basal regions and fines into sandstone with minor convolute structure (Fig. 3.11). Rare trace fossils include *Palaeophycus* and *Planolites*. The upper parts of the beds contain minor cross-laminations, pedoturbation, and flat linguoid ripples. Other shallow nearshore features include mudchip-plant debris, fossil tree casts (*Archaeocalamites*) aligned with paleocurrent directions, and in situ root traces.

Interpretation: Storm-dominated flow in shallow water predominated during deposition of this facies. Shoaling waves deposited the sandstone whereas turbulent suspension clouds deposited the siltstones. The abundant sublittoral features at unit tops indicate proximity to the shore. In situ trees and other plant types would serve as energy buffers of the shoaling waves. This would explain the thin clay-shale interbeds that contain plant impressions and branches aligned with paleoflow trends.

Green Mudstone

A greenish grey color, intensely pedoturbated layers (rooted horizons), and rare siltstone and sandstone interbeds with desiccation cracks characterise this facies. The mudcracks are common in cycle tops penetrating several centimetres through muddy siltstone. Microcrystalline carbonate and clay minerals comprise the bulk of the rocks. Rare root traces and ferruginous staining are the only observable features in thin section. Fossils include fossil plants of *Lepidodendron* (Bell, 1960) and rare

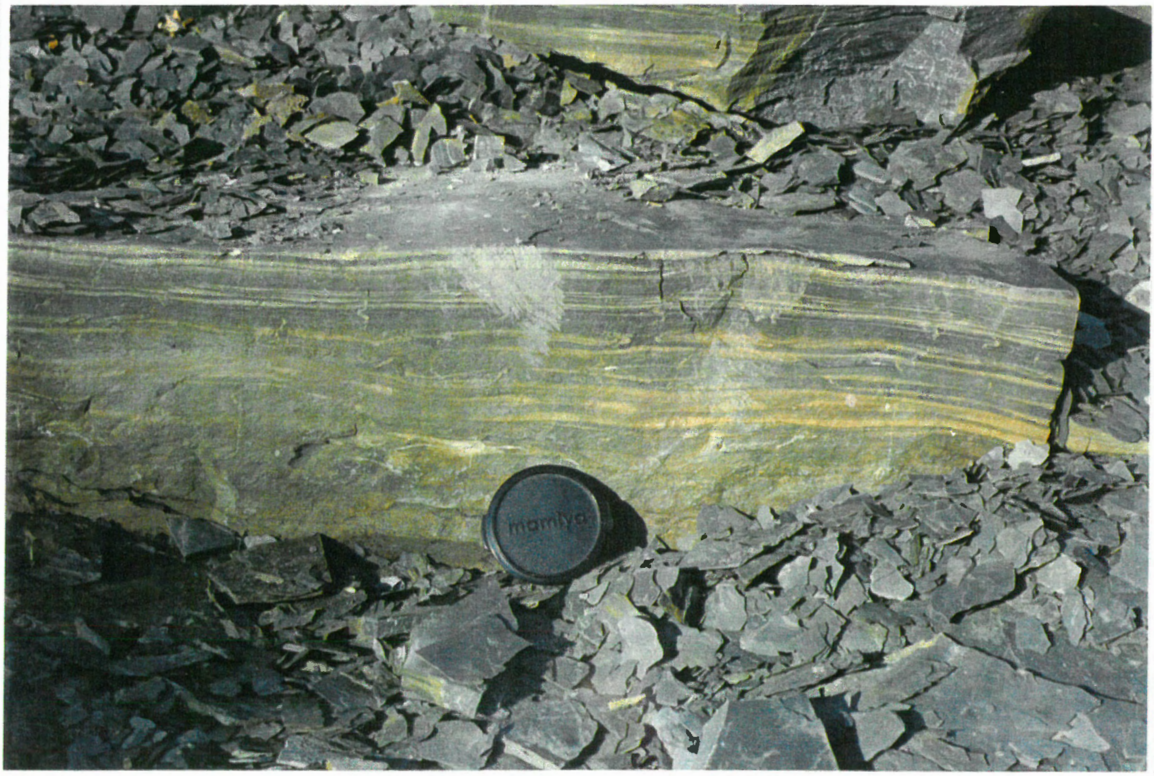


Figure 3.11 Planar siltstone with thin sandstone interbeds midway in cycle 2 (see Fig. 3.1). Note the convolute/contorted bedding. Lense cap is 55 mm wide.

foraminifera. These mudstone horizons often cap cycle tops, sharply overlying burrowed horizons (Fig. 3.12).

Interpretation: The pedoturbation, rare root traces, and microcrystalline nature of this facies indicates a poorly developed paleosol (Retallack, 1990). The mudcracks indicate periodic subaerial exposure. The general scarcity of plants and rare occurrence of foraminifera is indicative of modern paralic marsh environments that experience seasonal fluctuations of water level and salinity.

Dololutite

There are three types of fine grained magnesium carbonate: tabular dololutite; nodular dolostone; and isolated septarian nodules.

Tabular Dololutite

The well-indurated tabular dololutites predominate in the basal strata of the coastal outcrop and can be recognised by their grey color, vertical fracturing with polygonal habit (Fig. 3.13). The beds in the lower cycles range from 15-30 cm in thickness and are laterally extensive (Fig. 3.14). The tabular beds comprise 95 % microcrystalline dolomite and yield only sparse root traces, calcite veins, and opaque minerals. The chemistry of the dolostones match those expected for microcrystalline dolomite (Deer et al, 1989) (Table 3.4). The tops of beds have small millimeter sized sandstone injections disrupting the otherwise featureless rock. Underlying many of the dolostone horizons are thin sandstone and siltstone beds. The siltstones have randomly oriented needle-like quartz grains ("Herkimers Diamonds") that range from approximately 200 to 750 um (Fig. 3.15). These elongate grains resemble gypsum pseudomorphs. Finally, the lower bedding surfaces of these siliceous beds contain small 100-500 μm concentric disk-like algal bodies that resemble *Chuaria sp.* (Hantzschel, 1975).

Figure 3.12 A representative cycle top (cycle 2) low in the coastal section. Bioturbated mudstone is prominent. Key features are as follows: A. planar siltstone with *Isopodichnus* burrows; B. bioturbated calcareous mudstone containing root traces and foraminifera; C. alternating siltsone and sandstone resembling tidal bundles; and D. thin mudcracked horizon (see Fig. 3.10).

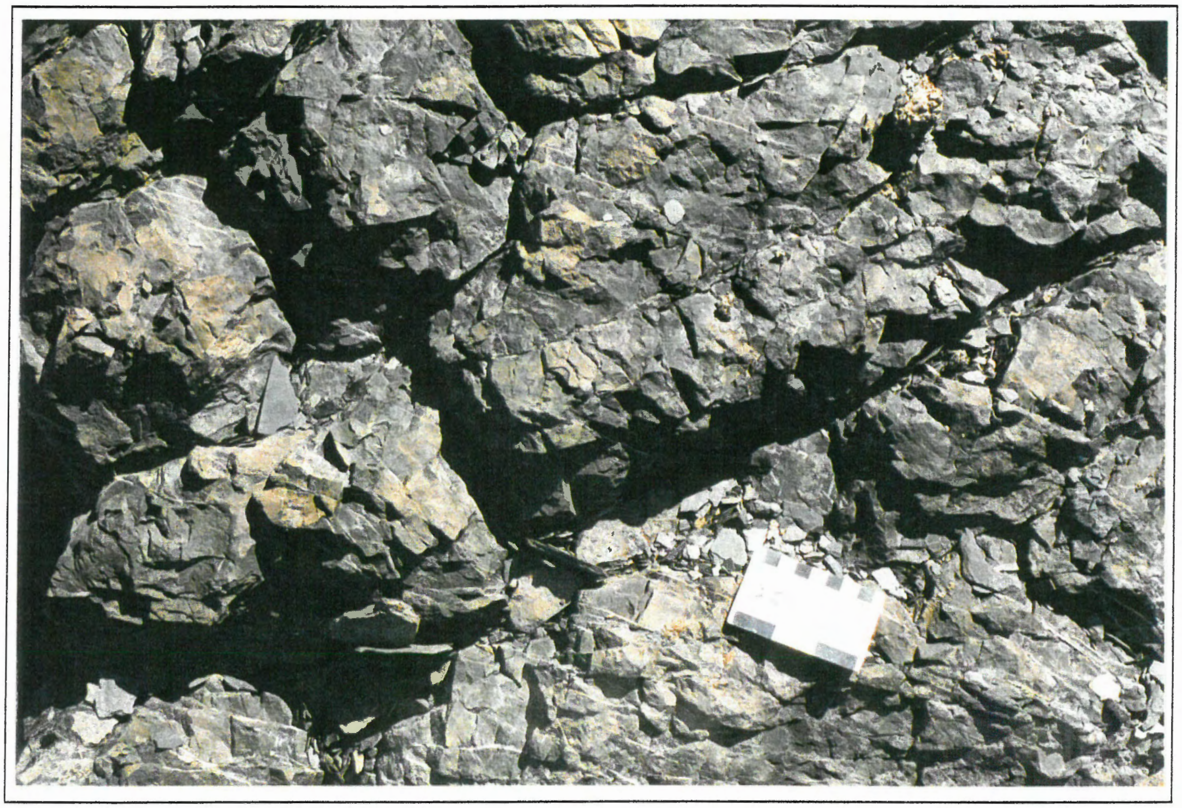


Figure 3.13 Top surface of the first tabular dolostone horizon from the coastal section at Blue Beach. Note the vertical octagonal fracturing. Thin sections reveal sediment injection stuctures in the uppermost surfaces.

Figure 3.14 Tabular dolostone horizons from the coastal section at Blue Beach. These two dolostones cap the first cycle. Bioturbated muddy shales separate the horizons. Figure 3.13 is a plan view of the upper surface of the first limestone.

Table 3.4 The chemical proportion of oxides in a tabular dolostone horizon (BB57). Note the distinguishing high proportion of CaO and approximately half those values for MgO. These values approximately match those from Deer et al. (1989) for dolomite (magnesium carbonate).

Oxide	BB57a	BB57b	BB57c
SiO_2	0.238	3.045	1.03
Al_2O_3		1.723	0.519
FeO	4.459	6.231	6.754
MnO	0.506	0.688	0.408
MgO	16.298	14.771	17.792
CaO	31.07	29.095	31.885
Na_2O			0.199
K_2O	0.075	0.269	
P_2O_5		0.191	0.241
SrO	0.136	0.271	
Total %	52.781	56.282	58.827

Figure 3.15 Herkimers Diamonds or Gypsum pseudomorphs? These elongate quartz crystals, with a calcareous secondary coating, occur directlly below the lowermost surfaces of the first tabular dolostone (Fig. 3.14) at the top of the first cycle at Blue Beach.

Septarian Nodules

The septarian nodules resemble the tabular dolostone in mineralogy and sparse primary structures. However, they generally form ellipsoids to slightly flattened spheres ranging in size from 5 up to 40 cm and are parallel to bedding (Fig. 3.16). They commonly have a "turtle shell" appearance because of the shrinkage cracks that are infilled with calcite. The only associated fossils are sparse fish material. The nodules commonly occur low in the cycles associated with black shales.

Nodular Dolostone

This carbonate facies usually occurs as locally coalesced continuous layers overlying pedoturbated and desiccated mudstones at cycle tops (Fig. 3.17). The horizons are less continuous lower in the stratigraphic section at Blue Beach (Fig. 3.5). Rhizoliths and vertical lycopsid trees occur in the uppermost units at Blue Beach.

Interpretation: The tabular dololutites and septarian nodules are interpreted as offshore penecontemporaneous in formation, whereas the nodular dolomites are vadose-zone diagenetic carbonates. The sediment injection structures in the uppermost dolostone surfaces suggest an increase in hydraulic activity near the sediment/water interface.

3.1.3 Sediment Chemistry

The shales from the BBM contain glaucony grains, pyrite, and dolomite (see above). Precipitation of these minerals bears directly on the environment they formed in.

The Glauconitization Process

The glauconitization of clay minerals has four modes of occurrence: 1. fossil molds of ostracodes and foraminiferal tests; 2. faecal pellets (disaggregated organic matter); 3.

Figure 3.16 Dolostone concretion extending outwards from the cliff face. The oblong concretion is broken in half. These septarian nodules contain sparse fish scales.

Figure 3.17 A continuous nodular dolostone horizon (A) separating sandstone beds. This stratigraphic unit marks the top of the Blue Beach Member (Martel and Gibling, 1995); the cycles are thinner and contain a higher proportion of sandstones, mudstones, and limestones. A couple of metres above this unit marks the termination of the ostracode fauna, the uppermost ostracode bearing bed, at Blue Beach (see Fig. 3.1).

bioclasts (replacement along fractures where chemical dissolution has occurred); and 4. mineral and rock grains of which most minerals such as quartz, feldspar, dolomite, calcite, and volcaniclastics are known to glauconize (Hughes and Whitehead, 1987). For glauconitization to occur there must be the following: 1. a confined porous substrate with an optimal pore size of 250-500 μm (Odin and Fullagar, 1988); 2. replacement of the substrate in water depths greater than 60 m (most commonly 60-550 m); 3. temperatures that range from 7 to 20° C; 4. a pH of approximately eight; and 5. approximately 10^4 to 10^5 years of reduced detrital influx with constant K_2O concentrations of approximately 6-8% (Carozzi, 1993). When glaucony constitutes up to 30% of the total rock, with most grains ranging from 160-500 μm size fractions, they are considered to represent a maximum flooding surface (Amorosi, 1995). Occurrences of this nature have been documented from the base of transgressive sequences such as the world-wide Cenomanian transgression (Odin and Hunzaker, 1982) and the transgressive episode 18,000 to 6000 years ago on the Congolese continental shelf (Odin, 1988).

Pyrite Formation

Pyrite framboids form syngenetically in anoxic sediments from the reaction between H_2S generated by sulphate-reducing bacteria and iron mono-sulphides (Goldhaber and Kaplan, 1974), whereas euhedral pyrite precipitates directly from chemical solution (Sawlowicz, 1993). In marine environments pyrite forms either at the sediment/water interface when oxidising and reducing conditions exist simultaneously or diagenetically associated with the decomposition of organic matter (Davison, 1988; Raiswell et al., 1993). If the sediment/water interface is reducing and levels of sulphate are near those of normal seawater, framboidal pyrite will precipitate. In contrast, pyrite formation in nonmarine environments is limited by the low sulphate levels. In this case, the decomposition of humic matter over extended periods of time is required for pyrite to precipitate, usually with euhedral habit (Berner, 1984). As a result of these differences in pyrite formation, researchers have used carbon/sulfur ratios from Carboniferous strata in the British Isles to distinguish between marine and freshwater environments (Davison, 1984).

Dolomite Formation

Dolomite formation is governed by: 1. the rate of crystallization; 2. the Mg/Ca ratio; and 3. a CO_3/Ca ratio greater than one (Morrow, 1990). In general when fresh water is mixed with up to 30% marine water, the result is an undersaturation of calcite raising the Mg/Ca ratio and facilitating dolomite precipitation. In nonmarine settings, however, the source for magnesium becomes problematic. This is exemplified in the sediments of the Devonian Orcadian Basin where Duncan and Hamilton (1988) postulated that the deterioration of clay minerals associated with high salinity was the source of Mg for the dolomites. In other nonmarine settings, Von Der Borch and Lock (1979) proposed that evaporation models controlled by meteoric recharge led to the formation of the Coorong dolomites. In these recent sediments, the absence of saline and sulphate minerals is attributed to seasonal flushing of the hydrologic system. Although the source of magnesium in Coorong strata is not yet determined, Von Der Borch and Lock (1979) postulate derivation from leaching of adjacent widespread volcanic ash.

3.2 PALEONTOLOGY

3.2.1 Introduction

Overall, this study incorporates paleontological data from 8818 ostracodes and 431 agglutinated rhizopods for a total of 9249 fossil specimens. Table 3.5 lists the species used for the statistical representations and their total numbers from both the coastal outcrop and the Saarberg core. Histograms showing the relative proportions of the taxa are given in Figures 3.18 and 3.19. Tables 3.6 and 3.7 contain the absolute species numbers, the stratigraphic level, sedimentary features, and qualitative observations of other fossil groups (algal, plant, invertebrate, and vertebrate) from Blue Beach and the Saarberg core respectively. Figure 3.20 demonstrates the relative proportion of the microfossils from their respective samples and stratigraphic positions.

Definitions of the following fossil assemblages incorporates both paleontological and sedimentological features. Every assemblage contains both allochthonous and autochthonous fossil components. The most important criterion for the definition of each assemblage is the dominance of a single species. For most of the representative samples, single bedding planes on the centimetre scale were used. In general, the representative samples were carefully chosen, the absolute numbers combined for each species, and the average species percentages were calculated and graphically portrayed using simple pie charts. Table 3.8 summarises the fossil assemblages and their associated features.

3.2.2 Assemblage 1 (A1)

This assemblage is restricted to the black shale facies within the 9-10 m stratigraphic interval at the coastal outcrop and the lower glauconitic shales of the Saarberg Core (Figs. 3.1, 3.2, 3.20). The representative samples are two distinct single bedding planes that are separated by a palaeoniscid fish horizon in which a complete body fossil was discovered (Fig. 3.21). An organic rich 3 cm petroliferous horizon also occurs

Table 3.5 Summary of the ostracode and foraminifera taxa from the Blue Beach Member.

OSTRACODES	**Blue Beach**	**Saarberg Core**
Total No. ostracodes	**8,159**	**659**
Shemonaella scotoburdigalensis	2,995	98
Shemonaella tatei	843	93
Chamishaella sp.	425	228
Copelandella novascotica.	746	2
Carbonita scalpellus	1,990	127
Cavellina lovatica?	938	
Carbonita rankiniana	94	
Bairdiacypris striatiformis	21	
Geisina sp.	0	40
Youngiella sp.	40	51
Bairdia pruniseminata	33	17
Paraparchites sp.	10	3
Encysted Eggs?	55	0
FORAMINIFERA		
Total No.	**391**	**40**
Trochammina sp.	305	37
Ammobaculites sp.	68	2
Ammotium sp.	18	1
Total No. Ostracodes		**8,818**
Total No. Foraminifera		**431**
Total No. Microfossils		**9,249**

Sample	BB51	BB50	BB53	BB54	BB55	BB02	BB20	BB21	BB22	BB57	BB23	BB34	BB26	BB28	BB29	BB31	BB30	BB36
Stratigraphic Level	0	0.3	2.25	2.29	3.82	5.72	6.77	7.12	7.4	7.42	7.5	7.55	8.82	9.8	9.97	10.35	10.47	10.6
Ostracodes																		
Total No. ostracodes		**5**	**11**	**666**	**1058**	**746**	**228**	**3**	**2**				**132**	**209**	**76**			
Total No. Ostracode Species		**2**	**4**	**5**	**5**	**5**	**4**	**1**	**1**				**3**	**5**	**4**			
Shemonaella scotoburdigalensis		4	6	99	595	388	109							22	10			
Shemonaella tatei																		
Chamishaella sp.				1	12	44												
Copelandella novascotica.							8						50	173	43			
Carbonita scalpellus			4	544	436	273	99	3	2				79	8	23			
Cavellina lovatica?																		
Carbonita rankiniana				22	13	40	12						3					
Bairdiacypris striatiformis																		
Geisina sp.																		
Youngiella sp.					2	1												
Bairdia pruniseminata		1	3											6				
Paraparchites sp.																		
Spheres			4	4										13	2		2	
Foraminifera																		
Trochammina			14	22									11	6	16	4	10	
Ammotium			1										4				1	
Ammobaculites			4										5	3	5		4	
Other Fossils																		
Fish Scales	R	C	A	A	C	A	C						A	A	C		R	
Fish Bones		C	C	A	C	A	C						A	A	C	A		
Fish Teeth			C	A	C	A								A	C	A		
Serpulids			C		A	A								R		A		
Coprolites			A	A			C						A					
Algal Bodies																		
Megaspores																		
Bivalves			1	24		17	2											
Plant Fragments			R?	A					A	A?	A							
Sedimentary Features																		
Facies	Dol	Sh	Sh	Shm	Slt	Shm	Slt/Sh	Slt/Sh	Slt	Dol	Fm	Slt/mud	Slt/Sh	Sh	Slt	Sh	Sh/petr	Slt
Structures										Oct	Slk	Slk	Plan		Plan			Plan
Pyrite Framboids			C				R						A	R	C		R	
Pyrite Crystals				C									C	C				
Glaucony grains/pellets													R	C		R		
Lithic Clasts									C		A							
Reaction to HCl	W		M	S	M					M				S				S
Mica								A										
CaC03 Spheres			C															
Sample Purpose	Ha	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Prb	Vs	Ha	Vs	Vs	Vs	Vs	Vs	Ha
Other	iron stained							coarse	Herkimers Diamonds		rooted	pedoturbated				Fish	dirt ball	Cone-In-Cone

Table 3.6 Data table for the Blue Beach coastal section near Avonport.

BB27 11.6	BB33 11.7	BB40 11.87	BB46 12.1	BB41 16.1	BB58 16.76	BB59 18.52	BB60 21.32	BB61 21.45	BB62 21.89	BB63 21.95	BB64 23.02	BB65 23.81	BB66 28.09	BB80 30	BB67 33.23	BB68 37.17	BB45 39.5	BB44 40	BB43 40.5
1224	**124**	**1209**	**255**	**369**						**3**	**195**	**1278**		**1**				**1**	
5	**5**	**7**	**5**	**4**						**1**	**6**	**5**		**1**				**1**	
504	51	592	138	313							9			1				1	
												803							
16	1	23	4	2								202							
69	29	281	29								64								
17	26	17	76	22						3	78	229							
618	17	295	8																
				2							2								
											21								
												3							
												37							
		1									22								
												7							
		4	7			6													
						6	4	11		25	7		2					5	
						11		5		12									
A		A	R	A		R	A				A	R	C	A	A	A	R		
A		A					A				A		C	A	A	A			
A		A					A				A		A	A		A			
C		C					R				A								
C				C							A	R							
			5										C						
2				1?															
					A											A		C	C
Sh	Sh/slt	Slt	Ss/Slt	Slt/Sh	Lmst	cSlt	Cgl	Slt/fSs	grey Ms	cSlt/Ss	muddy Slt	Sh	cSlt/Ss	Md/Slt	Bio/Cgl	Slt/Sh	Ss	Md/Slt	Dol
		Rip/HCS	Rip			spy	Lens	Plan	Ped	Ms int		Blk	Slk		Lens	Hcs	Rip	Ped	Ped
C	A			C		A					R	R	R		R		A		
																		C	
		C						R			C							C	
C					A	A	A						A		C	A	A	C	
					S										S	W		S	M
					A						A		A	A	A		A	R	
C					A	A	C		C		C			A	A				
Vs	Vs		Vs	Vs	Ha	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Ts
							burrow linings	ripples; ostracode clasts	assoc. mudcracks	burrows; no plants*; and mudcrack	glauc. grains	Shemon plot?	Slump Zone	C:3	scour; burrows paleophycos	2m below rippled Ss	below oscillatory ripples	soapy; detrital glauc.	root traces

Table 3.6 Data table for the Blue Beach coastal section near Avonport.

BB70	BB71	BB72	BB73	BB74	BB75	BB76	BB81	BB101	BB82	BB102	BB77	BB83	BB84	BB104	BB86	BB85	BB88	BB05	BB04	BB891
41	44.08	44.96	45.63	47	48.13	54.17	56	57	65	70	72.5	72	74.37	75	77.65	78.47	94.87	97	98	113
	44		170	72																
	3		4	3																
	35		97	21																
	2		68	18																
	7		2	33																
			3																	
								1					1		2			3		
	6						7	6					14		10	8		44	3	
																			2	
							2									2			5	
	A	R	A		A				A				A			A		A		A
	A		A		A				A				A		A	A		A		A
	A		A						A				A			A		A		
	A		A										A					C		
														A	R		A			
										C										
		C			A		C			C		A	A			A				
Md/Ss	Bio/Cgl	cSlt	Slt/Cgl	cSlt	Md/Sh	cSs	Slt/Sh	Md/Sh	mSlt	Md	cSs	fSlt	mSlt	mSlt	fSh	Slt/Sh	cSlt	cSs	fSlt	Slt
	lens		lens	plan		Bio	Slk	Slt?	rip/plan	Slk			Plan			nod				rip?
				R			R					R	C		C		R			R
						R	A					A				A		A		
	C		A		C			R										R		
	C	A			C	A		C								A		A		A
	S					S	S	S					S		W	W				
	A		A	A	C	A						A	A			A	C	A		
						C														
Ha	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Ha	Vs	Vs	Ha	Vs	Vs	Vs	Vs	Vs	Vs
burrowed layer	Glauc. pellets	well-sorted rounded Qtz clasts	Glauc. pellets; no pyrite	well-sorted; micro laminae	Glauc. detrital	burrowed	pyritized forams?	red clasts?; Glauc. detrital	well-sorted; dolo nodule above	soil; soapy texture; rooted	burrow layer	humic rich; pyritized forams?		well-sorted	burrows	13 pyritized forams?	Chuaria trace fossil	17 pyrite casts?; 250-125um	C:18	vertebrate skin and bones?

Table 3.6 Data table for the Blue Beach coastal section near Avonport.

BB42 114	BB06 116	BB90 118	BB91 122	BB92 122.1	BB94 129	BB105 129	BB96 132	BB07 133	BB95 134	BB08 135	BB09 146	BB10 147	BB11 154	BB97 154.5	BB99 160	BB13 161	BB98 163	BB46 215	BB47 216	Total
			1												33		44			8159
															3		3			95
																				2995
															20		20			843
															11		21			425
																				746
			1												2		3			1987
																				938
																				94
																				21
																				3
																				40
																				33
																				10
	6																			55
10	8		4					13					2					2	25	305
								10												18
2	1							4										3		68
A		A		C	C	C		A	A	C	A				R		A			
A			R		C	C		A	A		A						A			
A		A						A	A		A						A			
												C					C			
			C						A	C	A				R		C			
											A			C						
C									C							C	C			
							C									R				
Dol	Slt	Slt	cSlt	Dol	Bio/Cgl	Bio/Cgl	cSlt	Slt	Slt/Sh	cSlt	cSlt	cSlt	cSlt	fSs/Slt	cSlt	Md	cSlt	mSlt/Sh	mSlt	
S&P	Plan			nod	lens	lens			S&P						Plan	Slk			Ped?	
			R					C	A			C	C	C	R					
			R											C						
																	C			
A		A			A	A	C		C			C	C							
M	S				S	S	W		W											
A		A			R	R			C				R	C			R			
C								C												
Vs	Vs	Vs	Vs	Ha	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	Vs	
septarian nodules and shales	nodules	C:20	pyritized coprolites	septarian nodule	112.26?	112.26?	c:23	dirt balls	c:23 micro pyrite 60-90um	c:24	directly below Ss; R. alberti fish?	above Ss c:27	poor forams	Chuaria 350um	poor preservation	green soapy Slt	glauc. detrital and peloidal	Hurd Creek Member, cycle base	"grainy" cycle top	

Table 3.6 Data table for the Blue Beach coastal section near Avonport.

Sample	84-21	84-20	84-22	84-19	84-18	84-17	84-16	84-15	84-22	84-13	84-12	84-11	84-10	84-08	84-75	84-09	84-04	84-03	84-02	84-01	Total No.
Stratigraphic Level	67	66	64	61	56	45	43	43	39	38	37	34	33.5	30	23	21	19	18	17	15	
Ostracodes																					
Total No. ostracodes	2	18			8					6				389	193	5			7	13	641
Total No. Species	1	1			1					1				7	3	2			2	2	
Shemonaella scotoburdigalensis		16			8					6					62					6	98
Shemonaella tatei														87					6		93
Chamishaella sp.		2												208	13	3				2	228
Copelandella novascotica	2																				2
Carbonita scalpellus														2	118	2				5	127
Cavellina lovatica?																					0
Carbonita rankiniana																					0
Baidiacypris striatiformis																					0
Geisina sp.														40							40
Youngiella sp.														51							51
Bairdia pruniseminata														16					1		17
Paraparchites sp.														3							3
Spheres																					0
Foraminifera																					
Trochammina	5	12													10				10		37
Ammotium	2																				2
Ammobaculites		1																			1
Other Fossils																					
Fish Scales	A	A		A			A	A			A		A			A	A	A	A		
Fish Bones	A	A		A			A	A					A			A	A	A	A		
Fish Teeth	A	A		A			A	A					A			A	A	A	A		
Serpulids										A						A		A			
Coprolites																			A		
Algal Bodies																					
Megaspores					10																
Bivalves															2				C	6	
Plant Fragments					C																
Sedimentological Features																					
Facies	cSlt	cSlt	cSlt	cSlt	cSlt	Slt	Slt	Slt		cSlt	Slt	Slt	Slt	cSlt	cSlt	fSs	Slt	Slt	mSlt	mSlt	
Structures		Plan																			
Pyrite Framboids															A				A	A	
Pyrite Crystals		C																		C	
Glauconite			R			C	C			C	R			R	A						
Lithic Clasts										C				A	A						
Reaction HCl																					
Mica										C											
Spheres																					
Sample Purpose	Vs	Vs	TS	Ha	Vs	Ha	Ha	Ha	Ha	Vs	Ha	Ha	Ha	Vs	Vs	Vs	Ha	Ha	Vs		
Other			Glauc. detr											BB27	Glauc. infilling shell	uncoiled Serpulids					

Table 3.7 Data table for the Saarberg Core near Falmouth.

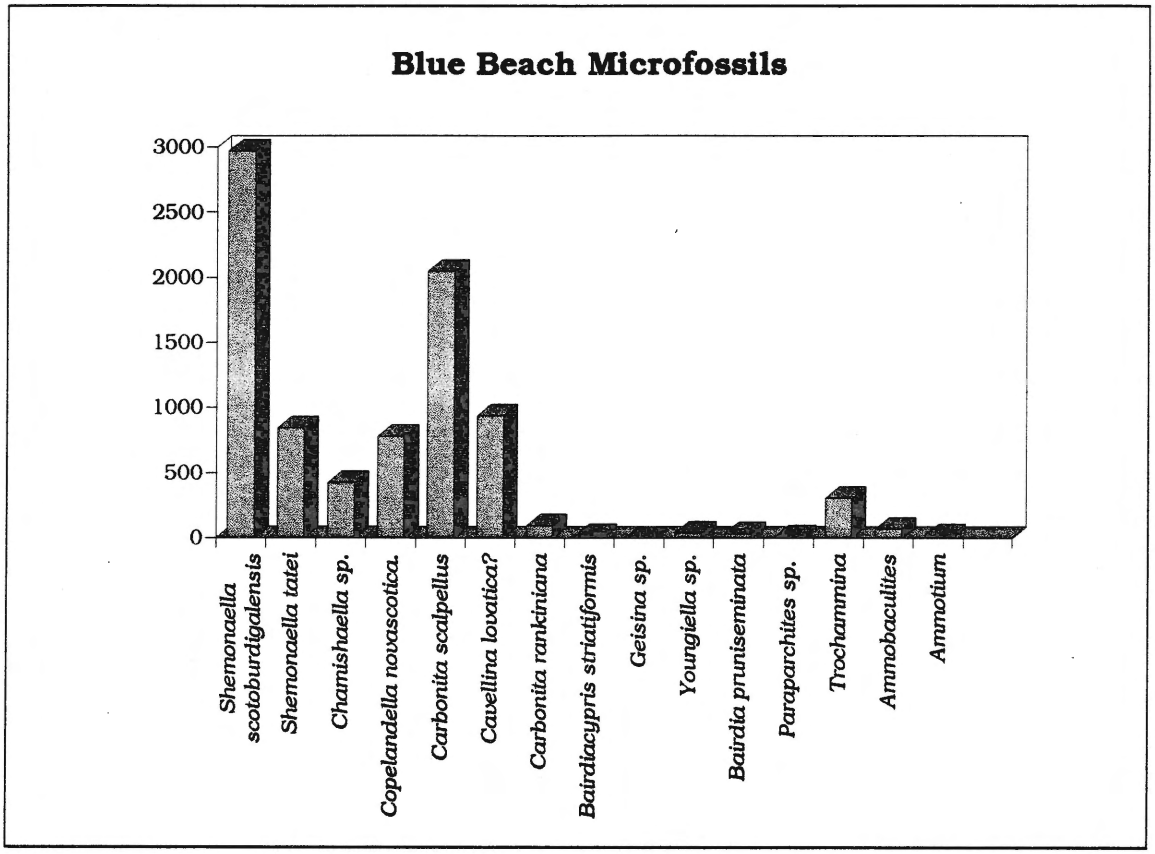


Figure 3.18 Histogram showing the relative proportion of ostracode and foraminifera taxa from the Blue Beach Member coastal section near Hantsport.

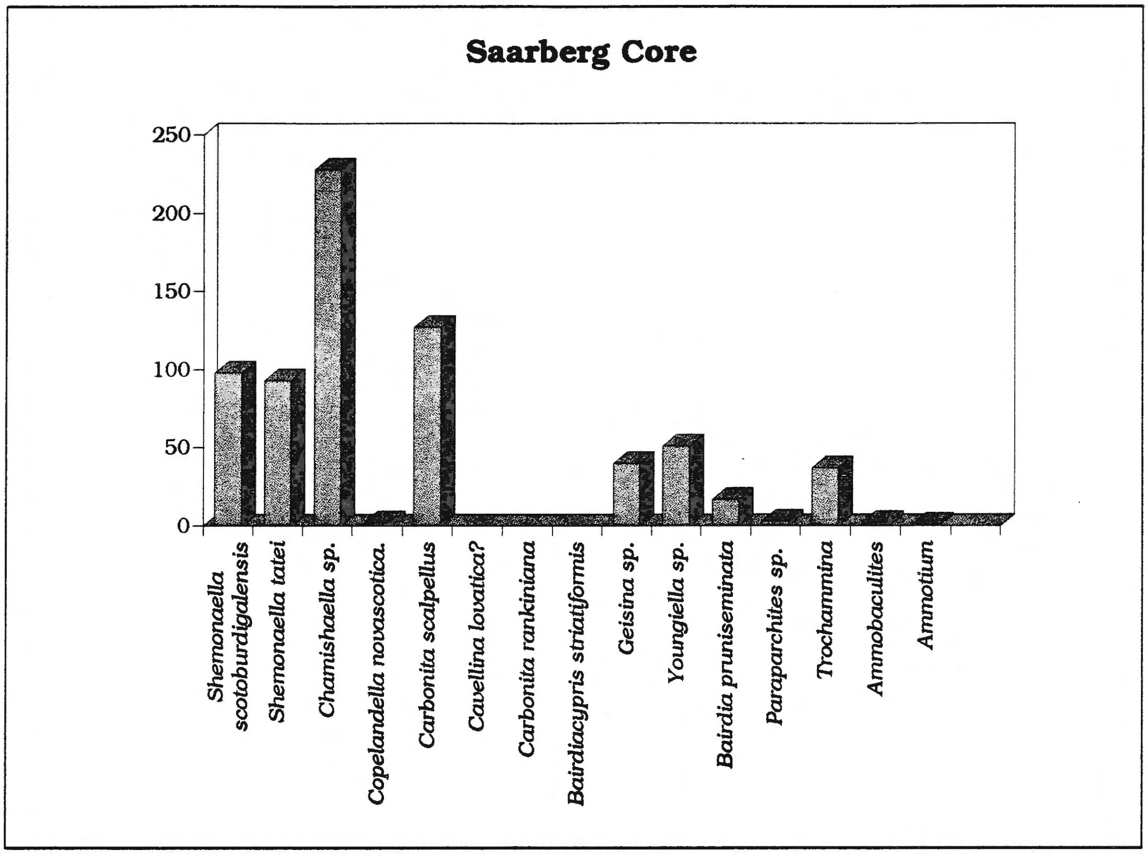


Figure 3.19 Histogram showing the relative proportions of ostracode and foraminifera taxa from the Saarberg Core near Falmouth.

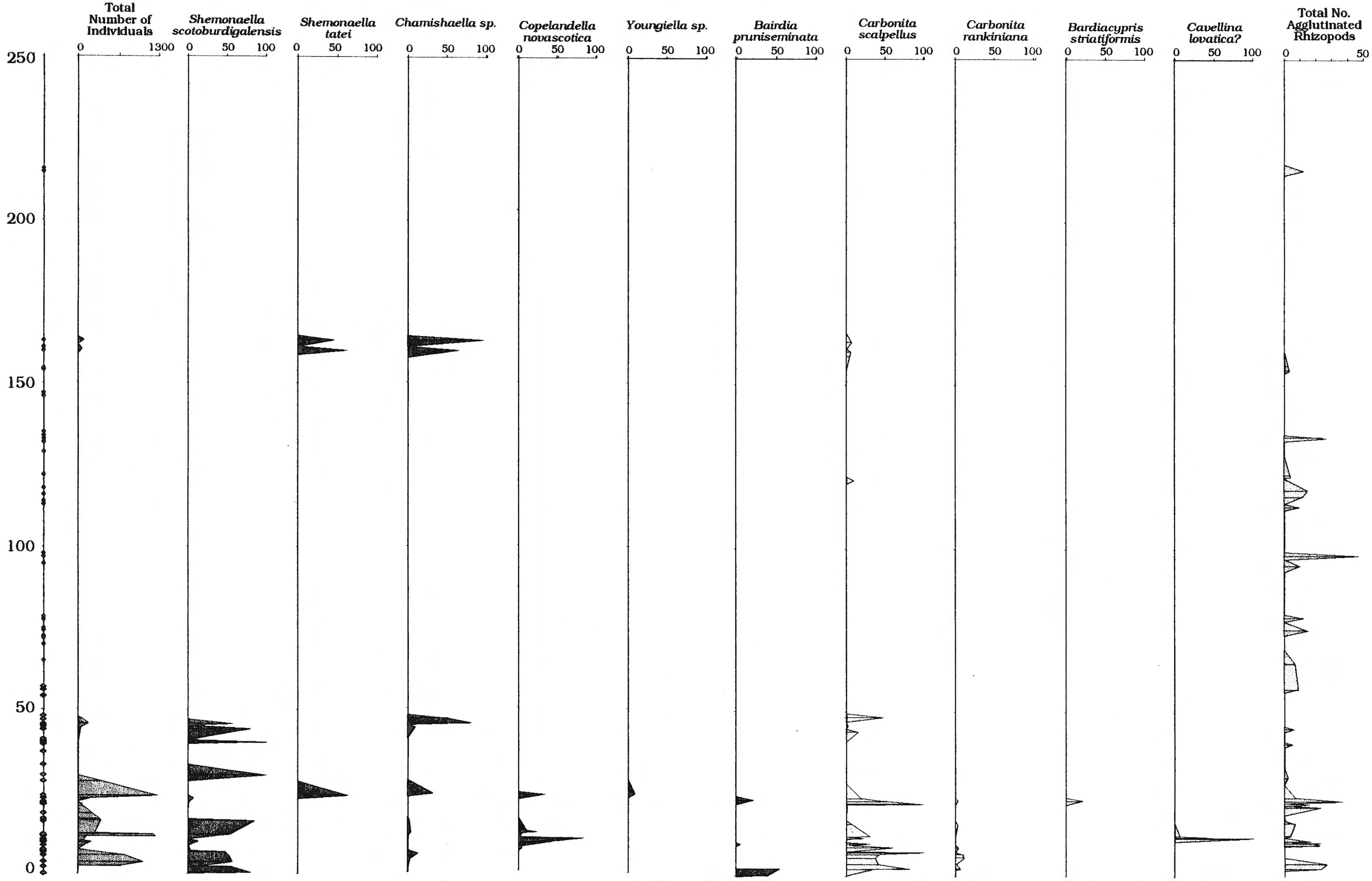


Figure 3.20 The relative proportion and stratigraphic position of the ostracode taxa. Agglutinated Foraminifera are plotted as total numbers.

Table 3.8 The fossil assemblages from the BBM. The main ostracode families for each assemblage are given in the first column.

Fossil Assemblages	**Sedimentary Features**	**Paleontological Features**	**Interpretation**
Assemblage 1 (A1) Beyrichiacea	carbonate and organic rich shale; framboidal pyrite; glauconized grains; horizontal laminae with minor ripple cross-laminae	*Copelandella sp.*, *Shemonaella sp.*, *Carbonita spp.*, agglutinated foraminifera, abundant paleoniscid fish	below wave base kenoxic profundal sediments; euryhaline marine/brackish
Assemblage 2a (A2a) Paraparchitacea Carbonitacea	siltstone with abundant mica; minor hummocky cross-stratification; ripple cross-laminae; rare pyrite and glauconite pellets	*Shemonaella scotoburdigalensis*, *Carbonita*, and sparse *Chamishaella sp.*; palaeoniscid fish scales, bones and teeth; sparse serpulid worms	shallow littoral zone where moderate wave and current activity keep bottom well-oxygenated; Mesohaline (low salinity) due to fresh/saline water mixing
Assemblage 2b (A2b) Paraparchitacea Kloedenellacea	siltstone, fine sandstone, and conglomeratic fish lenses; strongly associated with hummocky cross-stratification; abundant quartz and mica grains	*Shemonaella scotoburdigalensis* (disarticulated) and *Cavellina lovatica* (most juvenile articulate carapaces); serpulids and fish debris abundant; macrospores	high energy/ high fluvial recharge; *Cavellina* (oligohaline) transported into brackish nearshore during storms resulting in a pathological death assemblage; associated with other brackish/ marine species; salinity variable (mixo/oligohaline)
Assemblage 2c (A2c) Paraparchitacea	coarse siltstone and muddy shale; sandstone sheets	*Shemonaella tatei* and *Chamishaella sp.*; minor occurrence of stenohaline ostracodes; rare fish and serpulids	high energy shallow nearshore with rapidly changing salinities; low diversity; polyhaline/hyperhaline
Assemblage 3 (A3) Carbonitacea	muddy shale; octahedral pyrite; calcareous micro-concretions and mica	*Carbonita sp.* abundant; Foraminifera; fish teeth, scales, bones, and coprolites very abundant; serpulids common; plant detritus	shallow muddy wave attenuated shoreline; fluvial recharge high; herbivore ostracodes; some reworked brackish species; oligohaline
Assemblage 4 (A4) Paraparchitacea Kloedenellacea *Youngiella* *Bairdia*	coarse silty shale; abundant glaucony grains and possible hard ground	*Chamishaella sp.*, *Shemonaella tatei*, *Geisina sp.*, *Youngiella sp.*, and *Bairdia* ; euryhaline and stenohaline marine species; highest diversity of study	stable marine lagoon; low current activity; stenohaline?
Assemblage 5 (A5) Agglutinated Foraminifera Sparse Carbonitacea	mudstone, coarse silty interbeds; euhedral pyrite common to abundant; slightly reactive to HCl; micaceous; associated carbonate nodules and desiccation cracks	*Trochammina sp.*, *Ammobaculites sp.*, and *Ammotium sp.*; rare fish debris and coprolites; pyritized foraminiferal tests?; plant detritus common	upper salt marsh associated with vegetation (humic matter); stable shoreline during ponding; reduced fluvial recharge; limnetic/oligohaline

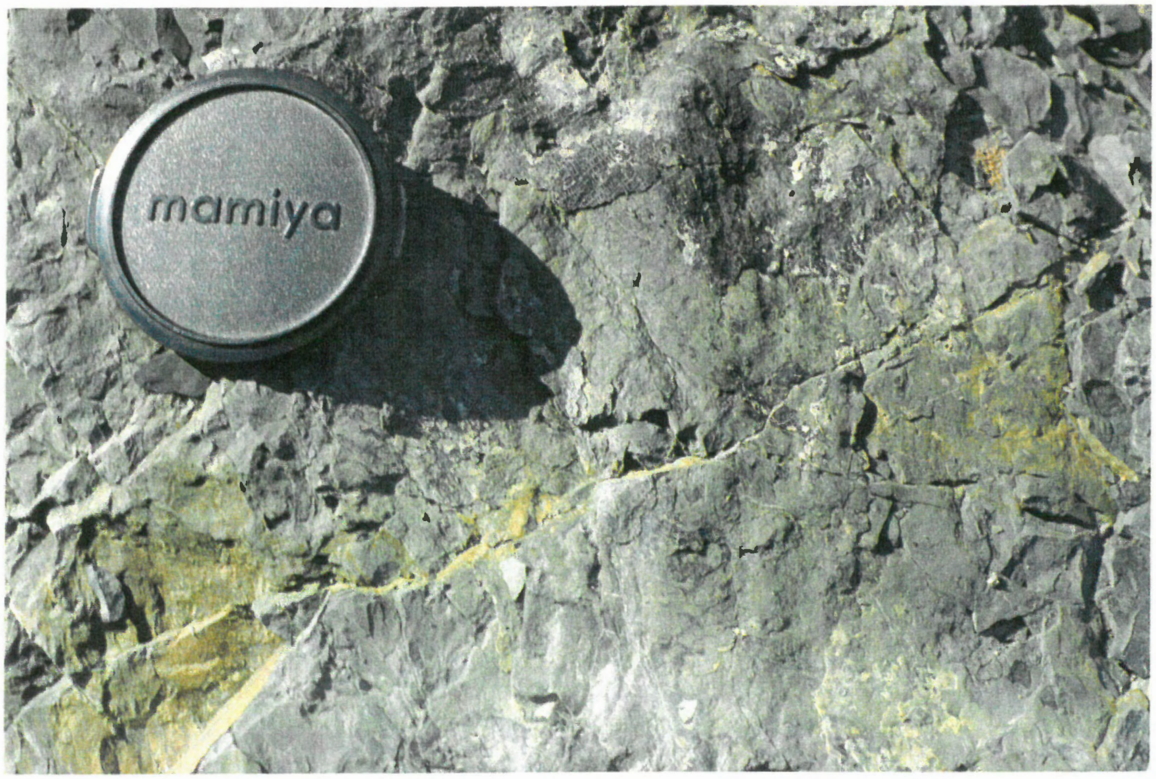


Figure 3.21 An insitu palaeoniscid fish fossil from the Blue Beach coastal section. It is associated with organic-rich shale and *Copelandella novascotica* ostracode horizons (Assemblage 1).

directly above both the fossiliferous ostracode layer and paleoniscid fish horizon. Palaeoniscid fish, serpulid worms, and plant detritus are locally abundant. Foraminifera include *Trochammina sp.* and rare *Ammobaculites sp.*. Sedimentological features include framboidal pyrite, glaucony grains, carbonate cement, and micro cross-laminae.

The ostracodes of this assemblage comprise 4 species from as many genera. The genera include *Copelandella*, *Shemonaella*. (11%), *Carbonita* (11%), and *Bairdia* (2%) (Table 3.9; Fig. 3.22). The ostracode species *C. novascotica*, comprises from 57% to 82% of the total numbers in the representative samples. The valves of *Shemonaella scotoburdigalensis* are disarticulated and comprise a near complete growth series. A thin section reveals a calcareous sphere preserved within the brood pouch of an adult female; several isolated calcareous spheres also occur within these representative samples.

3.2.3 Assemblage 2

Two genera and three species of paraparchitacean ostracodes all associated with siltstone and silty shale characterise this assemblage. Because two of the paraparchitacean species are mutually exclusive a further subdivision into three sub-components is necessary. Freshwater carbonitaceans play a significant role in this assemblage as well. The prominent sedimentological features associated with these ostracodes are hummocky cross-stratification, planar laminations, and ripple cross-laminations all of the alternating siltstone, sandstone, and claystone assemblages (see Sedimentology). Sparse reworked glaucony grains and euhedral pyrite are the only petrological features in all of the sub-assemblages.

Table 3.9 List of microfossils from Assemblage 1 (A1).

Sample	**BB28**	**BB29**	**S4-21**	**Total**	
Stratigraphic Level	9.8	9.97	67		
Ostracodes				**Total No.**	**Total %**
Total No. ostracodes	**209**	**76**	**3**	**288**	
Total No. Ostracode Species	**4**	**3**	**2**		
Shemonaella scotoburdigalensis	22	10	1	**33**	**11%**
Copelandella novascotica.	173	43	2	**218**	**76%**
Carbonita scalpellus	8	23		**31**	**11%**
Bairdia pruniseminata	6			**6**	**2%**
Encysted Eggs	13	2		**15**	
Foraminifera					
Trochammina	6	16	5	**27**	**73%**
Ammobaculites	3	5	2	**10**	**27%**
Ammotium					

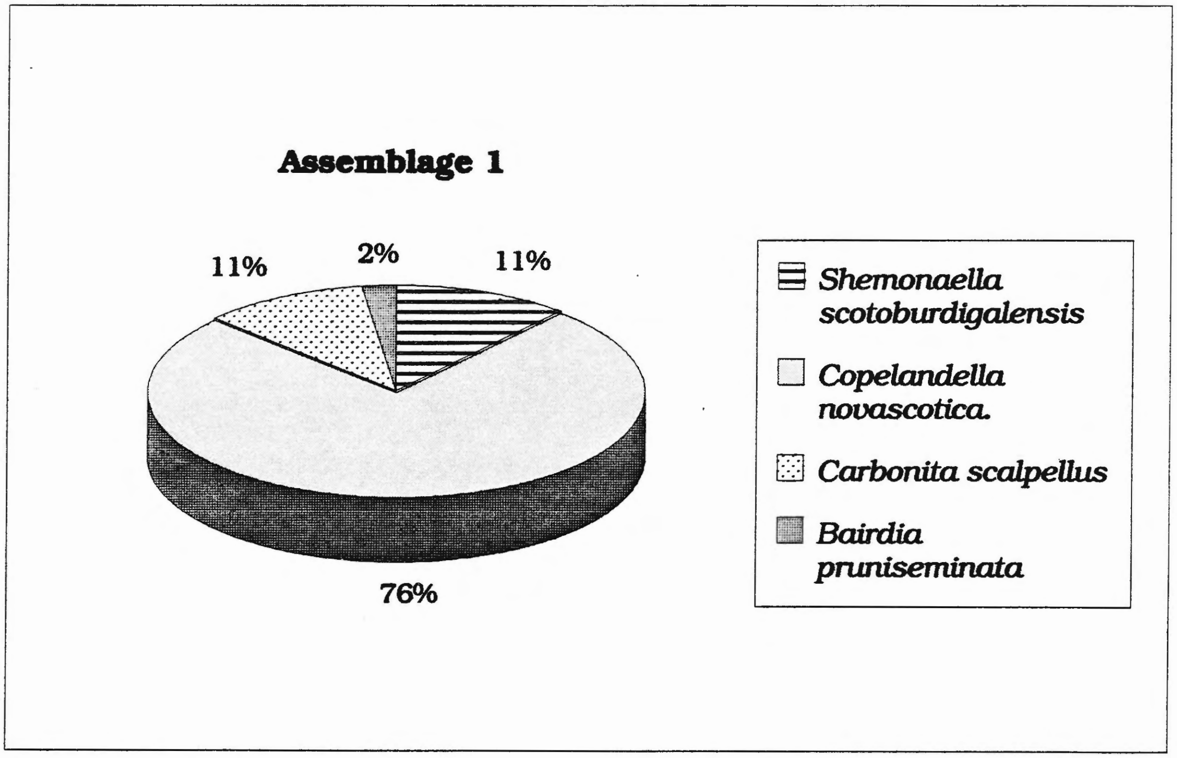


Figure 3.22 The percentages of ostracode taxa in Assemblage 1 (A1).

Sub-assemblage 2a (A2a)

This assemblage occupies three main stratigraphic zones. The first zone occurs in the first cycle at 3.82-6.77 metres. The other two zones are located at 16.1 m and 44.1 m respectively (Fig. 3.1). This assemblage occurs midway in the sedimentary cycles, usually in grey silty shales.

The restricted ostracode fauna of this assemblage includes *Shemonaella scotoburdigalensis*, *Carbonita scalpellus*, *Chamishaella* and *Copelandella novascotica*. (Table 3.10 and Fig. 3.23). The large smooth shelled *Shemonaella scotoburdigalensis* comprises 48-92% of the total numbers. Most of the specimens are single valves of which most are adults and the larger instars (A-1 through A-5). The absence of the smaller juveniles and completely disarticulated valves suggest moderate hydrologic activity. Small thinly calcified adult valves of *Carbonita scalpellus* and *Carbonita rankiniana* occur; they range from less than 1% to as much as 49% of their representative samples. Another paraparchitacean *Chamishaella sp.* constitutes approximately 5% of the assemblage comprising articulate carapaces of the last few instars. The stable marine forms are sparsely represented and include abraded adult specimens of *Copelandella novascotica* and *Youngiella sp.*.

Sub-assemblage 2b (A2b)

Shemonaella scotoburdigalensis comprises approximately 45 % of the specimens while *Copelandella novascotica* makes up 15%. (Table 3.11; Fig. 2.24). As in the sub-assemblage A2a, *Chamishaella sp.* are relatively uncommon. A curious aspect is the low numbers of *Carbonita scalpellus*. This sub-assemblage differs from the previous by the abundance of *Cavellina lovatica?* (See Taxonomy). This kloedenellacean comprises 33 % of the sub-assemblage and of the 938 small finely reticulate specimens approximately 90 percent are articulate juvenile carapaces (tecnomorphs) indicative of either a pathological death assemblage or selective grain size suspension and transport

Table 3.10 List of microfossils from Assemblage 2a (A2a).

Sample	**BB55**	**BB02**	**BB20**	**BB41**	**BB71**	**BB73**	**Total**	
Stratigraphic Level	**3.82**	**5.72**	**6.77**	**16.1**	**44.08**	**45.63**		
Ostracodes							**Total No.**	**Total %**
Total No. ostracodes	**1058**	**746**	**228**	**339**	**44**	**170**	**2585**	
Total No. Ostracode Species	**5**	**5**	**4**	**4**	**3**	**3**		
Shemonaella scotoburdigalensis	595	388	109	313	35	97	**1537**	**59.46%**
Chamishaella sp.	12	44		2	2	68	**128**	**4.95%**
Copelandella novascotica.			8				**8**	**0.31%**
Carbonita scalpellus	436	273	99	22	7	2	**839**	**32.46%**
Carbonita rankiniana	13	40	12	2			**67**	**2.59%**
Youngiella sp.	2	1					**3**	**0.12%**
Paraparchites sp.						3	**3**	**0.12%**
Foraminifera								
Trochammina sp.					6		6	

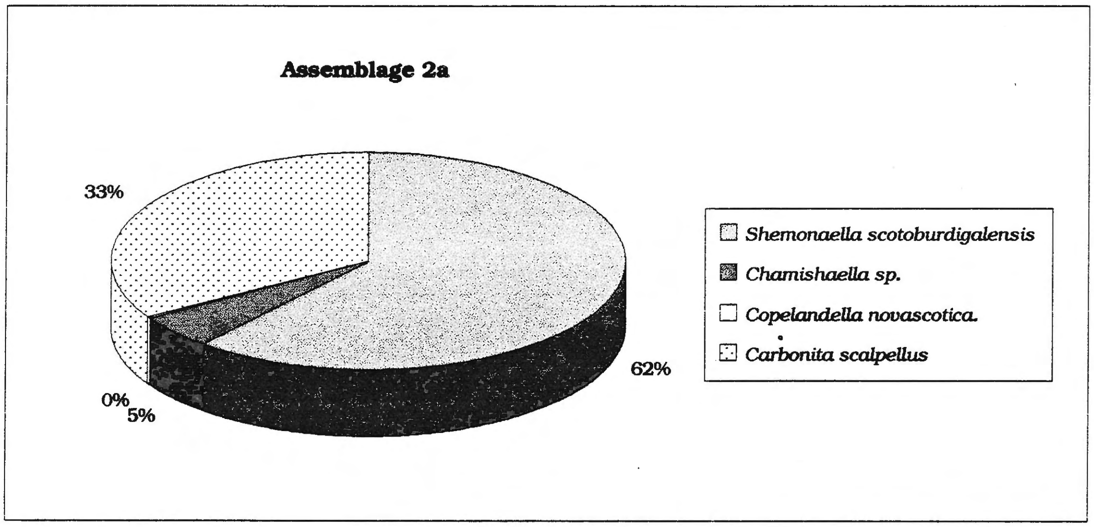


Figure 3.23 The percentages of ostracode taxa in Assemblage 2a (A2a).

Table 3.11 List of microfossils from Assemblage 2b (A2b).

Sample	**BB27**	**BB33**	**BB40**	**BB48**	**Total**	
Stratigraphic Level	**11.6**	**11.7**	**11.87**	**12.1**		
Ostracodes					**Total No.**	**Total %**
Total No. ostracodes	**1224**	**124**	**1209**	**255**	**2812**	
Total No. Ostracode Species	**5**	**5**	**7**	**5**	**22**	**0.78%**
Shemonaella scotoburdigalensis	504	51	592	138	**1285**	**45.70%**
Chamishaella sp.	16	1	23	4	**44**	**1.56%**
Copelandella novascotica.	69	29	281	29	**408**	**14.51%**
Carbonita scalpellus	17	26	17	76	**136**	**4.84%**
Cavellina lovatica?	618	17	295	6	**936**	**33.29%**
Carbonita rankiniana				2	**2**	**0.07%**
Bairdia pruniseminata			1		**1**	**0.04%**
Foraminifera						
Trochammina sp.				6	**6**	

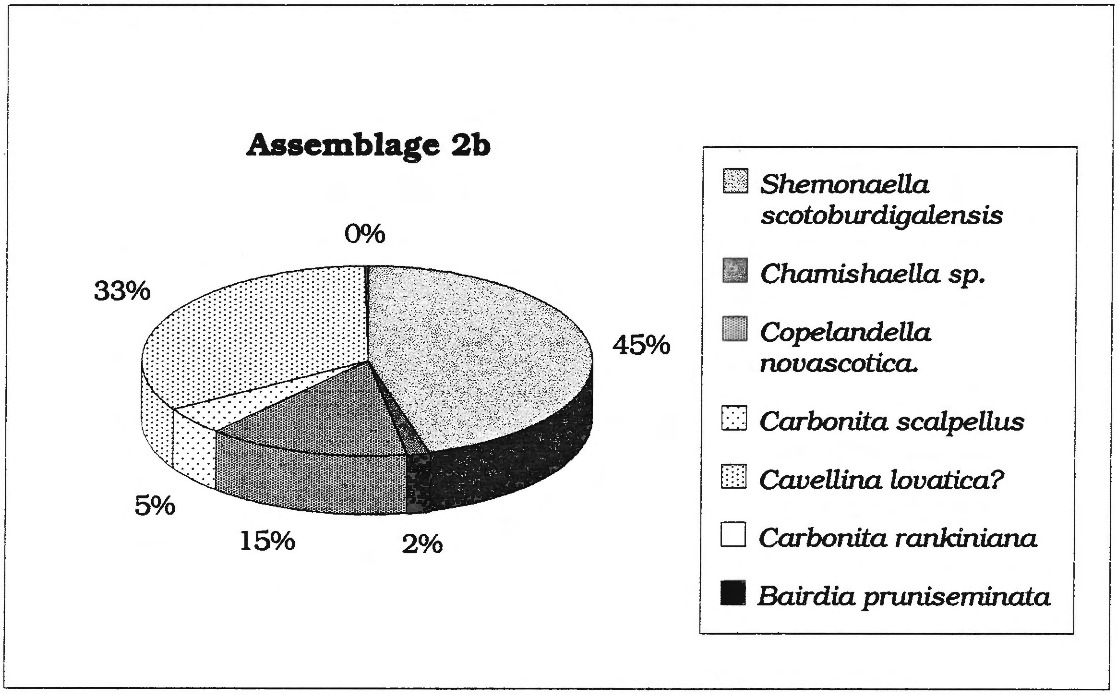


Figure 3.24 The percentages of ostracode taxa in Assemblage 2b (A2b).

from adjacent areas. The co-occurrence of *Shemonaella scotoburdigalensis* and *Cavellina lovatica?* correspond to the 11.6 to 12.1 m stratigraphic zone (Figs. 3.1 and 3.20).

Sub-assemblage 2c (A2c)

This assemblage occurs associated with muddy siltstones at 23.8 m and in the last two ostracode bearing beds at 150 and 153 m (Figs. 3.1 and 3.20). The identifying characteristic of this sub-assemblage are the small thinly calcified carapaces of *Shemonaella tatei* which comprise approximately 62 % of the total population (Table 3.12; Fig. 3.25). It should be noted that sample BB65 differs from the last two representative samples in that it occurs much lower in the stratigraphic section and contains the marine morphotype *Youngiella.* Samples BB99 and BB98 show complete domination of both *Chamishaella sp.* and *Shemonaella tatei* with *Carbonita scalpellus* comprising less than 1 % of the total numbers (Figs. 3.1 and 3.20). In general the specimens are in a much better fossilised state than the previous two sub-assemblages. Both *Shemonaella tatei* and *Chamishaella sp.* demonstrate complete growth series with a high percentage of articulate carapaces. Specimens of *Shemonaella tatei* have well-preserved internal structures including mandibular and adductor muscle scars and internal pore structures (see Taxonomy).

3.2.4 Assemblage 3 (A3)

This assemblage (A3) occurs at the base of the first two cycles at 2.29 and 8.82 m (Fig 3.1). This assemblage is relatively uncommon but is easily distinguished by the large proportion of the Carbonitacea. Sedimentological features include muddy shale containing euhedral (octahedral) pyrite, spherical microconcretions of carbonate (probably pedogenic), and mica. Other fossils include relatively abundant *Trochammina sp.*, palaeoniscid fish , serpulid worms, coprolites, and sparse plant detritus.

Table 3.12 List of microfossils from Assemblage 2c (A2c).

Sample	**RB65**	**RB99**	**RB98**	**Total**	
Stratigraphic Level	**23.81**	**160**	**163**		
Ostracodes				**Total No.**	**Total %**
Total No. ostracodes	**1278**	**33**	**44**	**1355**	
Total No. Ostracode Species	**5**	**3**	**3**		
Shemonaella tatei	803	20	20	**843**	**62.21%**
Chamishaella sp.	202	11	21	**234**	**17.27%**
Carbonita scalpellus	229	2	3	**234**	**17.27%**
Youngiella sp.	37			**37**	**2.73%**
Paraparchites sp.	7			**7**	**0.52%**

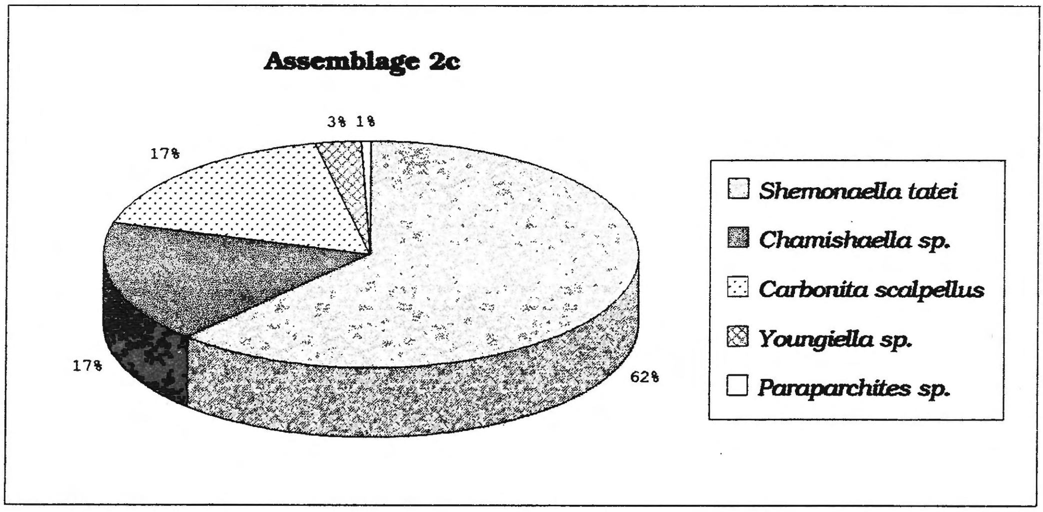


Figure 3.25 The percentages of ostracode taxa in Assemblage 2c (A2c).

Carbonita scalpellus comprises the autochthonous ostracode component of this assemblage (approximately 72 %) of which there is a complete growth series, a small proportion being articulate adults (Table 3.13; Fig. 3.26). Both *Shemonaella scotoburdigalensis* and *Copelandella novascotica* constitute 11% of the total numbers, most being adult valves. Sample BB64 contrasts with the other two representative samples as it contains a relatively high proportion of *Copelandella novascotica* and sparse *Bairdia pruniseminata*. This sample also contains the only occurrence of *Bairdiacypris striatiformis* which has a distinct striated surface. Also, sample BB54 contained 24 unidentified ostracodes, all of which are steinkerns. *Carbonita scalpellus* are evenly distributed in both the core and the coastal section (Figs. 3.1, 3.2, and 3.20), however, the other species of this genus are restricted to Cycle 2 of the coastal section (Fig. 3.1).

3.2.5 Assemblage 4 (A4)

This assemblage is exclusive to the Saarberg core at 30 m depth (Fig. 3.2) comprising only 2 % of the total ostracodes identified from the Blue Beach Member. Sedimentary features include abundant glaucony grains and pellets in a coarse silty shale in which quartz and feldspathic clasts are common. Other fossils include abundant palaeoniscid fish and serpulid worms.

Ostracodes include the locally abundant Paraparchitacea, Kloedenellacea, Youngiellacea, and Bairdiacea (see chapter 5 for the paleoecological discussions for these super-families). Two paraparchitacean ostracodes *Chamishaella sp.* and *Shemonaella tatei* comprise 51% and 22% of the total numbers respectively (Table 3.14; Fig. 3.27). This assemblage resembles the subassemblage 2c (A2c) but differs as it has a high proportion of *Chamishaella sp.*. The majority of the specimens are articulate adults. The adults range in size from 125-700 µm which contrast with the

Table 3.13 List of microfossils from Assemblage 3 (A3).

Sample	**BB54**	**BB26**	**BB64**	**Total**	
Stratigraphic Level	**2.29**	**8.82**	**23.02**	**Total No.**	**Total %**
Ostracodes					
Total No. ostracodes	**666**	**132**	**196**	**994**	
Total No. Ostracode Species	**5**	**3**	**6**		
Shemonaella scotoburdigalensis	99		9	**108**	**10.87%**
Chamishaella sp.	1			**1**	**0.10%**
Copelandella novascotica.		50	64	**114**	**11.47%**
Carbonita scalpellus	544	79	78	**701**	**70.52%**
Carbonita rankiniana	22	3	2	**27**	**2.72%**
Bairdiacypris striatiformis			21	**21**	**2.11%**
Bairdia pruniseminata			22	**22**	**2.21%**
Foraminifera					
Total No. Foraminifera	**22**	**20**	**7**		
Trochammina	22	11	7	**40**	**81.63%**
Ammotium		4		**4**	**8.16%**
Ammobaculites		5		**5**	**10.20%**

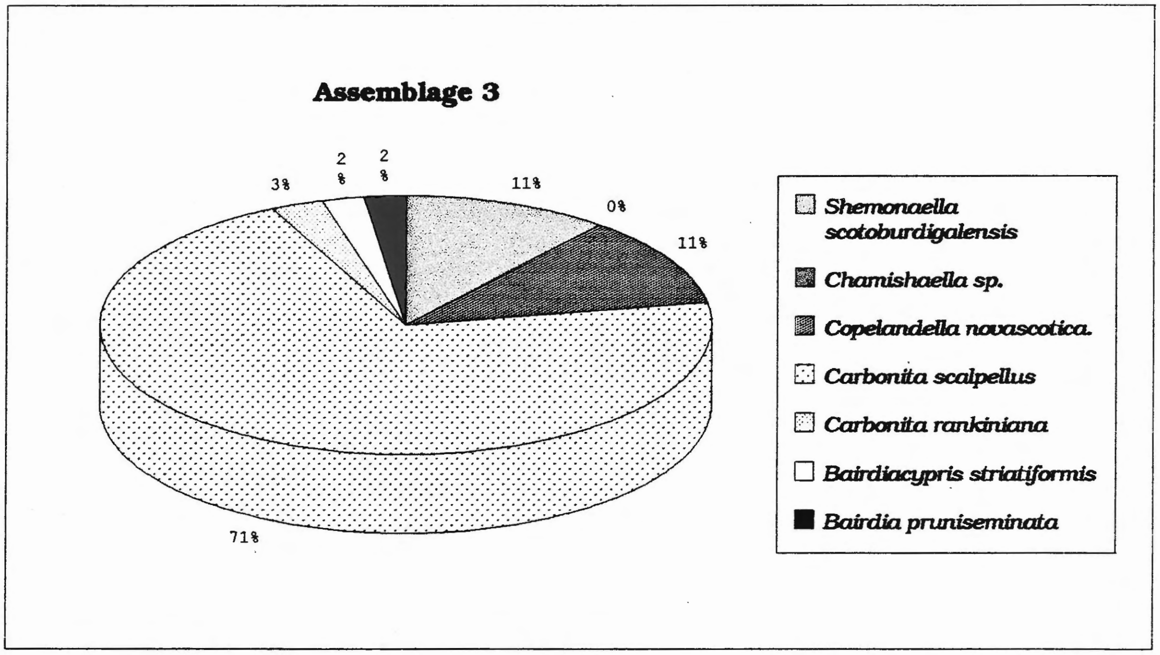


Figure 3.26 The percentages of ostracode taxa in Assemblage 3 (A3).

Table 3.14 List of microfossils from Assemblage 4 (A4).

Sample	**84-08**	**Total %**
Stratigraphic Level	**30**	
Ostracodes		
Total No. ostracodes	**389**	
Total No. Ostracode Species	**7**	
Shemonaella tatei	87	**22.37%**
Chamishaella sp.	208	**53.47%**
Carbonita scalpellus	2	**0.51%**
Geisina sp.	40	**10.28%**
Youngiella sp.	51	**13.11%**
Bairdia pruniseminata	16	**4.11%**
Paraparchites sp.	3	**0.77%**

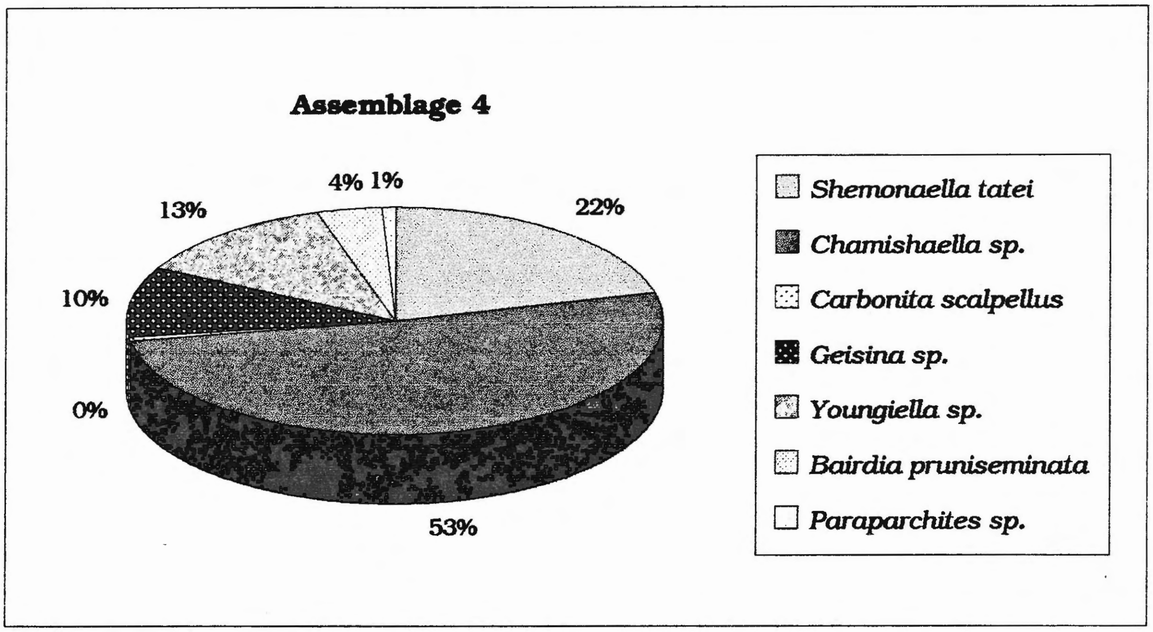


Figure 3.27 The percentages of ostracode taxa in Assemblage 4 (A4).

somewhat larger specimens (up to 4000 μm) common at Blue Beach. *Youngiella sp.* (13%) and *Bairdia pruniseminata* (4%) demonstrating articulate valves in a poorly-represented growth series (see Taxonomy). The kloedenellacean, *Geisina sp.* (10%), are represented by adult carapaces and few juvenile tecnomorphs (A-1 to A-3). The heteromorph to tecnomorph ratio for *Geisina sp.* is approximately 2:1 (24 females/16 males). The fresh water *Carbonita scalpellus* comprises less than one percent of the total numbers.

3.2.6 Assemblage 5 (A5)

Although agglutinated foraminifera occur with the ostracodes in other assemblages, they occur almost exclusively by themselves in the green carbonate rich mudstones. Ostracodes are almost exlusively absent from this ecozone in the Blue Beach Member (Fig. 3.20). Sedimentological features in this mudstone dominated zone include coarse silty interbeds, micaceous interbeds, carbonate nodules, and desiccation cracks. Euhedral pyrite is prominent in these assemblages as well. Other fossils include abundant faecal pellets, burrowed horizons (*Palaeophycus*, *Planolites*, and *Isopodichnus*: Fig. 3.28), and abundant plant detritus (Fig. 3.29). The uppermost units contain in situ lycopsid tree trunks of a potential fossil forest (Fig. 3.30). Finally, the last foraminifera bearing bed occurs several metres above an identified tetrapod trackway (Fig. 3.32).

The Foraminifera include agglutinated morphotypes that resemble the modern genera of *Trochammina*, *Ammobaculites*, and *Ammotium*. *Trochammina* are the most abundant comprising 76 % of the total numbers (Table 3.15; Fig. 3.31) and are frequently associated with insitu plant matter, euhedral pyrite, and desiccation cracked horizons in the top half of the section. The lower marsh, *Ammobaculites* and *Ammotium*, comprise 15% and 2% of the total numbers respectively. These paralic marsh morphotypes are most common in the first few cycles associated with the black

Figure 3.28 Burrows of the ichnogenus *Palaeophycus* associated with desiccation cracks infilled with sand. The muddy sandstone has a carbonate cement. This slab was obtained from the burrow horizon in Cycle 4 from the coastal outcrop (Fig. 3.5).

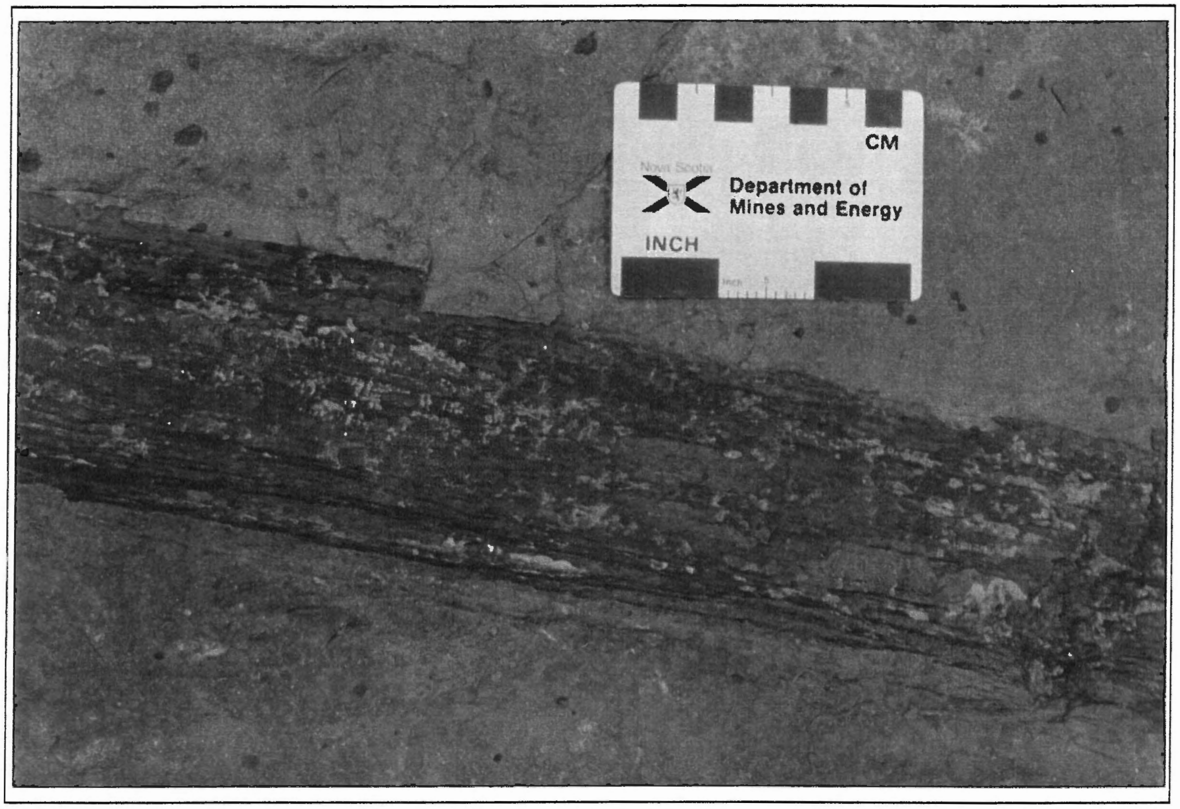


Figure 3.29 A fossil tree branch in sandstone associated with the Assemblage 5 (A5).

Figure 3.30 Insitu lycopsid tree casts from coastal section Blue Beach in the lower Hurd Creek Member. Note the dessication cracks in the calcareous (dolomitized?) silty mudstones. This unit corresponds to the first observed occurrence of Tetrapod trackways immediately overlying the upper-most ostracode bearing bed in the BBM.

Figure 3.32 Tetrapod trackways from the Hurd Creek Member immediately above the BBM boundary and uppermost ostracode bearing bed (Fig. 3.1). Foraminifera and insitu lycopsid trees occur below and above this horizon (see Fig 3.30).

Table 3.15 List of microfossils from Assemblage 5 (A5).

Sample	**BB26**	**BB63**	**BB81**	**BB101**	**BB84**	**BB86**
Stratigraphic Level	**8.82**	**21.95**	**56**	**57**	**74.37**	**77.65**
Foraminifera						
Trochammina	11	25	7	6	14	10
Ammotium	4					
Ammobaculites	5	12	2			
Carbonita scalpellus		3				

Sample	**BB85**	**BB05**	**BB04**	**BB42**	**BB06**	**BB91**	**Total**	**Total %**
Stratigraphic Level	**78.5**	**97**	**98**	**114**	**116**	**122**	**No.**	
Foraminifera							**216**	
Trochammina	8	44	3	10	8	4	**163**	**75.46%**
Ammotium			2				**16**	**7.41%**
Ammobaculites	2		5	2	1		**33**	**15.28%**
Carbonita scalpellus						1	**4**	**1.85%**

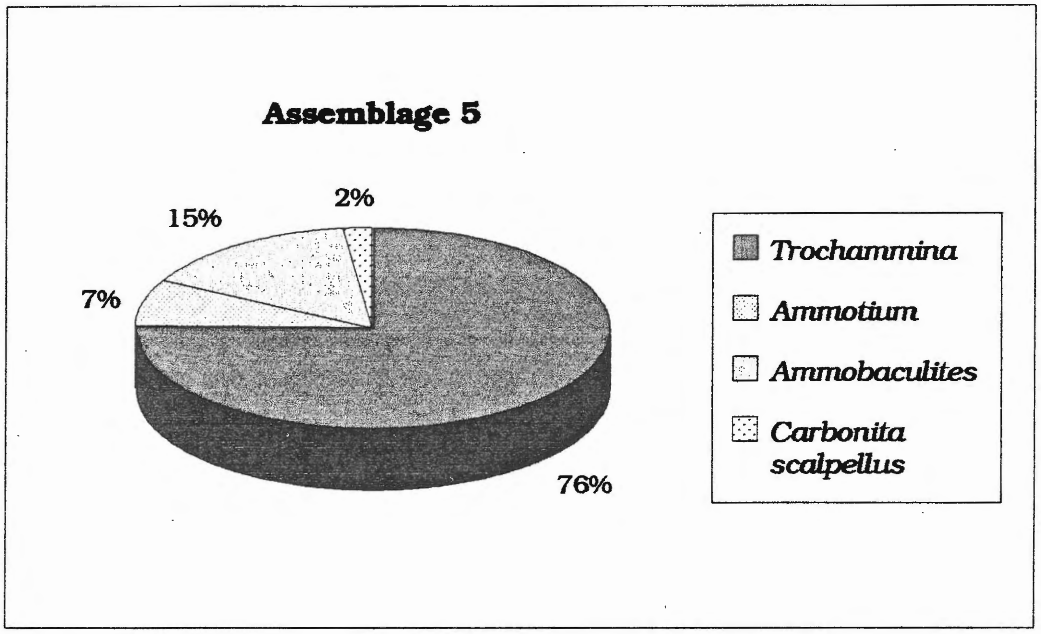


Figure 3.31 The percentages of foraminifera and ostracode taxa in Assemblage 5 (A5).

shales and the marine ostracode *Copelandella.* The fresh water *Carbonita scalpellus* comprises only 3 disarticulate specimens of the sample.

CHAPTER 4 OSTRACODE PALEOECOLOGY

4.1 OVERVIEW

The morphology of the ostracode carapace is known to reflect the environment the animal occupies. In light of the numerous ecological studies on ostracodes in recent and ancient deposits (Benson, 1959; Swain, 1974; Bless, 1983; Becker and Bless, 1990), an extensive data base exists from which the author will briefly review the main environmental aspects and ecological controls for recent ostracodes which can be applied directly to ancient assemblages. This information will be used in the next chapter to interpret the fossil assemblages.

4.2 OSTRACODE MORPHOLOGY

4.2.1 Surface Ornamentation

The prominent features of the ostracode carapace are as follows (see Fig. 1.5): 1. pore canals that permit the passage of hair or setae in living forms; 2. spines that are either ornamental or useful for transport in aquatic systems with high current activity (Benson et al., 1961); 3. lobes or elevations of the shell that reflect internal depressions and troughs; and 4. sulci or elongate depressions that mirror internal elevations of the shell.

4.2.2 Dimorphism

Some ostracodes are parthenogenetic and reproduce primarily without male fertilisation. Paleozoic beyrichiacean and kloedenellacean female ostracodes have distinct brood-pouches or cruminae located anterioventrally on the shell (Fig. 1.5). This cruminal dimorphism provides a protective mechanism to enclose the eggs and ensure successful development of the offspring (Benson et al., 1961).

4.2.3 Muscle Scars

The adductor muscle of living ostracodes allows the organism to open and close the shell. Fossilised specimens commonly have fossil scars where the muscle was attached to the internal region of the shell (Fig. 1.5). Preservation of the scars in Paleozoic forms is uncommon; however, using oil immersion and coating techniques, it was possible to identify some scars from the paraparchitid and cavellinid ostracode families found at Blue Beach.

4.3 ECOLOGICAL ASPECTS OF RECENT OSTRACODES

4.3.1 Overview of Environmental Controls

Given the availability of ecological information for recent ostracodes, interpretations for extinct families have greatly improved in the past 20 years. Homologous comparisons of ancient to living forms has its limitations, however, the basic functional morphology of the ostracode carapace is considered to be similar in both. Physical, chemical, and biological aspects control the shape, size, and mode of life the ostracodes exhibit. This section briefly outlines the basic ecological maxims of modern ostracodes.

4.3.2 Chemical Factors (Salinity)

Since ostracodes occupy all environments ranging from oligohaline (0-3 ppt) to hyperhaline (35-80 ppt) and demonstrate variable diversity and speciation in these environments, they lend themselves to paleosalinity reconstructions. In most of these numerous studies, salinity is considered to be the critical controlling factor for ostracode distribution in marine, brackish, and saline lacustrine environments (Kilenyi, 1969; Forester and Brouwers, 1985; Chivas et al., 1986; Neale, 1988).

Water Chemistry and Shell Composition

Forester (1983) provided examples of how the shell composition of two species of nonmarine ostracodes responded to solute composition in saline lakes from the United States and Mexico. Calcite will precipitate in normal fresh water, however, when the Mg/Ca ratio changes there will be an enrichment or depletion of Ca^{2+} or HCO_3^- depending on the bacterial reduction of sulphate and gypsum precipitation pathways. Forester (1983) documented the modern ostracode *Limnocythere sappaensis* in fresh waters (below 3 ppt salinity) enriched in Na, HCO3-, and -CO_3^2 but depleted in Ca_2- while *Limnocythere staplini* was associated with saline environments enriched in Na, Mg^2, Ca^2, and SO_4^2. DeDecker and Forester (1988) later theorised that increases in salinity in non-marine terrestrial ecosystems would cause species diversity to first rise then fall. Smith (1993) provided evidence to support this theory demonstrating maximum species diversities occur where freshwater overlaps with saline water. Some researchers have applied these principles, using both Mg/Ca and Sr/Ca ratios of ostracode shells, to paleosalinity and paleotemperature reconsructions (Chivas et al. 1986; Engstrom and Nelson, 1991).

Similar paleo-hydrochemical studies showed that distinct ostracode faunal boundaries occur between freshwater and the brackish estuarine zone in Alaska (Forester and Brouwers, 1985). They demonstrated that if Na and Cl compositional differences were low, then nonmarine and brackish forms could occur simultaneously. In contrast, when the Na and Cl differences were high the species were mutually exclusive. Forester and Brouwers (1985) concluded that ostracodes do not just respond to salinity but to the solute composition (mainly Na and Cl) of the waters. Essentially, marine ostracodes can live in non-marine environments providing the dominant ions are Na and Cl, whereas, freshwater species occupy environments dominated by Ca^{2+} and HCO_3^-. In general salinity was shown to control the geographical distribution of the species in an estuary.

Effects of Salinity on the Carapace

Ostracodes absorb all of the chemical components necessary to secrete their shells directly from the surrounding water. The three main types of morphological variation due to solute composition of the water are:

1. *Reticulation:* The reticulation and punctation of the carapace has been linked to increased Mg/Ca ratios related to carbonate equilibria in the environment (Carbonel, 1982 in van den Bold, 1990).

2. *Noding: Cyprideis torosa* provides an example of a modern ostracode that occurs in NaCl dominated nonmarine lakes, brackish lagoons, and normal marine environments. Noding increases in frequency when salinity fluctuates from the optimal range for a given species. Although no conclusive evidence has been provided in the literature, various authors theorise noding may be a response of the organism to maintain buoyancy (Neale, 1988).

3. *Size:* Ostracodes may show a decrease in size with reduced salinity. Also, hypersaline ostracodes are often smaller in size and have a more rounded anterior margin. In general, any variation from the optimum salinity values for any given species usually results in size diminution (Neale, 1988).

4.3.3 Physical Controls

Benson (1959) studied the ecology of ostracodes from the Baja California discussing the basic size and shape of recent ostracodes from a marginal marine environment (lagoons, bays, and estuaries). Benson (1959) concluded that ostracodes found on soft marine substrates usually have strong hinges, smooth shells (less friction), and are phytal feeders that burrow into the fine muddy sediments. These muddy burrowers are thin and long while those ostracodes that burrow into coarser sands are short and small. Wanderers (nectobenthic) have rough reticulate shells with or without longitudinal ribbing and less commonly some have thick, smooth larger carapaces that serve to reinforce the shell under higher hydrologic flow regimes. Essentially, ostracode distribution is related to water depth, wave activity, and sediment supply. Typically, the populations are lower where sedimentation rates are highest, corresponding to deposition of coarser grain size, higher current activity, and preferential sorting. Benson (1959) observed such distribution patterns at the mouth of a large coastal lagoon.

Swain (1974) found that freshwater ostracodes preferred vegetation rich littoral zones, shallow ditches and ponds. Some species lay their eggs at the shoreline and require seasonal desiccation prior to hatching. Swain (1974) considered that the important restrictions for the dispersal of fresh water ostracodes into a new habitat were related to nutrition, substrate, morphology, and temperatures for egg hatching.

4.3.4 Nutrient Availability

Nutrient availability in any ecosystem is an important factor. In highly productive ecosystems, there must be a supply of nutrients from either cold water oceanic upwelling or at the mouth of a river where nutrient laden sediment enters a lake, lagoon, or estuary. In the marine realm, the high population and dominance of one species of brackish water ostracode can be attributed to a high riverine input of nutrient laden water, which provides a rich food source, while at the same time restricting stenohaline and oligohaline species by lowering the mean salinity values in the bay. At the mouth of these fluvio-deltaic systems diversities and populations are usually lowest because of rapidly changing environmental conditions.

4.3.5 Diversity and Dominance

Populations of brackish water assemblages in both modern and ancient environments commonly demonstrate low diversity, dominance, and gigantism (Bless, 1983). The Pleistocene Champlain Sea, in the St. Lawrence Lowlands, Canada, contains both foraminifera and ostracodes. Diversity trends for both these benthic organisms was highest during marine inundation of the St. Lawrence Valley. Lower diversities during the regressive stages, however, are attributed to an increase in fluvial activity and lower salinity (Cronin, 1979). In general, diversities decrease in freshwater species above 3 ppt while marine species diversity decreases below 10 ppt.

4.3.6 Life Cycles (Growth and Ontogeny)

Most modern podocopids produce one generation or more per year. A few species have either overwintering instars or eggs that require a period of desiccation prior to hatching (Horne, 1983). Seasonal migrations are common. As mentioned above, salinity controls distribution of the ostracodes, however, as the reproductive process is thermally sensitive, ostracodes can only reproduce within specific temperature ranges, especially in a seasonal climate. In some instances, there can be both syngamic (males and females) and parthenogenetic (females that lay only female eggs) populations of one species in differing geographic localities (Horne, 1983). Salinity and temperature are considered to be the most probable explanation for this type of temporal variability. It is possible that males or females could migrate and congregate periodically to reproduce.

Morphological variability of the fresh water genus *Limnocythere* occurs when there is a sharp seasonal contrast. In ecosystems where the seasonal contrast is minimal, there is usually only one morphotype present. The processes responsible for this variability are carbonate equilibrium at the water/sediment interface and the influx of both fine grained sediment and other allochthonous matter (Carbonel et al., 1990). *Cyprideis* also demonstrates morphological variability when exposed to changing water chemistries (Neale, 1988).

4.3.7 Adaptive Strategies

Changes in salinity invoke stress on any aquatic organisms which in turn greatly affects the ability of the organism to osmoregulate. For a species to survive in this type of environment, a reproductive strategy is required. There are two reproductive growth responses of a given population. Rapid rates of increase of a population typify an unstable environment where organisms show rapid development and high juvenile mortality rates, single reproductive periods, variable competition, and opportunistic behaviour; these aspects favour colonisation and dispersal of a species (*r-selective* strategists). Populations that are at their carrying capacity (*K-selective* strategists) are stable and usually demonstrate mortality rates dependent on competition and predation, long life cycles, multiple reproductive periods, and are restricted to their habitat making them unfavourable for dispersal of the species into new environments. Observable features for *r*-selective reproductive responses include a fluctuating population, a high frequency of morphotypes, common changes in shell morphology, and parthenogenetic reproduction (Ducasse et al., 1990). Ostracodes satisfy some of the basic requirements for an opportunistic *r-selective* population. First, they reproduce seasonally in great numbers, respond morphologically to changing environmental parameters, and can reproduce both syngamically and parthenogenetically. For example the modern species *Cyprideis torosa* is known to care for its young in brood pouches (Horne, 1983). Second, eggs of cypridaceans resist desiccation and can be transported by dust-laden winds explaining the occurrence of marine relict species in inland saline lakes in Australia (McKenzie, 1981).

4.3.8 Passive and Active Transport

Because ostracodes span the marine/fresh water transitional zone of marginal marine environments, transport of both eggs and live forms across physical barriers is possible. The probability of successful transport depends on contact with dispersal agents, survival during transport, and survival in the new environment. There are two modes by which this can be accomplished. Active transport occurs when the live, dead or, encysted eggs are wind blown, transported during storm surges from hurricanes, or transported by currents both fluvial and estuarine (Carbonel et al., 1988). Sohn and Kornicker (1979 *cited in* Carbonel et al. 1988) freeze-dried ostracode eggs at low temperatures and pressures and later reintroduced them to water. Thirty seven percent of the eggs hatched and because ostracode eggs are approximately the same size as wind blown particles, Sohn and Kornicker (1979 *cited in* Carbonel et al. 1988) speculated that some species of ostracodes could endure long range aeolian transport over thousands of kilometres.

Passive transport involves ostracode ecological interaction and transport by fish, birds, and amphibians. Kornicker and Sohn (1971) carried out several experiments by feeding both ostracodes and their eggs to fish and later recovered their faecal sleeves to observe survivorship. The faecal pellets were recovered up to 24 hr following egestion. No adults survived, however, several of the encysted eggs hatched later on. Kornicker and Sohn (1971) also discovered that the eggs and valves were not totally decalcified, although some had dissolution holes, leading to the speculation that the eggs could withstand short term transport in the digestive tracts of fish.

Laboratory experiments involving the extraction of the live ostracode genus *Cyprideis* from seawater and placement into petri dishes for extended periods, demonstrated that live specimens can resist desiccation for as much as 6 days (Sandberg and Plusquelle, 1974). The live specimens were removed from seawater and allowed to dry in the petri dishes. After 6 hours survivorship was 82% and decreased steadily to 17% after 6 days. Several juveniles in the broodpouches remained active after reintroduction into fresh seawater after 9 days. Sandberg and Plusquelle (1974) speculated that specimens picked up by birds, either egested or within their feathers, could be transported great distances in a short timespan, whereas eggs and carapaces egested by fish only have approximately 24 hours of transport before the fish defecates. Therefore, long distance passive dispersal of *Cyprideis* in low salinity marginal marine environments could be best explained by avian/ostracode interactions.

4.4 DEFINITION OF A BRACKISH WATER ENVIRONMENT

Because of the various usages of the term "brackish" in the literature, the author will discuss the classification of brackish water assemblages as will be used for the paleoecological interpretation for the ostracodes of this study.

A brackish water ecosystem implies open communication with marine waters at one extreme and a fresh water connection landward. Therefore, salinities vary from approximately 0 ppt through 35 ppt. The faunae constitute a fresh water oligohaline (low salinity ~0-5 ppt) component, a marine euryhaline component, a brackish component (neither fresh or marine), and a migratory component of species that spend only periodic ontogenetic stages in brackish waters. In general the characteristics of a brackish water community include: 1. an impoverished marine suite of benthic organisms; 2. an increase in the soft bodied organisms; 3. a reduction in size; and 4. a high number of individuals (Pemberton and Wightman, 1992). In general species adaptability is low, excluding most marine and fresh water organisms. Marine benthic species, however, better tolerate salinity changes and will not show decreases in diversity as rapidly as fresh water species. Brackish environments are usually sheltered from wave and storm activity, have a rich supply of food from riverine, marsh, mangrove, or coastal marine sources, and have shallow depths. Tolerant benthic organisms flourish under these conditions but are susceptible to local extinction due to the ephemeral characteristic of most estuaries and lagoons. The following classification scheme is modified after Knox (1986 *cited in* Pemberton and Wightman, 1992) and will be used to define the salinity tolerance for each species of this study (Fig. 4.1).

4.5 INTERPRETIVE METHODS

As discussed in the first chapter ostracodes have many features that make them ideal for paleoenvironmental reconstructions. Simple statistical procedures such as adult to juvenile ratios, valve to carapace ratios, and growth series plots can help to determine if the sample represents either an in situ biocoenosis (life assemblage) or thanatocoenosis (death assemblage). Whatley (1983, 1988) demonstrated the potential applications using simple statistical procedures (Table 4.1). As the adult and juvenile valves represent sedimentary particles, their ratios can be plotted as simple histograms to determine whether or not the population was transported or in place (Whatley, 1988). This type of procedure can be used to interpret water depths and distance from the shore (Brouwers, 1988). Although these procedures are difficult to apply even in recent environments, the basic principles can be applied to ancient deposits. For example, an ideal population of adult ostracodes will have 7 or 8 pairs of successively smaller instar valves (Adult, Adult-1, Adult-2, ... Adult-8, and ostranauplius). In reality the majority of the first few instars (A-8, A-7, A-6) will either be crushed, predated, or transported out of the ecosystem. Therefore, Brouwers (1988) suggests that a ratio of 5:1 and even as small as 3:1 can be used to determine if a fossil assemblage is living in situ or transported into place (Table 4.1).

Dimorphism also yields important ecological data. A normal breeding population would be expected to have an equal number of both heteromorphs and tecnomorphs (1:1). Differing sex ratios of recent ostracodes indicate an unstable environment in which the organism is required to adapt to rapidly changing

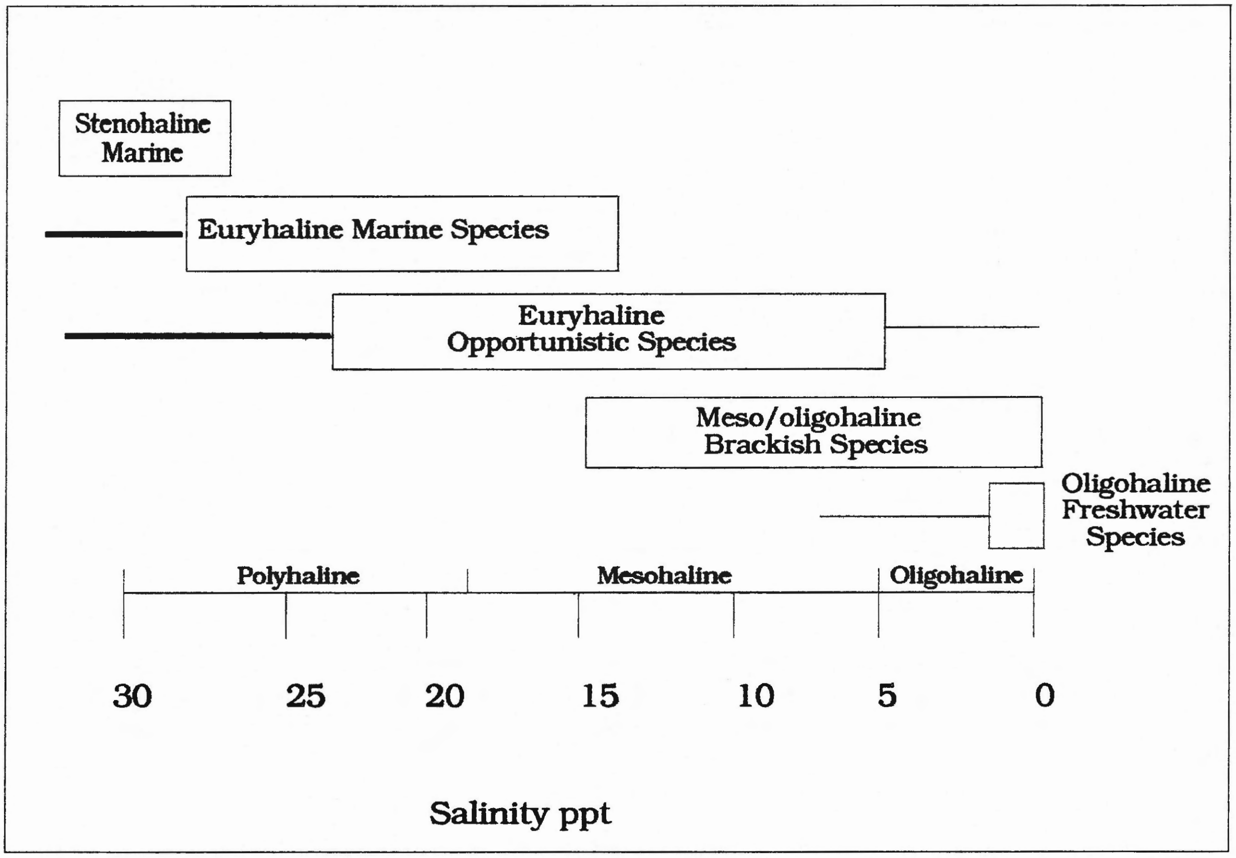


Figure 4.1 The classification of species from the brackish water environment (after Pemberton and Wightman, 1992). Boxes indicate optimal range.

Table 4.1 The use of juvenile to adult ratios, tecnomorph to heteromorph ratios, and valve to carapce ratios for the recognition of paleoenvironments (after Whatley, 1983, 1988; Brouwers, 1988).

Assemblage Type	**Characteristic Features**	**Interpretation**
Low Energy Biocoenosis	large number of individuals both adults and juveniles	stagnant conditions extremely rare (lagoons and lakes)
High Energy Biocoenosis	large number of larger instars (adults); both males and females	moderate current activity carries off juveniles (common in marine environments)
Low Energy Thanatocoenosis	large number of juveniles; early instars A-4 to A-7; lacking males and females	small size fractions transported offshore from littoral zone; shells settle to bottom
High Energy Thanatocoenosis	large number of only one instar fraction; disarticulated	preferential sorting and accumulation of abraded single valves
Pathological Assemblages	high percentage of articulated juveniles (complete carapaces)	radically changing physical and chemical parameters; juveniles die before maturity

conditions- organisms that brood their young or eggs have a better chance that their offspring will develop into reproducing adults (Abe, 1990). Simple male (tecnomorph) versus female (heteromorph) ratios of ostracode carapaces in an assemblage provide such information.

Most of these simple techniques were devised for the non specialist; however, an ostracodologist can usually qualitatively assess a population after careful evaluation of a complete sample. When dealing with 350 Ma fossil assemblages the potential of error greatly increases, such as time average sampling and contamination due to reworking. Therefore, simple ratios are used only to demonstrate some of the diagnostic features of an assemblage in support of a qualitative paleoecological assessment.

CHAPTER 5 PALEOECOLOGICAL ANALYSIS

5.1 OSTRACODE PALEOECOLOGY

This section provides a paleoecological interpretation for the fossil assemblages from the Blue Beach Member with emphasis on the dominant ostracode and foraminifera species, genera, and where applicable super-families. Following each paleoecological definition a comparison is made with cospecific assemblages in other Carboniferous localities.

5.1.1 Assemblage 1 Beyrichiacea

Interpretation

Copelandella novascotica belongs to the Beyrichiacea, a super-family of the first straight-hinged Paleozoic ostracodes. In the BBM *Copelandella novascotica* occurs in organic-rich shales associated with palaeoniscid fish, framboidal pyrite, and glaucony grains all in agreement with quiescent waters (below wave base) in either the profundal sediments of a shallow kenoxic lagoon or restricted marine embayment. The lobation, spines, and reticulation of *C. novascotica,* however, suggest moderate current activity. The high ratio of heteromorphs to tecnomorphs (130/43 ~3:1) in sample BB28 indicates parthenogenetic reproduction. The cruminal dimorphism indicates brood rearing. The finely punctate spheres, observed in thin section and the microfossil residues, resemble both size and shape of modern eggs of brood rearing ostracodes (Sohn and Kornicker, 1969; Kornicker and Sohn, 1971; Gramm, 1972). The reproductive strategies of *Copelandella novascotica* better enabled it to survive the high stress of transport into a restricted marine environment.

The allochthonous ostracodes associated with *C. novascotica* include *Shemonaella scotoburdigalensis*, representing high energy biocoenosis, and the poorly preserved steinkerns of the marine ostracode *Bairdia pruniseminata*, representing post mortem transport from a marine system. In contrast, the corroded valves of *Carbonita* and agglutinated marsh foraminifera indicate a nearby fluvial source. Given that *C. novascotica* occurs with both *Carbonita sp.* (oligohaline) and *Shemonaella sp.* (euryhaline opportunistic) the salinity tolerance for this species probably ranged from approximately 15 to slightly above 35 ppt (euryhaline marine).

Literature Review "Copelandella novascotica"

Carboniferous localities where *Copelandella sp.* (Table 5.1) occur are generally shallow carbonate producing environments. The marine units of the Codroy Group from Newfoundland contain *Copelandella sp.* associated with kloedenellacean and paraparchitacean ostracodes (Dewey, 1983; Dewey and Fahraeus, 1987). Dewey (1983) interpreted the community as opportunistic that lived in a quiet siliciclastic nearshore lagoon. Bless (1983) and Bless and Jordan (1971) provided a similar shallow-marine littoral to nearshore environmental interpretation for *C. novascotica* in the HBF. In northeastern Siberia, a shallow nearshore marine assemblage including both *Copelandella sp.* and *Hollinella sp.* occupy the same niche in Tournaisian marine strata defined as the Thuringian assemblage in western Europe; these assemblages are characterised by thick smooth shelled podocopid (paraparchitaceans and bairdiaceans) and lobate and spinose ostracode faunas (reticulate palaeocopids) that occupied shallow nearshore environments (Becker and Bless, 1990). In general the lobate, reticulate carapace with anterior spines and velate frills all typify nearshore nectobenthic marine morphotypes where current activity is moderate (Bless, 1983; Neale, 1988; Becker and Bless, 1990).

Table 5.1 The main Blue Beach ostracode genera identified in other Carboniferous strata (Sohn, 1971a, b; Bless and Jordan, 1971; Bless and Pollard, 1973; Dewey, 1983, 1987; Copeland, 1957; Jones and Kirkby, 1867,1884, 1898).

Blue Beach Ostracodes	**Carboniferous Localities**	**Associated Fossils**	**Paleoenvironment**
Shemonaella	Cultra Ireland; Burdiehouse Scotland; Mabou Group Nova Scotia; Windsor Group Nova Scotia; Codroy Group Newfoundland; Alapah Marine Limestone Alaska; Black Warrior Basin Central United States	lingula; conularids; brachiopod;;bryozoans; goniatites; fish	inner shelf; intra/supra tidal; euryhaline; filter feeders can tolerate low oxygen; opportunistic species
Copelandella	Cultra Ireland; Moscow Basin; Codroy Group Newfoundland (Nodosinella Band Robinson River Formation)	marine limestones and shales with bivalves and gastropods	shallow offshore-nearshore zone; brackish to normal marine
Carbonita sp.	Mabou Group Nova Scotia; Sydney Basin Nova Scotia; Cumberland Group Nova Scotia; Western European Coal Basins	plants; bivalves; fish; serpulids (*Spirorbis sp.*)	shallow muddy pools; coal swamps and coastal marsh; low salinity

5.1.2 Assemblage 2 Paraparchitacea

Interpretation

Of the 4 species of paraparchitaceans, *Shemonaella scotoburdigalensis*, *Shemonaella tatei*, *Chamishaella sp.*, and *Paraparchites sp.*, identified from Blue Beach and the Saarberg Core, all exhibit relatively large, thick carapaces and display sexual dimorphism. In addition to the thick carapace, the paraparchitaceans of this study have a wide inner lamella that may have enabled them to tightly close their shells during periods of increase toxicity. In fact, recent studies on the functional morphology of the ostracode shell demonstrate that there are differences in the inner lamella between modern freshwater and marine podocopids which may explain the adaptability of many opportunistic species (Keyser, 1990). It may be this ability for marine podocopid ostracodes to tightly close their shells, during brief hostile physical and chemical episodes, that give them the advantage over other ostracodes. This strategy would result in high survivorship during passive and active transport.

Subassemblage 2a

Shemonaella scotoburdigalensis has the largest carapace size of the paraparchitaceans from the BBM and is the most abundant species in this subassemblage. The valve to carapace ratio for *S. scotoburdigalensis* is extremely high, however, most samples have a successive series of instars indicating high energy biocoenosis. The co-occurrence of *Carbonita spp.* with these euryhaline paraparchitaceans indicates periodic lower salinities. The disarticulated adult valves of *Carbonita scalpellus* and the associated hummocky cross-strata indicate high energy (storm related) and a strong fluvial component. Salinity probably ranged from mesohaline through to oligohaline in the brackish nearshore.

Chamishaella suboriculata is the second most common paraparchitacean in this assemblage. Although the carapaces are flattened, the specimens are frequently articulate and demonstrate a complete growth series. It is important to note, however, that the adults are often absent. The lack of adult specimens combined with the high ratio of carapace to valve ratios suggest low energy thanatocoenosis, possibly representing post-mortem transport from low energy littoral areas where salinities were either slightly elevated or reduced, such as in assemblage A2c of this study.

Subassemblage 2b

The large accumulation of articulate juveniles of *Cavellina lovatica?* in subassemblage 2b provides evidence for rapidly changing water chemistry and pathological thanatocoenosis. The associated *Bairdia pruniseminata* and *Copelandella novascotica,* however, suggest either periodic near-normal salinity values or transport from a nearby offshore normal marine source (Kornicker, 1961; Bless, 1983). It is likely that a strong riverine input during more humid periods exceeded evaporation of the restricted saline waters in the littoral zone, ultimately controlling the distribution of the ostracode population. It may be the great size and carapace thickness of the paraparchitaceans, *Shemonaella scotoburdigalensis* and *Chamishaella sp.*, that allowed them to tolerate turbulent rapidly changing environmental conditions of the shallow nearshore.

Subassemblage 2c

Shemonaella tatei occurs in great numbers exclusively with *Chamishaella sp.* in this subassemblage. *Shemonaella tatei* is somewhat of curiosity as it appears to occupy the niche usually satisfied by *Shemonaella scotoburdigalensis*. Because *S. tatei* and *S. scotoburdigalensis* are mutually exclusive of each other, they are interpreted as isolated breeding populations. The morphological difference between *S. tatei* and *S. scotoburdigalensis* is the generally smaller, thinner, carapace of the former. As discussed in the preceding chapter, any variation from the optimal salinity range of a species usually results in size diminution (Neale, 1988). Therefore, the biotypically smaller *Shemonaella tatei* and *Chamishaella sp.* may represent opportunistic populations where only 2 euryhaline species occur (note the allochthonous component is missing). Given the associated muddy sediments and excellent preservation of the carapaces, fluvial recharge and strong current activity was probably minimal. This would allow evaporation during arid periods, perhaps seasonal, to exceed marine and fresh water influxes. Salinity probably exceeded normal ranges but not in excess of 40-50 ppt (hypersaline) as indicated by the absence of evaporite minerals. These periodic salinity increases would explain both the absence of marine and limnic species and the biotypic change from the larger more robust *Shemonaella scotoburdigalensis* to the smaller, thinner, elongate carapace of *Shemonaella tatei.*

Literature Review "Paraparchitacea"

Paraparchitaceans are a marine family of ostracodes that can tolerate both brackish and hypersaline environmental conditions (Sohn, 1971a, b). The genera identified in this study are well-documented in the literature from other Palaeozoic localities from both Europe and North America.

Western Europe

British occurrences have been documented from calcareous shales in Northumberland England (Robinson, 1978), the Lower Limestone Shale series in Fife, Scotland with normal marine fauna (Latham, 1933), the Visean Abden limestone near Fife, Scotland with *Bairdia sp.* (Ferguson, 1977), and near Cultra, Ireland where *Shemonaella scotoburdigalensis* (Jones and Kirkby *Leperditia okeni*, 1898) occurs with both *Copelandella novascotica* (Jones and Kirkby *Beyrichia collicus*, 1898) and *Bairdia.*

Upper Famennian strata in Belgium contain paraparchitaceans (*Chamishaella sp.*), beyrichiaceans (related to *Copelandella sp.*), bairdiaceans, kloedenellaceans (resembling *Geisina*), and abundant fish remains from coarsening upwards cycles of sediment interpreted as a lagoonal/sublagoonal tidal deposit (Bless et al. 1988). In southwest Belgium, a Tournaisian carbonate-mud contains ostracodes dominated by paraparchitaceans, kloedenellaceans, with sparse beyrichiaceans associated with conodonts, crinoids, and brachiopods interpreted as a mixohaline deposit (Bless et al. 1988). Also, paraparchitaceans are documented from brackish water deposits of northwestern Europe in both the Upper and Lower Westphalian Campine Basin and the Westphalian A from the Finefrau Nebenbank Marine Band in the Netherlands (Bless, 1973b, Bless et al., 1988; Paproth et al. manuscript in preparation). The Lower Westphalian strata of the Campine basin contain paraparchitaceans associated with the trace fossil *Planolites*, the attached worm *Spirorbis*, agglutinated foraminifera, and the inarticulate brachiopod *Lingula* interpreted as a euryhaline assemblage that formed at the acme of a marine transgression (Paproth et al., manuscript in preparation). Furthermore, paraparchitaceans occur with other marine ostracodes, gastropods and the agglutinating foraminifera *Ammodiscus* in Westphalian C strata of the Aegir Marine Band, the Netherlands (Bless et al., 1969). In addition to these documented paraparchitacean occurrences, they are frequent in the Dinantian Rhadames Basin (Libya) associated with relatively small highly ornamented ostracodes. These ostracodes include the kloedenellaceans, *Geisina* and *Cavellina*, contained in shales and sandstone intercalated with gypsum and anhydrite interpreted as a tidal to supratidal (Bless and Massa, 1982 *cited in* Bless, 1983).

United States

Occurrences of the Paraparchitacea in North America include the Late Mississippian Amsden Formation of Wyoming (Morey, 1935), the Late Mississippian Alapah Limestone of Alaska occurring with kloedenellaceans and bairdiaceans (both found in this study) (Sohn, 1971a and 1971b), and the brackish to hyperhaline strata of the Black Water Basin in the U.S. interior (Dewey et al., 1990). Permian strata of the

Americanus Limestone in northeastern Kansas contain paraparchitaceans associated with *Bairdia sp.*, *Carbonita sp.*, and *Hollinella sp.* that form the following distinct assemblages (Peterson and Kaesler, 1980): 1. a brackish nearshore and carbonate shoal dominated by bairdiaceans, hollinellaceans, and *Carbonita sp.*; 2. lagoons and tidal mudflats dominated by paraparchitaceans and bairdiaceans; and 3. a brackish nearshore dominated by *Carbonita sp.* interpreted as nonmarine to brackish. Kaesler et al. (1990) later revaluated the ostracodes from the Americanus Limestone noting *Sansabella sp.* (allied to *Geisina sp.*) was locally abundant during more stable marine conditions while paraparchitaceans associated with stromatolitic beds preferred a restricted marine environment.

Nova Scotia

Windsor Group strata comprise three carbonate marine assemblages (Dewey, 1983, 1987, 1989; Dewey and Fahraeus, 1987) which occur in the St. Croix, Phillips, and Dimock limestones locally associated with siltstone and shale units all intercalated with thick successions of gypsum and evaporite minerals. The most diverse ostracode assemblages contain highly-ornamented bairdiaceans, kirkbyaceans, and sparse pararparchitaceans (less than 10%) interpreted as "abnormally saline" indicated by the scarcity of crinoids, corals, and calcareous foraminifera (Dewey, 1988). The second low diversity assemblage, obtained from a bioclastic limestone, comprises paraparchitaceans (*Chamishaella suboriculata*, *Shemonaella scotoburdigalensis*, and *Shivaella sp.*), bairdiaceans, and rare kirkbyaceans. Paraparchitaceans dominate comprising 75 % the total fauna. Dewey (1987) pointed out that the high proportion of heteromorphs to tecnomorphs, monospecific dominance, and the low species to genus ratio all indicate a rapidly developing opportunistic population. A population of this nature indicates physiologically stressful conditions where stenohaline forms are restricted and euryhaline species such as the paraparchitaceans can thrive with little interspecific competition (Dewey, 1987). Dewey (1983, 1987, 1988, 1989) considered that the paraparchitaceans suggest a hyperhaline paleo-environment, an interpretation supported by associated gypsum and anhydrite.

Newfoundland

Dewey (1983, 1989, 1993) and Dewey and Fahraeus (1987) described in detail the paraparchitacean ostracodes from the Port au Port Peninsula, Newfoundland. The limestones contain bryozoans, bivalves, gastropods, brachiopods, microbial mounds, conularids, peracarids, the vestimentiferan tube worm *Riftia*, and the serpulid worm *Spirorbis* (Dix and James, 1987; Von Bitter et al., 1990).

There are 3 low diversity, high abundance ostracode assemblages that all contain abundant paraparchitaceans (Dewey, 1983; Dewey, 1989; Dewey, 1993). The first assemblage is dominated by paraparchitaceans (80%) represented by *Chamishaella suboriculata*, *Chamishaella inverticonformis*, *Shemonaella scotoburdigalensis*, *Shishaella moreyi*, and *Shivaella sp.*. Other ostracodes include sparse bairdiaceans, kirkbyaceans, and youngiellaceans. Given the euryhaline tolerances of the paraparchitaceans, the tube worm *Riftia*, and the lack of hypersaline sedimentary evidence, Dewey (1993) proposed that this assemblage was a shallow opportunistic community.

The second assemblage comprises low numbers and low diversity where again paraparchitaceans dominate, more specifically *Chamishaella suboriculata*. There is a scarcity of normal marine ostracodes; however, *Copelandella sp.* and *Geisina sp.* indicate brackish/marine conditions. This assemblage and the enclosing sediments (Woody Cape Formation) were interpreted as deltaic restricted to marginal marine/lagoonal (Dewey, 1989).

The third assemblage, contained in a calcareous sandstone and sandy-shaly limestone (Boswarlos Facies), comprises *Chamishaella suboriculata*, *Shivaella moreyi*, and sparse *Shemonaella scotoburdigalensis* and *Acratia sp.* interpreted as a nearshore brackish water assemblage (Dewey and Fahraeus, 1987, Dewey, 1989, Dewey, 1993). This pelletoidal and plant bearing sandstone (Ships Cove Formation) overlies the sandstones and conglomerates of the Horton Group (Schenk et al., 1994). The sediments associated with the paraparchitacean ostracodes suggest an environment where intermittent high riverine input kept salinity values low, restricting the stenohaline species (Dewey, 1983, Dewey, 1993, Dewey, 1989).

The author would like to indicate that the ostracodes found in the more restricted marine phases of the Windsor and Codroy Groups resemble Assemblage 2 (A2) identified in the Blue Beach Member. Every genus of ostracode identified in the Horton Bluff Formation, with the exception of the low salinity genus *Carbonita*, occur in the overlying Visean rocks of the Maritimes Basin.

Paleoecological Synthesis of the Paraparchitacea

Parparchitaceans that occur in great numbers are not restricted by nutrient supply, as they frequently occur with stromatolites (algal bodies), but are probably more limited by competition with other species thus demonstrating opportunistic behaviour (Dewey 1988, Kaesler et al., 1990). Paraparchitaceans that have spines indicate nearshore to offshore normal marine species while the larger smooth shelled species appear to have hyperhaline affinities (Dewey, 1988; Bless, 1983). In most of the ostracode assemblages above (Dewey, 1988; Peterson and Kaesler, 1980; Bless, 1983; Becker and Bless, 1990; Kaesler et al., 1990), the factors controlling distribution appears to be physical and not biological. In many cases, the distribution appears directly related to the size, ornamentation, and shape of the carapace. In summary, Paraparchitaçeans were opportunists that existed as minor constituents in a stable marine community. When conditions became unsuitable for the stenohaline ostracode fauna, the Paraparchitacea bloomed, yielding very large populations often with carapace sizes of gigantic proportions. Given the hypersaline to brackish tolerance of the paraparchitaceans, the geographic control for the distribution of ostracodes was both physical and chemical, directly related to riverine influx and periodic aridity which led to rapid salinity fluctuations.

5.1.3 Assemblage 3 Carbonitacea

Interpretation

Assemblage 3 is dominated by the carbonitaceans, *Carbonita scalpellus* and *Carbonita rankiniana*. In most cases throughout the BBM, the specimens of *Carbonita scalpellus* are generally small, poorly preserved single valves indicative of post mortem transport (high energy thanatocoenosis). In contrast, this assemblage is characterised by articulate adults and molts of both *C. scalpellus* and *C. rankiniana* indicating low energy biocoenosis. Given that *Carbonita spp.* occur with agglutinated foraminifera, brackish/marine bivalves, and brackish/marine ostracodes, this genus is interpreted as a brackish water species that lived adjacent to a marginal marine environment. Periodic increases in hydrologic energy, due to storms surges or relative rises in basin water level, likely transported the marine component into the low salinity system. The high proportion of palaeoniscid fish scales, bones, and teeth are in agreement with post-mortem reworking. The association of calcareous mudstones with in situ root traces suggests the preferred environment of this ostracode was shallow muddy pools rich in organic detritus. Indeed, modern representatives of *Candona* and *Darwinula*, which resemble *Carbonita* in size and lateral outline, are incapable of swimming and therefore burrow in the mud immediately below the water-sediment interface.

Literature Review "Carbonita"

Perhaps no other Carboniferous ostracode has given researchers so many taxonomic challenges as the genus *Carbonita*. This is in part due to poor preservation of the small thin shells and often indistinguishable finer details of the carapace. In addition to the preservation problems there appears to be great morphological variability within a genus or even species (Bless and Pollard, 1973). Consequently the number of taxa are excessive. The family Carbonitidae was established by Sohn (1985) for the genus *Carbonita* (Strand), *Gutschickia* (Scott), and *Pruvostina* (Scott and Summerson). In general, the carapaces are small, thin, smooth, and lack ornamentation. They often demonstrate dimorphic variability. It is generally considered to be a fresh water genus, based both on its occurrence in ancient deposits and its homologies with modern forms. Nonetheless, they have been documented in brackish water and even marine deposits.

Western Europe

Carbonitacean ostracodes are common in the Upper Carboniferous coal measures in Europe. In the Durham and Northumberland coal measures in Britain, the ostracode genera *Carbonita* and *Geisina* are common (Rippon, 1984; Pollard, 1966; Calver, 1968). Pollard (1966) reported hollinacean and paraparchitacean assemblages associated with the marine bands while *Geisina/Carbonita* associations represented brackish lagoonal phases. Rippon (1984) documented brackish water assemblages from the Clowne Seam of the East Pennine coal measures. There, several species of *Carbonita* occupy thin single bedding planes, associated with fish debris and bivalves, that directly overlie thin coal seams.

The *Carbonita* and *Geisina* association is well-known. Calver (1968) reported *Geisina* in marine bands, from the lower coal measures in England, that commonly occur on the same bedding planes as *Lingula* and other normal marine ostracodes. In contrast, in strata where *Carbonita* predominate without *Geisina*, Calver (1968) inferred a nonmarine environment. It is important to note that *Carbonita* appears throughout the lower coal measures in England associated with both *Geisina* and other marine species, demonstrating its tolerance for elevated salinities beyond the oligohaline fresh water realm.

Bless and Pollard (1973) described two assemblages from Westphalian nonmarine ostracode bands. The Westphalian A Limbourg Meister Band and the Westphalian C *faveolata* bands contain a relatively diverse community of the ostracode genus *Carbonita*. Bless and Pollard (1973) suggested that the ostracodes lived in localised nonmarine pools post marine inundation of the flooded coal swamps. They identified two pools. First the Emma Pool comprises 5 species of *Carbonita* including *C. scalpellus*, the cochostracan *Estheria*, palaeoniscid fish including *Rhadynichthys*, bivalves (*Naiadites*), *Spirorbis*, and tracks of a crawling arthropod, interpreted as an exclusively fresh water assemblage. Second, the Wilhelmina Pool contains two species of *Carbonita* including *C. scalpellus*, *Geisina*, conchostracans, bivalves, and palaeoniscid fish interpreted as a brackish pool.

United States

Late Mississippian (Namurian A) nonmarine ostracodes were identified from the Bluestone Formation in west Virginia (Sohn, 1985). The stratigraphic sequence is interpreted as a transitional environment from brackish through to marine regressive. It is overlain by the nonmarine Bluestone Formation in which the genera *Carbonita*, *Whipplella*, and *Darwinula* are situated. Sohn (1985) postulated that the substrate preference for the genus *Carbonita* was clay-rich, silty sediments rich in organic matter.

The Permian Americanus Limestone of Kansas contains a fresh/brackish water assemblage comprised of *Carbonita* in addition to shallow marine through to restricted a lagoonal ostracode assemblage dominated by paraparchitaceans (Peterson and Kaesler, 1980). Peterson and Kaesler (1980) discussed the co-occurrence of the fresh water *Carbonita* with assemblages containing the genera *Bairdia*, *Paraparchites*, and

Amphissites. They speculated that the carbonitaceans, specifically *Carbonita inflata*, was perhaps more salinity tolerant (eurytopic) than previous authors have assumed (see Taxonomy). Given the proximity of freshwater systems to near-shore high energy marine environments, post mortem transport of freshwater/brackish tolerant genera into the marine system is likely. In these systems a low diversity fauna would be expected. Indeed, cluster analysis of the Americanus limestones indicate that species diversity was highest (all above 1.0) when there was open communication with the lagoonal, tidal, and carbonate shoal environments. Conversely, the restricted lagoonal through to nonmarine environments of the Hamlin Shale displayed values less than 0.5 for mean species diversity.

New Brunswick

Greiner (1974) identified ostracodes from the coeval Albert Formation in the Moncton Subbasin. His taxonomic designations are outdated and include the following possible taxonomic synonymies: *Carbonita sp. cf subula* (*C. scalpellus*); *Hilboldtina sp.* (*Bairdiacypris striatiformis*); and *Leperditia sp.* (*Shemonaella sp.*). *Carbonita spp.* predominates in the basal Hiram Brook Member, however, *Carbonita scalpellus* and *Carbonita evelinae* are more frequent in the uppermost units (Greiner, 1974). The petroliferous oil shales, dolostones, and evaporite units of the Albert Formation were interpreted as a shallow nonmarine lake (Greiner, 1974; Belt 1969; Pickerill et al., 1985). Given the reports of the paraparchitacean ostracodes in the Albert Fm, a further evaluation of the ostracode taxa may indicate a marine influence for the depositional system.

Nova Scotia

Late Carboniferous ostracodes from Nova Scotia include *Carbonita scalpellus* and *Carbonita rankiniana.* The ostracodes are associated with both conchostracans and lamellibranchs. *Carbonita* occurs with *Paraparchites scotoburdigalensis* and *Paraparchites okeni*, potentially synonymous with *Shemonaella scotoburdigalensis*, in the Mabou group interpreted as a marine/brackish water system (Copeland, 1957). In contrast, the Westphalian deposits of the Cumberland and Pictou Groups show a predominance of *Carbonita*, interpreted as nonmarine. Copeland (1957) notes that *Carbonita inflata* and *Carbonita scalpellus* are the most common in the Pictou, Sydney, and Mabou Mines coal fields. Zodrow and Vasey (1986) also reported *C. scalpellus* from the Mabou coal field in western Cape Breton.

Paleoecological Synthesis of "Carbonita"

Although *Carbonita* is considered a low salinity genus, in most reported cases the specimens are associated with either brackish/marine kloedenellaceans (*Geisina* and *Cavellina*) or the wide ranging (euryhaline) opportunistic paraparchitaceans. The frequent association of *Carbonita spp.* with *Geisina*, *Shemonaella*, and serpulid worms suggest a tolerance for elevated salinities waters. It is likely that this genus of Carboniferous ostracode represents an low salinity biotype that occupied the upper marine/freshwater transition zone.

5.1.4 Assemblage 4 Paraparchitaceans, Kloedenellaceans, Bairdiaceans, and Youngielliaceans

This assemblage is restricted to the Saarberg core in a thick shale succession. Given the coarse nature of the shales and glaucony layers it is probable that the allochthonous brackish/marine ostracodes settled from suspension on the deep profundal zone of the distal shelf at the mouth of an estuary or delta front. For the substrate to become glauconitized, there must have been substantial periods of time when water depths exceeded 65 m and temperatures and normal marine salinities were stable. It is during this prolonged period of time that the ostracode carapaces would accumulate as a low energy thanatocoenosis probably transported from more proximal shallow brackish areas.

Paraparchitaceans

This assemblage is dominated by *Chamishaella sp.* and *Shemonaella tatei* both considered to be euryhaline (see above). In this assemblage the carapaces are generally small and lack adult representatives, indicating low energy transport.

Bairdiaceans

Interpretation

The specimens from this study are poorly preserved and only a few have articulate carapaces, the most being steinkerns. They are generally small with no distinguishable dimorphism. A growth series is present with adults being the most prominent. The abundance of steinkerns in the more littoral assemblages suggest post mortem transport. The well-preserved specimens in this assemblage indicate proximity to a marine source. Because this genus is extant and there have been numerous studies on their ecology (see below), the preferred habitat is considered to be a shallow, warm, and sandy marine system.

Literature Review Bairdiacea

Bairdia is the longest ranging ostracode genus spanning Ordovician through to Recent strata. There are numerous references of this family in the literature, probably over 600 species names assigned to this genus alone, all of which are from shallow marine environments. Kornicker (1961) provided one of the first comprehensive studies on the ecology of recent bairdiaceans from shallow warm tropical waters of the great Bahaman Bank. He found that Bairdiaceans are stenohaline with optimal salinity ranges of 30-40 ppt. Most occurred in water less than 24 m in depth and temperatures ranging form 24° to 31°. A large number of species in an assemblage usually represent shallow warm seas, however, if only a few species are found in low numbers the temperatures may be as low as 1 or 2 degrees. Kornicker (1961) also observed that recent species tend to favour fine sandy to muddy substrates whereas Paleozoic forms are frequently found in shales and limestones. Haack and Kaesler (1980) demonstrated that in Westphalian marine ostracodes (including *Bairdia*) diversity decreased as the percentage of terrigenous mud increased in a mixed carbonate terrigenous environment.

Bairdiaceans are common in the Windsor and Codroy Groups from Nova Scotia and Newfoundland (see above Paraparchitacea). Also, Tournaisian strata from both the North of France, Belgium, and the Southern Canadian Rocky Mountains contain ostracode assemblages that resemble greatly those from this study.

Crasquin (1984) established ecozones based on the distribution of paraparchitaceans, bairdiaceans (including *Bairdiacypris sp. 2 sensu* synonymous with *Carbonita rankiniana* this study), and kloedenellaceans. Associated fauna include brachiopods, goniatites, foraminifera and conodonts. Crasquin (1984) established a tripartite ecozone from data from the Tournaisian western Ardennes and Visean Boulonnais in France, the Mississippian Rocky Mountains, and the Dinantian Russian Platform as follows: Bairdiacean dominated (57-70% total assemblage) reflecting a warm shallow carbonate platform ecosystem ; a 15-24% Paraparchitacean component comprising *Shemonaella, Paraparchites, Shivaella, Shishaella, and Samarella,* mainly spinose forms characterising a more restricted marine ecosystem; and the 2-17% kloedenellacean component that characterises an unstable confined environment.

An interesting study from Tournaisian strata from the Kuznetsk Basin demonstrates bairdiacean assemblages that thrived at the acme of a marine transgression which were succeeded by paraparchitacean dominated faunae at the onset of a latest Tournaisian/earlist Visean regression (Kurilina, 1977).

Kloedenellaceans

Interpretation

Geisina sp. and *Cavellina lovatica?* (see above Assemblage 2b) are the only kloedenellacean ostracodes identified in the BBM. *Geisina* from the BBM is locally abundant in the Saarberg core associated with glauconitic shales indicating a nearby marine source. In general the carapaces are small, reticulate, and display a distinct posterial swelling (dimorphism) indicative of parthenogenetic reproduction. The higher proportion of heteromorphs and tecnomorphs indicates opportunistic behaviour. A growth succession of the last three or four instars with a few adult carapaces represent low energy thanatocoenosis. The low salinity preference for *Geisina* was not suited for the unstability of the littoral area. This species represents an allochthonous component for this assemblage.

Literature Review "Geisina"

Bless et al. (1988) suggested that the genus *Geisina* was the diagnostic ostracode species for Carboniferous brackish environments. In Westphalian strata of western Europe, this genus is commonly associated with arenaceous agglutinated foraminifera (*Ammodiscus* and *Hyperammina*), the low salinity genus of *Carbonita*, and lamellibranchs indicate its brackish water affinities.

Youngiella sp.

Most of the specimens from the BBM are well preserved articulate carapaces showing reticulation and hingement. No dimorphism was observed and most specimens were adults. Given the association of *Youngiella* with other stenohaline marine species in Carboniferous strata in Newfoundland, it is interpreted as an euryhaline marine indicator in low to moderate hydrologic regimes. The genus *Youngiella* is not common, however, it was documented from relatively stable marine environments from the Codroy Group of Newfoundland (Dewey, 1983 and Dewey and Fahraeus, 1987) and the U.S. western interior (Dewey, 1991).

5.2 FORAMINIFERA PALEOECOLOGY

Agglutinated foraminifera are common in the BBM and represent a significant paleoecological component. First, they have modern living representatives and second, they are present in the Blue Beach strata where ostracodes are absent allowing a more comprehensive paleoenvironmental interpretation for the BBM. They mainly comprise three genera including *Trochammina*, *Ammobaculites*, and *Ammotium*. with minor occurrences of *Ammodiscus sp.* (Plate I, Fig. 11) and Thecamoebians (Plate I, Fig. 12 and Plate X, Fig. 10).

5.2.1 Assemblage 5 Foraminifera

Interpretation

Foraminifera almost exclusively dominate Assemblage 5 with the exception of a few carbonitacean ostracodes. The associated sedimentological indicators and euhedral pyritization suggests proximity to vegetated substrates. *Trochammina* dominated assemblages represent a high marsh phase while *Ammotium* and *Ammobaculites* represent the low marsh. The absence of nearshore marine and fresh water biotypes indicate the stressed nature of this ecosystem. Given the numerous modern and ancient analogues, the protozoans documented at Blue Beach resemble upper estuarine to infringing paralic marsh environments.

Literature review Foraminifera

Since the first reports of agglutinated foraminifera in the Maritimes Basin (Thibaudeau and Medioli, 1986), there have been several studies relating the distribution of agglutinated foraminifera and thecamoebians to coal bearing strata (Thibaudeau, 1993; Wightman et al., 1993; Wightman, 1993; Gibling and Wightman, 1994). In all cases, the morphotypes were compared to their modern counterparts for paleoecological definitions. Three main environmental assemblages are recognised in the Maritimes Basin: 1. the mixed assemblage of *Trochammina* (75%), *Ammobaculites*, and *Ammotium* situated in medium to fine grained siltstone; 2. the *Trochammina* dominated assemblage (90-100%); and 3. the thecamoebian dominated assemblage where both difflugid and spherical forms occur with sparse *Trochammina*. Compared with modern ecosystems, the assemblages from the Maritimes Basin are interpreted as lower salt marsh, upper salt marsh, and freshwater marsh, respectively (Wightman et al., 1994). Given the numerous publications documenting these modern genera (Scott and Medioli, 1986; Scott and Medioli, 1980; Scott et al., 1991; Medioli et al., 1990; Medioli and Scott, 1983) the paleoecological tolerances can be inferred with a high degree of confidence.

Agglutinated foraminifera have been reported from the Tonganoxie paleovalley fill from the Lower Pennsylvanian in Kansas, United States (Feldman et al., 1995). The succession progresses from coarse grained fluvial sediments, deposited following a regression and incision of the valley, to a thin marine shale (Vinland Shale) that caps the uppermost strata. Underlying the shale units are sparsely distributed marsh and estuarine *Trochammina*, *Ammotium*, and Difflugid thecamoebian assemblages representing the first stage of marine inundation of the fluvial system. Protozoan fossil assemblages within the Vinland Shale comprise normal marine genera: *Hyperammina*, *Ammodiscus*, and *Thurammina*. The shale unit is capped by a marine limestone which contains a rich assemblage of bivalves, brachiopods, echinoderms, bryozoans, and, ammonoids representing a transgressive high stand.

European agglutinated foraminifera have been documented from Westphalian A coal measures in Western Europe (Bless, 1973) (See above for discussion of paraparchitaceans from Western Europe). The genera included shallow marine *Hyperammina* and *Ammodiscus*. Vangerow (1964) documented a similar assemblage from Westphalian strata in South Limburg where these shelf foraminifera occur with high frequency.

5.3 OTHER FOSSIL GROUPS

This section will briefly describe and discuss the paleoecology of the other fossil groups observed in the BBM.

5.3.1 Macro-Invertebrates

The invertebrate fossils of the HBF include abundant trace fossils, serpulid worms, and several arthropod species (conchostracans) (Bell, 1960). During examination of the shale and siltstone residues of this study, several hundred specimens of serpulid worm, three trace fossil ichnogenera, and both macrophytes and megaspores were observed. Although not the focus of this study, a brief description and discussion for these fossils follows.

Serpulid Worms or Vermiform Gastropods?

Controversy arises as to the classification of the so called serpulid or spirorbid worms. Burchette and Riding (1977) and Weedon (1990) argue that the internal structure displays mollusc-like chambers, wall structures, and a protoconch. In light of this they interpreted the serpulid worms as vermiform gastropods that may either be coiled or erect tubes. The author does not wish to attempt in any way to solve this taxonomic dilemma, however, they are relatively abundant in the BBM. Therefore, the author will attempt to bracket their paleoecological preferences at the end of this brief discussion.

Spirorbids are common in the coal measures of Carboniferous strata around the world. Calver (1968) identified *Spirorbis* associated with lamellibranchs, the ostracodes

Carbonita and *Geisina*, and conchostracans such as *Leaia*. Bell (1960) identified *Spirorbis avonensis* from the HBF. Both Bell (1960) and Calver (1968) note the occurrence of these serpulid worms mounted on the backs of either lamellibranchs or ostracodes. Burchette and Riding (1977) and Weedon (1989) documented them from both peritidal bioherms and nonmarine deposits indicating their eurytopic nature. The prostrate (coiled) forms (i.e. *Spirorbis avonensis*) attach themselves to current-swept substrates such as reefs and subtidal deposits while the erect forms typify quieter conditions where the tubes extend upwards into the water columns of intertidal environments (Burchette and Riding, 1977). The preferred environment for these worms is unknown, however, their association with both fresh water and marine fauna suggest they are euryhaline. In fact, most documented occurrences are from marginal marine restricted environments (see numerous references to them associated with the carbonitaceans). Since the modern worms and gastropods that occupy high energy environments feed on hard algal substrates, they usually indicate well-oxygenated conditions.

There are two serpulid morphotypes identified from this study. The coiled *Spirorbis avonensis* (Bell, 1960) and the uncoiled serpulid morphotype (Plate 11, Figs. 4, 5, 6, 7). *Spirorbis avonensis* are most commonly associated with *Carbonita* and the paraparchitaceans. It is interesting to note that *Spirorbis avonensis* was observed attached to the carapace of the euryhaline paraparchitacean ostracode *Shemonaella scotoburdigalensis*. The uncoiled serpulids are locally abundant in a sandy layer from the Saarberg core in which there are several in situ erect tubes. Given that modern representatives of the Serpulida are generally considered to be eurytopic (Hantzschel, 1962), their frequent association with both paraparchitacean ostracodes and desiccation cracks testifies to their ability to tolerate elevated salinities and even subaerial exposure.

Conchostracans

It is curious that Calver (1968) discusses the presence of the branchiopods or conchostracans (related to crustaceans but somewhat of an enigma) such as *Estheria* and *Euestheria*. These genera are generally considered to be a fresh water endemic fauna by comparison with modern representatives. Calver (1968) recognised large populations either directly above or below the marine bands and interpreted these Carboniferous conchostracans as brackish tolerant. Calver (1968) also reports abundant lamellibranchs associated with the nonmarine fresh water ostracode assemblages. Of the numerous species identified, all occur with fresh water indicators.

Of the 9249 microfossils identified from the BBM there were no conchostracans, however, Bell (1960) identified several specimens including *Euestheria belli, Euestheria lirella, Euestheria dawsoni, Leaia sp.*, *Eoleaia laevicostata*, and *Eoleaia leaiaformis* in the overlying fluvial Cheverie Formation. *Eoleaia laevicostata* is the only species identified in the fluvial Harding Creek Member (Bell, 1960). These species are common in western European coal measures and usually indicate a low salinity environment. Their absence in the strata of this study suggests the BBM may have not experienced extended freshwater phases. However, both previous to and following deposition of the Blue Beach member, the ponding of water associated with the fluvial strata may have been predominantly fresh water.

5.3.2 Trace Fossils

There are abundant trace fossils within the Horton Bluff Formation. Four ichnogenera were observed at coastal outcrop: *Skolithos*, *Paleophycus*, *Isopodichnus*, and *Planolites*.

The most notable features of the trace fossils from Blue Beach are the low diversity and complete domination of one ichnogenus for a single bedding plane. *Paleophycus* are the most common of the ichnogenera observed at the coastal outcrop. They usually occur in medium grained calcareous sandstone layers 10-30 cm in thickness (Fig. 3.10). Some of these sandstone units are associated with rippled bedding surfaces. *Planolites* and *Isopodichnus* are generally found on muddy siltstone bedding surfaces preceding desiccation crack horizons and pedoturbated mudstones (Fig. 3.12).

All of the ichnogenera from the BBM are commonly found in both shallow marine and nonmarine environments (Pemberton et al., 1992). The low diversity and dominance typify brackish water assemblages. Given the association of the ichnogenera with marine euryhaline microfossils, bi-directional current indicators, and desiccation cracks, a rapidly fluctuating shore line is envisioned for the paleoenvironment these organisms thrived in. The high frequencies of these organisms indicate well-oxygenated conditions.

5.3.3 Vertebrates

The vertebrate fossils from the BBM include abundant palaeoniscid fish and trackways from some of the first amphibian-like creatures (tetrapods). This study will briefly describe both with a general discussion on the significance of their occurrence.

Palaeoniscid Fish

The microfossil residues from the BBM contain abundant scales and teeth representing all three of these genera reported in the Albert shales including *Rhadinichthys*, *Elonichthys*, and *Canobius* (Plate 11, Figs. 1, 2, and 3). The tentative identification of a Rhizodont fish jaw (Hitchcock pers. comm., 1994 from Andrews, 1985) in the spring of 1994 represents previously undocumented species from the Horton Bluff Formation (Plate 12). It is curious that the only articulate fossils of these palaeoniscid fish horizons in the HBF occur associated with the marine ostracode *Copelandella novascotica* and glaucony grains. Another curious association is a petroliferous shale horizon that occur with the fish "kills" at the base of the Blue Beach outcrop (Fig. 3.21).

The fish kill in the BBM may represent a period of stagnation in the restricted water body (lagoon) when an excess of bacterial activity consumed all of the oxygen in the system, perhaps due to an algal bloom, causing the fish population to be catastrophically decimated. The presence of primary pyrite and benthic straight hinged ostracodes also indicate periods of low oxygen (Whatley and Lethiers, 1994; see Chapter 6) too toxic for a macro-invertebrate fauna. The distribution of the fish fragments are generally evenly distributed throughout both the coastal section and the Saarberg core (Tables 3.1 and 3.2).

It is probable that these fish , being mobile, could migrate from one environment to the other, probably feeding on many of the invertebrate organisms including the ostracodes. Although these fish-invertebrate interactions are hard to evaluate, the fish may have served as a medium for active transport within the immediate environment or connected series of lagoons (HBF) and coastal saline lakes (Albert Formation). If the water was chemically stratified, this would further allow the fish to migrate either along the fresh water stratified well-oxygenated upper layer or along a salt water wedge up an estuary. Given that complex nature of these active organisms, they would require relatively high levels of oxygen for aerobic respiration, which restricts them to the upper fresh/brackish water layer of the stratified water body.

Palaeoniscid fish are common throughout Carboniferous and Permian strata. The paleoecology of these nektonic organisms is difficult to assess because of their great mobility within the ecosystem. Many researchers consider them fully marine while others believe they occupied fresh water environments during Carboniferous times.

In the Carboniferous of Atlantic Canada, the most famous locality known for

Palaeoniscid fish fossils is the Albert Oil Shales of New Brunswick where articulate specimens of *Rhadynichthys alberti, Elonichthys browni,* and *Canobius modulus* occur with great frequency (Lambe, 1910). Carroll et al. (1972) reported these same genera from the HBF but no formal descriptions have been published to date. Palaeoniscid fish and paraparchitacean ostracodes have been reported from the other coeval lacustrine deposits such as the Strathlorne Formation on Cape Breton Island (Murray, 1960; Hamblin and Rust, 1989).

Palaeoniscid fish are documented from organic rich shales of the Orcadian Basin (Duncan and Hamilton, 1988) and the Burdiehouse Formation (Loftus and Greensmith, 1988) of Scotland. The Burdiehouse Formation contains palaeoniscid fish associated with both carbonitacean and paraparchitacean ostracodes, resembling assemblage 2a of this study, interpreted as a lagoonal/lacustrine deposit (Loftus and Greensmith, 1988). In the Late Devonian Escuminac shales from Quebec, Hesse and Sawh (1992) suggested that palaeoniscid fish and sparse shelly invertebrate fauna indicate a marginal marine low oxygen environment.

Westoll (1968) summarised much of the older literature documenting some of the early fish and tetrapods associated with the Carboniferous coal measures from both Europe and Nova Scotia. Palaeoniscid fish were thought to inhabit the upper waters spanning the marginal marine/freshwater transition zone.

Given the association of both marine and freshwater fauna from this study and in the numerous reports from Upper Carboniferous strata from Europe (Calver, 1968; Bless and Pollard, 1973; Pollard, 1966; Bless et al., 1973; Paproth et al., in press), these fish appear to be tolerant of fresh and saline waters.

Tetrapods (Early Amphibians)

Some of the more interesting trace fossils at Blue Beach are the tetrapod trackways (Fig. 3.32). Sarjeant and Mossman (1978) identified several trace fossils including

Baropezia sp. an amphibian form and *Anticheiropus bishopi* from the class Reptilia. No trackways occur together with the ostracodes, however, Bell (1960) reported them at the base of Blue Beach section corresponding to a rich marine/brackish ostracode zone (Fig. 3.1). For this project the first observed trackway is situated above the last ostracode bearing unit and below the last foraminifera bearing bed (Fig. 3.1). It is likely that these semiaquatic vertebrates fed in shallow marsh-like pools surrounding the marginal marine embayment. As they do not occur in the lowermost brackish/marine units, they most likely preferred near freshwater conditions as do modern amphibians.

5.3.4 Macrophytes

This section summarises briefly the work of Bell (1929; 1960) concerning the plant fossils identified from the Horton Bluff Formation. A brief interpretation follows. Table 5.2 summarises the fossil plants identified from the Horton Bluff Formation (Bell, 1960).

In general there were few indications of insitu plants within the Blue Beach Member. However, they increase in frequency up section into the overlying strata of the Hurd Creek Member. The species identified from the shale residues and coastal outcrop include the megaspore *Triletes cheveriensis* (Plate 10, Fig. 8) and the plant species *Lepidodendron sp.*, *Lepidodendropsis sp.*, and *Aneimites acadica* (see Fig. 3.29). The plant horizons commonly contain the foraminifera *Trochammina* and *Ammobaculites*. Euhedral pyrite, calcareous concretions, and localised pedoturbation of carbonate rich muds are the most common sedimentological features associated with the plant rich horizons. Given the similarities of the plants of the HBF with the other Carboniferous coal measures in Atlantic Canada, Bell (1960) interpreted the Horton Bluff Formation as an exclusively fresh water system. This may be the case for the underlying and overlying members but the BBM demonstrates sparsely distributed plant fragments suggesting secondary fluvial transport into the depositional system.

Table 5.2 The plant fossils identified from the Horton Bluff Formation and coeval Lower Carboniferous localities in the Maritimes Basin (after Bell, 1960).

Fossil	**Type**	**Location**
Lepidodendropsis corrugata	Plant and sporangia	HBF and the Albert Fm
Triletes glaber	Megaspore	HBF
Triletes cheveriensis n. sp.	Megaspore	Cheverie Fm and Albert Fm
Lepidostrobophyllum sp.	Plant	Albert Fm
Lepidodendropsis sp.	Plant	HBF
Asterocalamites scobiculatus	Plant	HBF
Aneimites acadica	Plant	HBF and Albert Fm
Sphenopteridium macconochiei?	Plant	Cheverie Fm
Sphenopteris strigosa	Plant	Albert Fm
Diplotmema patentissimum	Plant	HBF and Albert Fm
Adiantites tenuifolius	Plant	Albert Fm
Telangium bretonis n. sp.	Plant	Windsor and Codroy Groups
Carpolithus tenellus	Seed	HBF
Rhacopteris robusta	Plant	Windsor Group
Triphyllopteris minor	Plant	Cheverie Fm
Lepidophyllum fimbriatum	Plant	HBF

Not withstanding, some of these plant species may have in fact been tolerant of brackish conditions. Given the association of foraminifera with the more plant rich horizons, a paralic marsh is envisioned for the upper strata of the Blue Beach Member.

5.3.5 Algal Bodies (Chuaria?)

A curious feature observed on the bottom surface of siltstone and shale directly underlying the tabular dolostone horizons are small concentric disk-like siliceous bodies (Plate 10, Fig. 11). Although it is hard to determine the identity of these small algae-like bodies, they resemble *Chuaria sp.*; a species reported as a body fossil in the Trace Fossil and Problematica Supplement 1, Treatise of Invertebrate Paleontology (see figure 6 page W150 *in* Hantzschel, 1975).

The disk-like bodies resemble conical shells with a peloidal shape (Hantzshel, 1975). They range in size from approximately 100 to greater than 375 um in diameter, however, some may be as much as 5 mm in diameter. They are concentrically wrinkled and have a shiny bituminous outer layer (Plate 10, Fig. 11). They occur in great numbers along the base of bedding planes, usually directly below sandstone and tabular dolostone horizons. The tops of the cycles from which they occur usually have desiccation horizons and rootlets. They form stacked micro-layers parallel with the bedding surfaces of the shales. Their outermost concentric rings overlap. Martel (1990) reported these features in the siltstones from the BBM as "spotted" shales.

The author cannot interpret these bodies directly, however, associations can be made with the strata in which they occur. The stacked overlapping bodies are oriented parallel to bedding indicating that these organisms probably grew on the depositional substrate. The plant matter and framboidal pyrite suggest concentric growth occurred in shallow stagnant muddy pools along the infringing marsh. Algal growth of this nature is common in many shallow marine and lacustrine environments (Duncan and Hamilton, 1988).

Walcott first reported these disk-like bodies in Precambrian strata in 1899. They have since been described from other coeval localities from Europe, North America, and Russia (Hantzchel, 1976). Some researchers regarded these fossils as flattened brachiopods, concretions, foraminifera, acritarchs, and algae.

5.4 DISTRIBUTION OF THE FOSSILS

Figure 5.1 shows the vertical distribution for the fossil assemblages of the BBM. A schematic cross-section between the Blue Beach coastal outcrop to the Saarberg Core (see Fig. 1.2) shows the lateral distribution of the main fossil groups. Assemblage 1 (profundal) and Assemblage 4 (distal) comprise the basal 50 m of both the Saarberg core and the coastal outcrop (Fig. 5.1). The deep water phases of the BBM are characterised by the more reticulate, lobate, cruminate, and spinose ostracodes (beyrichiaceans and kloedenellaceans) associated with glaucony grains. Directly overlying the profundal dominated zone are the high energy nearshore assemblages A2a and A2b characterised by the large robust, smooth shelled paraparchitaceans and post mortem carbonitaceans (Figs. 5.1 and 5.2). Hummocky cross-stratified and planar siltstone are common. Also in the restricted lagoon, there are isolated bedding planes where small, thin, smooth shelled carbonitacean ostracodes (A3) proliferate representing low salinity ponding adjacent to the restricted embayment (Fig. 5.2). The uppermost strata of the BBM contain agglutinated foraminifera (Assemblage 5) associated with in situ plants and poorly developed paleosols interpreted as the infringing marsh (see Fig. 3.20). This paralic marsh is intercalated with shale cycles that formed during ponding stages. The first two cycles of the Hurd Creek Member contain the lowest diversity assemblage (A2c) dominated by two species of paraparchitacean ostracodes (Figure 3.20). These ostracodes, *Shemonaella tatei* and *Chamishaella sp.*, are morphologically smaller than the similar biotypes situated in the lower strata. This dominance of one or two species (oligotypic fauna) with its notable

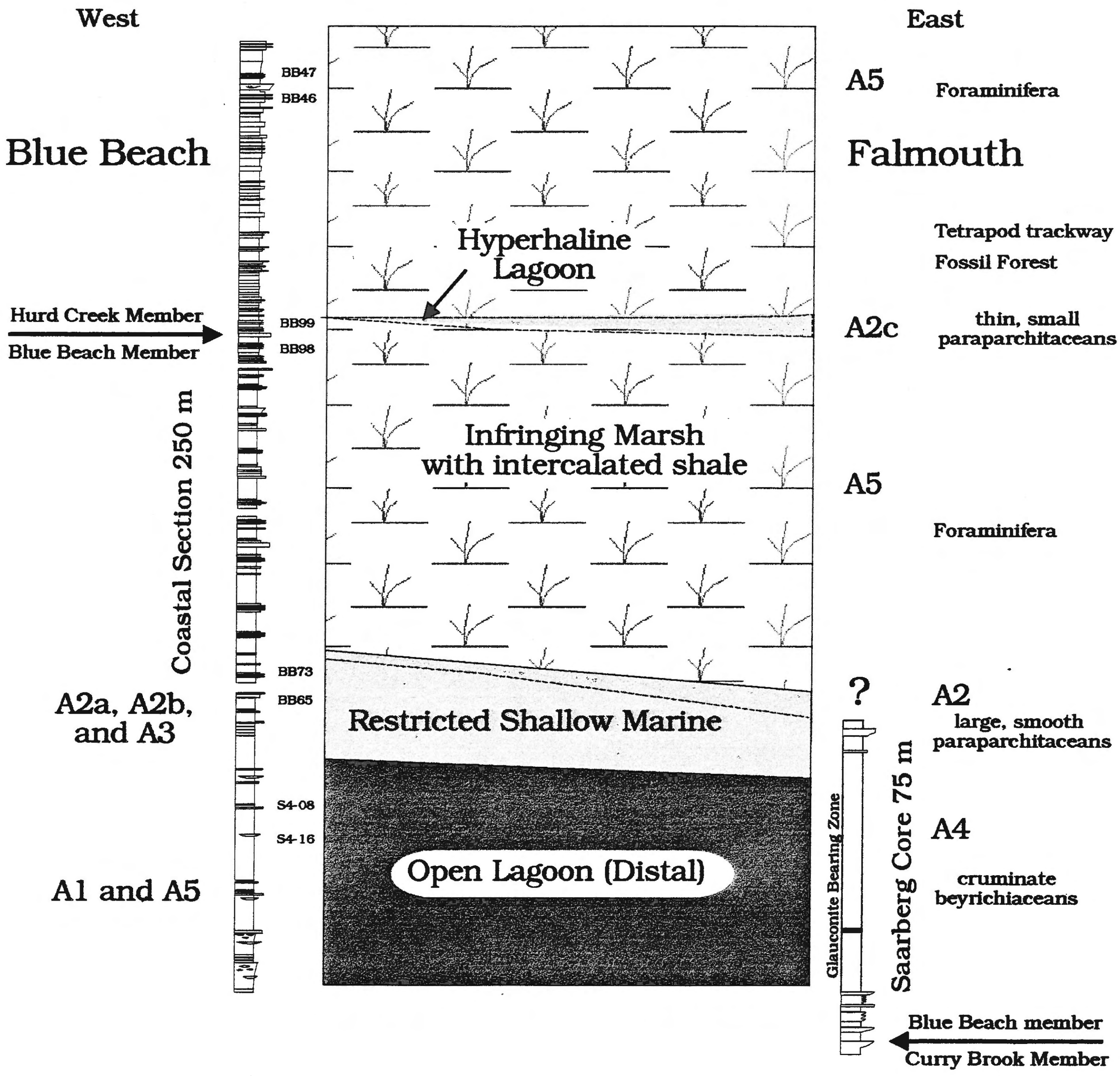


Figure 5.1 The vertical distribution of the fossils from the BBM. See Table 3.8 for assemblage definitions.

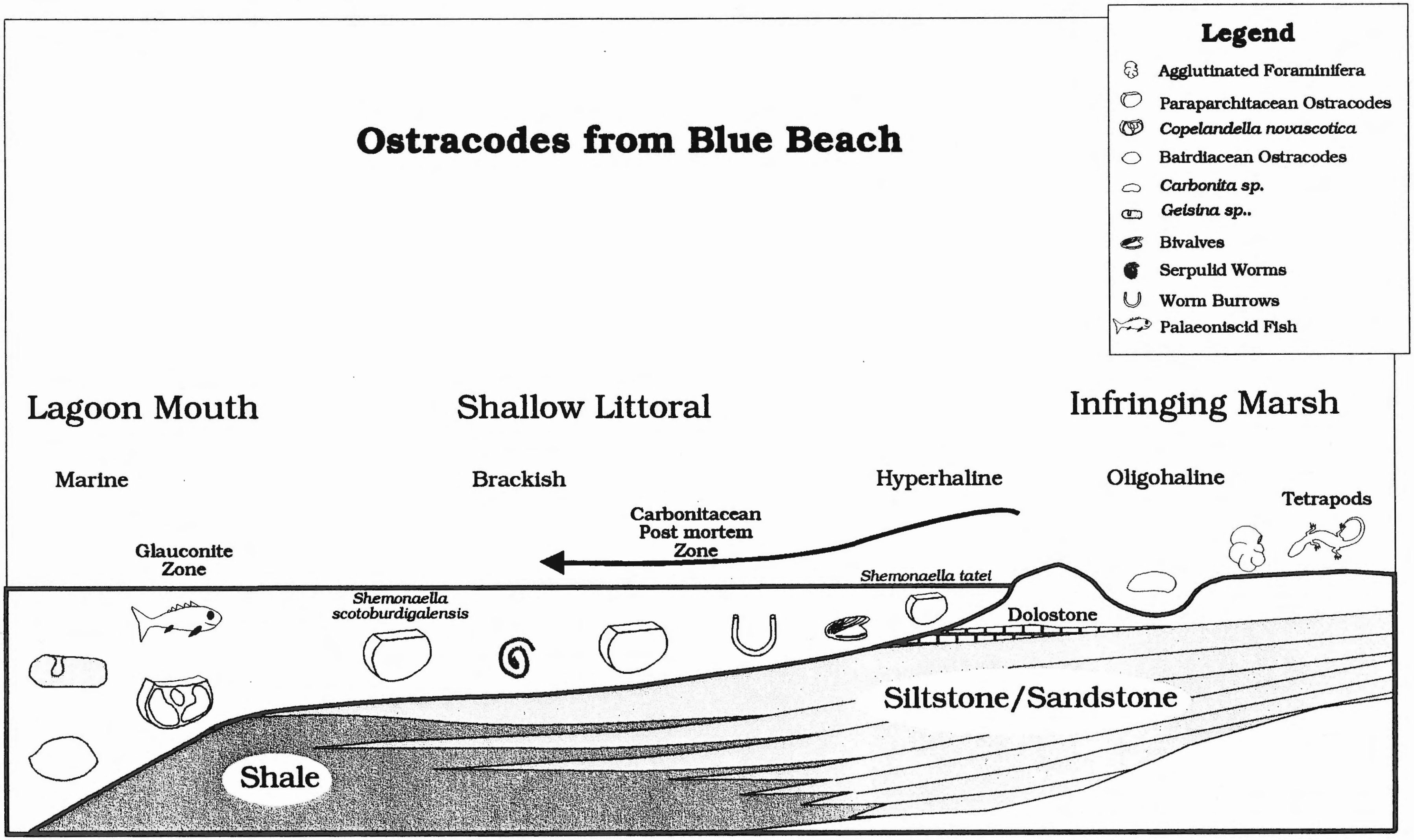


Figure 5.2 A schematic cross-section of the Blue Beach Member demonstrating the distribution of ostracodes and sedimentary facies.

reduction in size and shell thickness, suggests brief periods of hypersalinity in the shallow nearshore (Figs 5.1 and 5.2). A fossil forest and tetrapod trackways, associated with sparsely distributed foraminifera (A5) of the low salinity infringing marsh, appear at the transition between the Blue Beach and the Hurd Creek Member (Fig. 5.1).

The core and outcrop differ both biologically and sedimentologically. The most obvious feature is the higher frequency of coarsening upward cycles of sediment at Blue Beach (Fig. 3.1). Also, the higher proportion of allochthonous carbonitaceans and Foraminifera at the coastal outcrop contrast the glauconitic ostracode assemblage from the core (Figs. 3.1 and 3.2). The sudden facies changes are more evident in the core, specifically the change from deep water shales to fluvial sandstones (Figs. 3.2 and 5.1). The upper limit for correlation, given by *Shemonaella tatei* and *Youmgiella sp.*, suggests that the core was further from the infringing marsh where fluctuating salinity and water depth was not as profound. Further examination of the unexposed BBM strata at Blue Beach, however, would be necessary before any firm conclusions could be made.

CHAPTER 6 PALEOENVIRONMENTAL DISCUSSION

6.1 ANCIENT COEVAL LACUSTRINE/LAGOONAL DEPOSITS

There is much available literature pertaining to the oil shales of eastern Canada and western Europe. This section will review some of the coeval deposits with similar paleo-environmental signatures.

6.1.1 Maritimes Basin

The Horton Group of western Cape Breton (Fig 1.1) contains equivalent fine grained shales and siltstones of the Strathlorne Formation. Murray (1960) was the first to correlate these strata to those of the Albert Fm and the Horton Bluff Fm based on lithological similarities. The Strathlorne Fm contains grey-green and black coarsening-upward stacked sequences interpreted as hydrologically open lacustrine deposits (Hamblin, 1989, 1992; Hamblin and Rust, 1989). A similar interpretation was provided for the BBM (Martel, 1990; Martel and Gibling, 1991; Martel and Gibling, 1995).

The Albert Formation is a potential petroleum source rock and contains the evaporite mineral Albertite. Given the evaporite minerals, varved shale cycles, plants, and abundant palaeoniscid and crossopterygian fish beds, this deposit is generally considered to have a nonmarine origin (Lambe, 1910; Belt, 1967; Carrol et al, 1972; Greiner, 1974; Pickerill et al., 1985; Utting, 1987; Smith et al., 1991). The sparse ostracodes include carbonitaceans and paraparchitaceans.

Palynological studies of the Albert Formation indicate a terrestrial derived source of microphytes with no evidence for marine influence (Utting, 1987, 1996). Pyritization of the spore exines suggest periodic stagnation of the water body. Utting (1987, 1996) noted the presence of the hydrocarbon producing algae *Botryococcus* that may be the source of the hydrocarbons associated with the Albert oil shales. The miospore assemblage *Spelaeotriletes pretiosus-Raistricka clavata* correlates with Tournaisian (late Tn2 to early Tn3) ages in western Europe and the Horton Bluff Formation of this study (Utting, 1996; Martel et al., 1993). Utting (1996) suggested a shallow lacustrine setting for the Albert Fm sediments.

The HBF contrasts with both the Albert and the Strathlorne Formations by its abundant ostracodes, glauconitic shales, absence of evaporitic minerals, and scarcity of thick trough cross-bedded fluvial successions.

6.1.2 Lower Limestones and Shales (Scotland)

The shales occupying the same stratigraphic position in Scotland have been of particular interest to the author. There are several reports referring to the paleontological similarities between the HBF and the Burdiehouse limestone (Jones and Kirkby, 1867, 1869, 1884, 1886; Latham, 1933; Robinson, 1978). Greensmith (1961) described the sediments of this Lower Carboniferous Sandstone Series as a five fold rhythmic unit of predominantly nonmarine lacustrine shale cycles with marine bands. Loftus and Greensmith (1988), described three main phases of sedimentation in ascending order: 1. a trangressional phase of shales containing marine bands intercalated with thin limestones; 2. a lagoonal/lacustrine phase with significant accumulations of oil shale, fossiliferous ostracodal limestones (containing paraparchitaceans and carbonitaceans), and suncracked mudstones; 3. a progradational deltaic (distal) phase of coarsening-up packages of sediment; and 4. an aggradational phase of fining-up siltstone and sandstone crevasse splays and cross-bedded channel and fluvial-bar sandstones. The faunal assemblages comprise a large number of paraparchitacean ostracodes while spirorbid worms are sparsely distributed (Fig. 6.1). Vertebrates include abundant fish fragments, amphibians, and the large 7 m carnivorous fish *Rhizodus hibberti* (Loftus, 1985 cited in Loftus and

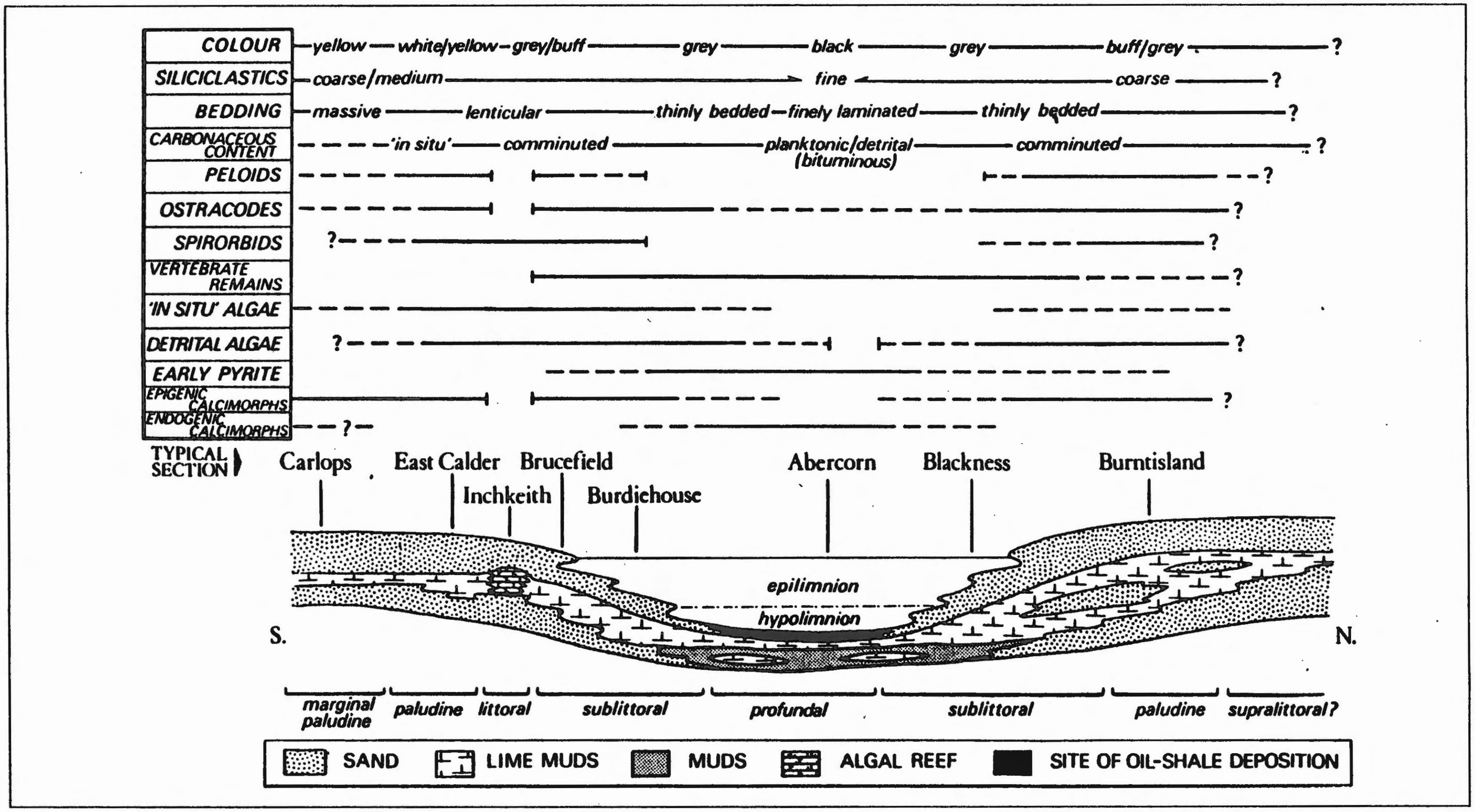


Figure 6.1 Cross-section of the Burdiehouse Limestone Formation in Dinantian strata from Fife Scotland (Loftus and Greensmith, 1988). This deposit has been interpreted as lagoonal/lacustrine. Latham (1933) and Jones and Kirkby (1867, 1884) reported paraparchitacean, bairdiacean, and carbonitacean ostracodes from this area that occur in the Horton Bluff Formation.

Greensmith, 1988) of the same genus identified from Blue Beach (Plate 12). Basin margins contain in situ plant remains associated with carbonate mudstones. Thick bioturbated ostracodal, algal limestones occur at basin margins associated with a littoral mudflat. Pyritic limestone and vertebrate remains occur in the basin center. This deposit was interpreted as a marginal marine lagoon turned fresh during transgressive and regressive events (Maddox and Andrews, 1987; Loftus and Greensmith, 1988).

The sedimentary cycles of the Burdiehouse shales resemble those of the BBM. Specifically, the pyrite bearing black shales and dolostones in combination with paraparchitacean ostracodes and fish resemble those of the BBM. Jones and Kirkby (1867) and Latham (1933) both reported species synonymous with *Shemonaella scotoburdigalensis* and *Bairdia sp.* from this Scottish locality. The marine ostracodal and glauconitic shales of this study would correspond to the marine transgressive phase of Loftus and Greensmith (1988).

6.2 DEPOSITIONAL ENVIRONMENTS

The following section discusses the physical and biogenic features of modern marginal marine depositional settings.

6.2.1 Coastal Saline Lakes

General Characteristics

A lake is the surface groundwater component of the hydrological basin where sedimentary and biologic activity can interact with meteoric waters. An open basin will be "flushed" regularly with fresh water as the outlet remains lower than lake baselevel. If a basin becomes closed, evaporation exceeds fresh water influx, resulting in a high concentration of solutes. If the solute concentration continues to increase then gypsum and halite will precipitate (Eugster and Hardie, 1978). It is important to recognise that an open basin can experience periods of excessive evaporation and may even dry up, however, evaporites will not precipitate in the absence of a true brine.

There are several phases of a salt lake; ephemeral, dry, and deep lake (DeDecker, 1981a). Dry lakes will have a well-developed brine below the lake floor and include such sedimentary features as cyanobacterial algal mats, gypsum and clay pellets, and evaporite minerals in brine pools. Wet phases will see lower salinities and increases in fish populations. Organic accumulations of shell and fishbones occur at the strandline of the receding shoreline during regressive phases as the fish and ostracodes are killed by excessive increases in salinity. Deep water saline lakes are relatively more stable than ephemeral lakes. They are usually stratified and have density driven turbidity flows that blanket the profundal areas during increased sedimentation. Anoxia or dysoxia may develop in the profundal hypolimnion which is favourable for sulfide deposition but restrictive for many benthic organisms. Plants usually grow along the relatively stable nearshore areas. The rapidly fluctuating shorelines are conducive to the formation of either carbonate crusts or oolitic horizons. The algae *Botryococcus* accumulates in the shallow part of the lake. Diversity is usually higher in more saline lakes than those of lower salinities. As a result many species, even fresh water, will migrate to the more distally connected brackish lagoon (DeDecker, 1981a and b). Lagoons, however, are less frequently flushed out and are more susceptible to desiccation making them unattractive for many aquatic organisms.

General Biology of Saline Lakes

Saline lakes typically have moderate diversity including isopods, decapods, conchostracans, cladocerans, molluscs, and insects. Foraminifera have also been documented from inland lakes with salinities ranging between 10-90 ppt; they were probably transported on the feet of birds (Cann and DeDecker, 1981a; Anadon, 1992). Transported foraminiferal populations have high numbers of one or two species while estuarine populations will be relatively more diverse (DeDecker, 1981a). Fish are common in most saline lakes in Australia, however, they occur only in systems where there is a high fluvial component during baselevel highstands (DeDecker, 1981a). Other biologic components include algal mats, plants, and insects.

Ostracodes from Saline Lakes

Ostracodes are the most diverse salinity tolerant (halobiont) organisms in saline lakes. Many of these recent taxa are known to respond morphologically with the advent of large salinity fluctuations. For example: *Cyprideis torosa* is nodose at elevated salinities while *Cyprideis littoralis* is smooth shelled under lower salinities (Kilenyi and Whittaker, 1974 in DeDecker, 1981b; see also Carbonel et al, 1988). Another example of the eurytopic nature of ostracodes is *Cyprideis vidua* which commonly lives in saline waters at 9.7 ppt but can tolerate salinity levels as much as 40 ppt for short periods of time (King and Kornicker, 1980 cited in DeDecker, 1981b). Other euryhaline ostracodes in saline lakes can tolerate salinities from as low as 3 ppt up to 30 ppt. In a rare case, the truly hyperhaline genus *Australocypris* has never been documented where salinities were less than 50 ppt (DeDecker, 1981b). The species *Eucypris inflata* from the former Soviet Union (U.S.S.R) area is tolerant to salinities as high as 110 ppt (DeDecker, 1981b).

The Pontocaspian region of Europe, a landlocked remnant of ancient Tethys of the eastern side of the Mediterranean, contains ostracode assemblages where diversity is low comprising a mixed marine/brackish freshwater association (Table 6.1). Most of the adjacent seas in this geographic area contain ostracodes with marine affinities. All of these seas are now cut off from an open marine source with the exception of the Black Sea which maintains a partial connection. The completely restricted saline water bodies contain a slightly higher number of fresh water species. The Caspian Sea, however, has an ostracode assemblage that has a four to one (4:1) ratio of marine to

Table 6.1 Ostracode species variability from the Pontocaspian region (from DeDecker, 1981b). The species numbers are included from the Blue Beach Member. Note they resemble the ratios found in the Caspian Sea but in general demonstrate a predominance for those species with marine affinities.

	No. Species	Marine Species	Freshwater Species
Caspian Sea	32	26	6
Aral Sea	10	4	6
Black Sea	21	10	11
Kuban Delta/Azov Sea	13	5	8
Issyk-Kul	11	3	8
Blue Beach	**11**	**8**	**3**

freshwater species similar to that obtained from Blue Beach (Table 6.1). The Caspian species include mainly estuarine species *Leptocythere*, *Loxoconcha*, and *Cyprideis* (DeDecker, 19981b).

In modern saline lakes *Cyprideis* is the only relict marine genus that can survive salinity concentrations exceeding those for normal seawater. In contrast, those species with nonmarine lacustrine affinities, such as *Limnocythere staplini* found in Canadian saline lakes, have been documented in extremely saline waters of 205 ppt. In general, *Cyprideis* can tolerate salinities from 3 ppt up to 96 ppt and therefore occurs in most saline lacustrine environments containing relict marine forms (commonly *Loxoconcha*). Lacustrine genera with high salinity tolerances include *Candona*, *Darwinula*, and *Limnocythere* (McKenzie, 1981). The first precipitation of alkaline carbonates or evaporites usually coincides with the disappearance of the ostracode fauna (Carbonel et al., 1988).

Biologic Classification of Modern Salt Lakes

There are 3 classes of saline lakes that can be defined on the basis of their faunal origins; thalassogenic, athalassic, and brackish (MacKenzie, 1981). Thalassogenic lakes have faunal assemblages comprising both surviving marine and saline tolerant freshwater species; the key being a marine origin. Athalassic lakes have an endemic freshwater fauna of nonmarine origin where the ostracode species bear desiccation resistant eggs and demonstrate parthenogenetic reproduction. Brackish lakes have continuity at both ends of the aquatic spectrum; fresh at the proximal end while open marine at the distal extreme (i.e. estuaries, enclosed bays, and lagoons).

Was the BBM a Saline Lake?

There are two important discrepancies that contradict a saline lacustrine model for the BBM. First, saline lacustrine deposits should, although not necessarily, contain evidence for chemical sedimentation. As pointed out by previous researchers the BBM, unlike the coeval Albert Fm, does not contain any evaporite minerals or even pseudomorphs thereof. Second, a true athalassic lake should have an endemic nonmarine fauna. The BBM, however, contains only two ostracode species with low salinity tolerances (*Carbonita*). Indeed, most of the ostracodes observed in the BBM are well-documented opportunistic euryhaline marine biotypes. Therefore, the BBM falls into the thalassogenic/brackish saline lake category. The presence of glaucony grains in the BBM sediments is direct evidence that the ostracode fauna is not a relict marine fauna surviving in an isolated basin. Consequently, the fossils of the BBM most closely resembles a brackish saline lake fauna which falls into the marginal marine depositional realm.

6.2.2 Marginal Marine Systems

There are many types of marginal marine brackish water environments. This section will briefly outline these systems.

Interdistributary Bays

Interdistributary basins are shallow, approximately 7-10 m in depth, and commonly occupy the lower portions of alluvial valleys. They can range from a few hundred meters in width to as much as 15-20 km, often connected to an open marine source. As a result of the marine connection, these embayments commonly contain an impoverished brackish faunal assemblage often comprising only sparse trace fossil horizons. The Mississippi delta demonstrates coarsening-up packages of sediment from interdistributary bays (Tye and Kosters, 1987; Tye and Coleman, 1989; Coleman and Prior, 1980). A typical succession progresses from a prodeltaic organic-rich mud, that accumulates during waning periods of episodic flooding events or extreme high tides, to delta front siltstone and sandstones deposited by traction/suspension as the hydraulic energy dissipates. Next, distributary mouth bars comprise medium well-sorted sandstone beds, with convolute structures, that indicate shallowing water depths and compaction. Finally, subaerial strata cap the sequence demonstrating pedoturbated mudstones with root traces and desiccation surfaces. When base level changes in response to basinal subsidence, tectonic subsidence, or relative sea-level rise, the capacity of the system changes. Changes in relative base level outpace sedimentation and the system floods starting the cycle over again. These cycles commonly occur as 3-5 m stacked sequences. There is a near absence of biologic activity with the exception of a few burrows.

The BBM sediments do not contain abundant channel or overbank deposits expected in these modern embayments. Also, the abundant fossils at Blue Beach are atypical of the impoverished suite of organisms commonly associated with these systems. The cyclic sedimentation of the HBF, however, resembles the coarsening-up sedimentary successions found in the interdistributary depositional realm.

Lagoonal and Estuarine Systems

Lagoons are quiescent systems that are connected to a marine source and are usually restricted by some sort of physical barrier. Estuaries are essentially drowned river valleys that are open to both fresh water and marine water at the proximal and distal extremities respectively. Estuaries and lagoons both commonly contain a proximal fresh water component, a medially mixed component, and a distal normal marine component. There may be a combination of the estuarine and lagoonal system which is open to the sea via a restricted physical barrier while at the same time is supplied with fresh water from fluvial sources (Reinson, 1992) such as the modern Annapolis Basin in South Western Nova Scotia. The restriction at the seaward end may be either a bar-built sand spit, an ephemeral sand bar, or a tectonic sill with higher relief than the landward embayment (Fig. 6.2) (Nichols and Biggs, 1985).

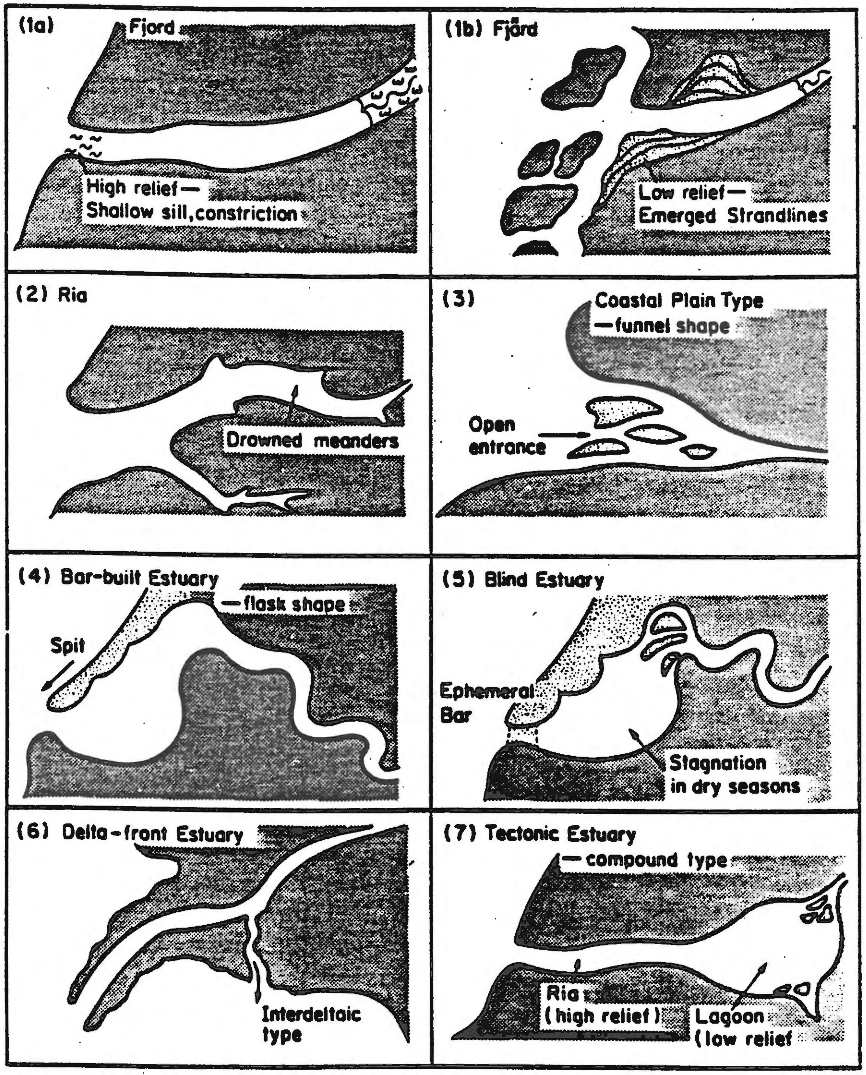


Figure 6.2 The various physiographic estuary styles (Nichols and Biggs, 1985). Note that the HBF probably resembled either a tectonic estuary (7), a blind estuary (5), or a combination thereof. Tectonic subsidence, relative sea level rise, and sedimentation rates control the depositional style.

Estuarine Systems

Dalrymple et al. (1992 p.1131) implicitly define an estuary as follows:

> ...the seaward portion of a drowned valley system which receives sediment from both fluvial and marine sources and which contains facies influenced by tide, wave, and fluvial; processes. The estuary is considered to extend from the landward limit of tidal facies at its head to the seaward limit of coastal facies at its mouth. It is implicit in this definition that estuaries can only form in the presence of relative sea-level rise.

The hydraulic gradient in an estuary decreases seaward resulting in a tripartite zonation of the system (Dalrymple et al., 1992): 1. the outer zone is dominated by tidal and current activity , mainly marine processes; 2. the central zone is where relative energy levels are lowest and are generally mixed marine/fluvial systems; and 3. the inner fluvial dominated zone surrounded by the infringing marsh. Wave dominated estuaries have this clear tripartite zonation with a marine fine and coarse grained sandbodies at the seaward mouth. Tide dominated systems will not show a tripartite zonation as tidal sandbodies extend further inland. Prominent sedimentary features include trough cross-bedding in sandbars and channels, planar sediments of the tidal flat, and mudstone and extensive marsh growth from the central regions to the estuary head (Dalrymple et al., 1992).

Lagoonal Systems

Lagoons are generally considered to be shallow stretches of seawater near or communicating with the sea and have many forms such as a sound, estuary, bay, or salt water lake adjacent to a marine body of water. There will often be a strong freshwater component that will contribute to the evolution of the system. Usually, in ancient deposits, the lack of distributary or fluvial progradational sediments makes lagoons distinguishable from interdistributary bay deposits. The characteristic features of ancient lagoonal deposits include coarsening-upward grain size, burrowed beds, and an impoverished marine fauna with high abundance low diversity assemblages. The sedimentary structures from base through to the top of each cycle usually include horizontal laminations, hummocky cross-bedding, trough cross-bedding or planar bedding (Kirschbaum, 1989). The sandstone sheets are laterally continuous, bioturbated, and are often truncated by scours. Back barrier lagoonal deposits will contain thick laterally extensive sandstone units containing abundant plant detritus washed landward during storm events.

Kirschbaum (1989) identified an ancient lagoonal deposit from the Upper Cretaceous Rock Springs Formation (MesaVerde Group) of southwest Wyoming. Three sedimentary sequences include: 1. a carbonaceous shale and coal dominated succession with abundant mudrocks and rippled and cross-bedded sandstone in fining and coarsening upward stacked cycles of sediment interpreted as distributary channels and interdistributary bays and crevasse splays; 2. a fossiliferous shale- euryhaline ostracodes, foraminifera including *Trochammina*, gastropods, burrows, and fish scales- that contain bioturbated sandy siltstone and minor rippled sandstone interpreted as a brackish water lagoonal sediment; and 3. a medium fine grained planar and trough cross-bedded sandstone unit containing basal erosional surface (ripup clasts), burrowed horizons, and agglutinated foraminifera interpreted as intertidal sand flats and flood tide deltas that shed outward into the lagoon. Initially, the high clastic supply saw the development of interdistributary channels. Basinal subsidence and a reduced clastic supply led to the development of brackish lagoons evident by the upward increase in coarsening-upward shale dominated cycles. In general, the landward area showed the most impoverished suite of fossils due to the high freshwater influx. The ostracodes favoured the brackish waters of the deeper basinal areas.

Ostracodes of Estuaries and Lagoons (Marginal Marine)

Ostracodes from modern lagoons are well-documented in the literature. For example: lagoons from the northeast coast of the Rio Grande do Sul, Brazil, at 29-30 degrees latitude, are connected to the sea by 2.5 km long channels (Wundig, 1983). Salinity at the proximal end (head) is approximately 0.1 ppt while salinities at the lagoon mouth are approximately 36 parts per thousand. Water depths range from approximately 4-15 meters. Temperatures range from 1.5° in the winter to 35° during the summer months (the annual average is 20°). Circulation is controlled by wind and not tidal energy. The euryhaline ostracode genera are dominated by *Cyprideis spp.*, *Cytherura*, *Minicythere*, and *Perissocytheridea* while the limnic forms comprise *Darwinula*, *Candona*, *Candonopsis*, and *Limnocythere*. Salinity controls the distribution of the ostracodes which can be broken up into lagoonal, estuarine, saltmarsh, and limnic assemblages. The oligohaline genera are generally smaller and smooth shelled while reticulation and ornamentation increases towards the marine/lagoonal end of the spectrum.

Benson (1959) discussed in detail the paleoecology of recent marginal marine ostracode assemblages from Todos Santos Bay, California. Benson reported the dominant species in the lagoonal and marsh environments to be *Cyprideis*, *Puriana*, *Loxoconcha*, and *Xestoleberis* that comprise euryhaline and stenohaline marine biotypes. *Cyprideis* also dominates the estuarine realms of the proximal areas. Stenohaline marine forms show moderate diversity in the shallow shelf regions of the open bay associated with current swept sandy substrates. Reticulation and ornamentation increases seaward. A similar association was documented for lagoons in San Diego County, California where ostracodes, dominated by *Cyprideis* and *Limnocythere*, occur with agglutinated foraminifera including *Trochammina*, *Ammotium*, and *Ammobaculites* (Scott, 1976; Scott et al., 1976).

Lac Tunis is a restricted lagoon from the north of France. It is shallow and rarely varies from 30 to 100 cm in water depth. It was artificially separated from the sea by canals in the mid 1800's. This isolated environment yields a low diversity high abundance marine assemblage. The characteristic ostracode species include *Cyprideis torosa* found on varying substrates, *Loxoconcha elliptica* associated with phytal substrates, and the calcareous benthic foraminifera *Ammonia beccarii* (Carbonel and Pujos, 1982). Three ecotypical environments are distinguishable usually with one species dominating up to 70 % of the total numbers.

The Dalmatian Coast of the Adriatic Sea has abundant ostracode assemblages with both brackish and freshwater affinities (Sokac and Hajek-Tadesse, 1993). The prominent ostracode, in variable proportions, is the euryhaline ostracode *Cyprideis torosa*. Freshwater forms such as *Candona* and *Darwinula* comprise a large nonmarine component. The assemblages have a small proportion of the marine genera *Loxoconcha* and *Carinocythereis*. Sokac and Hajek-Tadesse (1993) suggested fluvial discharge from adjacent rivers transported the freshwater specimens onto the shallow littoral shelf. Numerous reports in the literature have similar scenarios of post mortem transport for large limnic ostracode populations associated with both ancient and modern lagoonal deposits (Carbonel et al., 1988).

A Lagoonal Cycle from the BBM

It is difficult to identify marginal marine environments in the ancient geologic record because they contain elements of both marine and terrestrial systems. Indeed, the sediments from the BBM demonstrate repeated shallowing indicating the ephemeral nature of this deposit common in modern lakes, lagoons, coastal ponds, and estuarine deposits. Even though the fauna suggests a marine influence, the high abundance of one or two dominant species indicates this ecosystem was frequently isolated from an open marine source. Equally so, the system never sustained a truly nonmarine fauna. The BBM is interpreted as a restricted marine embayment that turned brackish. The term "lagoon" is used to describe the marine phases of the HBF as it implies an isolated marine embayment periodically connected to a marine source. The geographic extent of the embayment and the nature of physical barrier, however, are not known. In this section Cycle 2 (Fig. 6.3) from the coastal outcrop will be used to demonstrate a coarsening upward succession containing many of the marginal marine elements found in recent depositional systems discussed above.

The base of the cycle contains silty shale that unconformably overlie tabular dolostones with micro-scours and sediment injected down into the microcrystalline carbonate. Several centimetres above this unconformable surface are silty shales that contain a mixed euryhaline/oligohaline ostracode assemblage, *Copelandella* and *Carbonita*. The next ostracode bed is dominated by the euryhaline marine *Copelandella* with the brood pouches infilled with moderately evolved glauconitic clay (A1) (Fig. 3.6). The ostracodes *Shemonaella* and *Copelandella* are contained in black shales rich in framboidal pyrite and fish detritus (Fig. 6.4). Directly overlying this bed is a petroliferous shale horizon containing articulate palaeoniscid fish fossils (Figs. 3.21, 6.3). Next is a scour approximately one meter across and 30 cm thick that contains a rich accumulation of fish, ostracode shell fragments, and quartz and mica clasts. Medial in the cycle are hummocky cross-stratified sandstones (Fig. 3.8) that contain a mixed euryhaline opportunistic and fresh water ostracode fossil assemblages (paraparchitacean dominated) containing a pathological component of the brackish water species *Cavellina lovatica* (A2a). The cycle coarsens upward into siltstone that contain sparse paraparchitaceans and a few transported carbonitaceans (Fig. 3.11). Another fossil lag horizon precedes an intensely bioturbated muddy sandstone layer less than 5 cm in thickness (Fig. 3.12). Unconformably overlying the burrowed horizon is a pedoturbated muddy shale unit approximately 40 cm in thickness (Fig. 3.12). Overlying the mudstones are couplets of ripple cross-lamintaed sandstone with thin muddy interbeds (Fig. 3.12). Also, ripple cross-laminated bedsets occur with discontinuous truncated surfaces, separated by muddy drapes, that

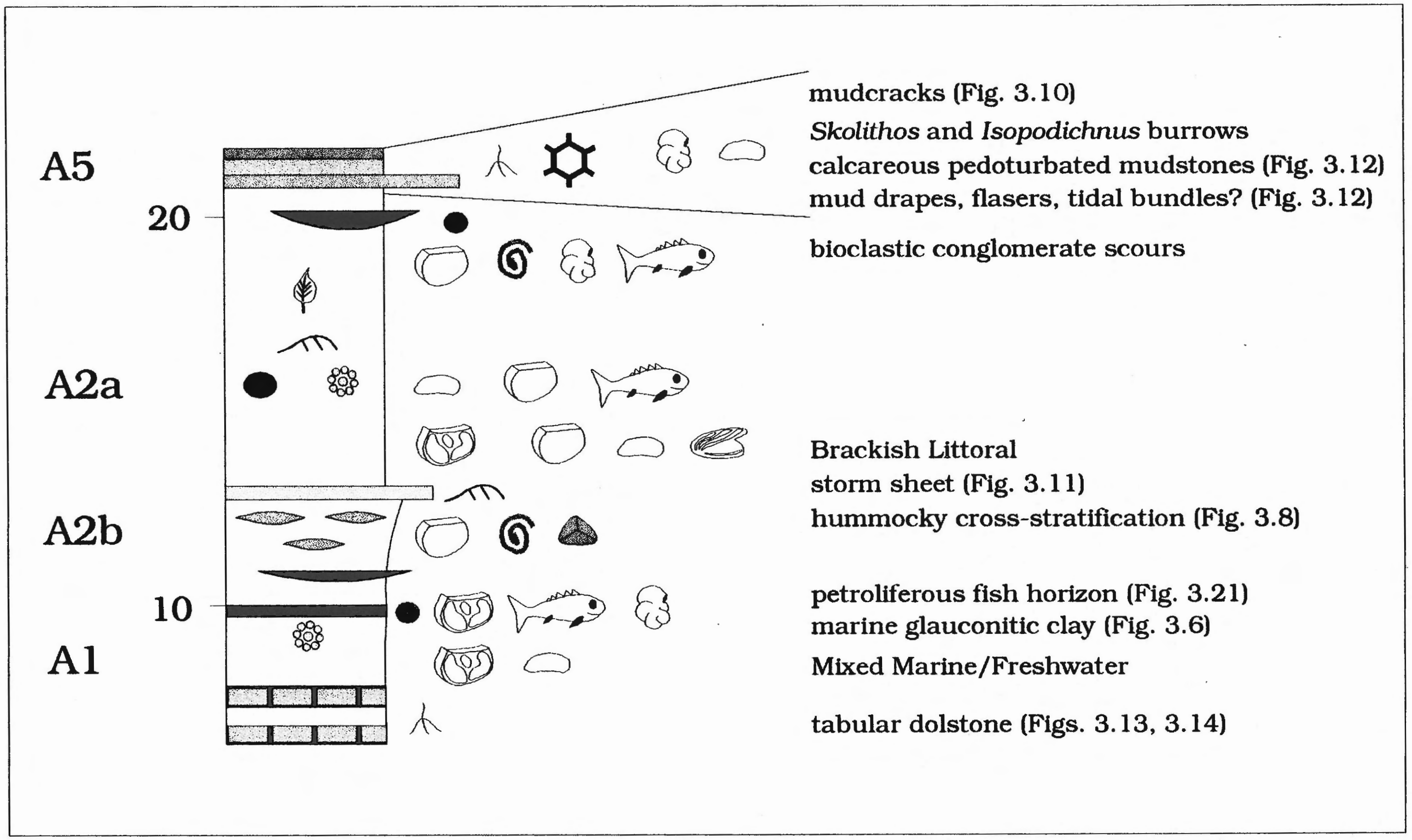


Figure 6.3 Cycle 2 from the Blue Beach Member. Fossil assemblages are given on the left (see Table 3.1 for symbol meanings).

Figure 6.4 Ostracode layer comprising mainly *Shemonaella scotoburdigalensis* and *Copelandella novascotica*. A complete growth series is present of which many are juveniles.

resemble rhythmic tidal sedimentary structures. The top several centimetres of the cycle contains a thin horizon of pedoturbated mud which is capped by a thin 3 cm mudcracked sandstone bed (Fig. 3.10).

6.3 THE MARINE CONNECTION

Although it is not the purpose of this thesis to reconstruct the paleogeography of the Early Carboniferous, a brief discussion follows pertaining to the possible source for marine waters in this previously interpreted freshwater deposit.

Biostratigraphic Correlations

Palynological correlations yield similar ages for the strata of the Maritimes Basin and those of Europe (Utting et al. 1988; Martel et al., 1993; Utting, 1987; Utting, 1988; and Playford, 1963). Specifically, the miospore zone *Spelaeotriletes cabotii* (HBF) corresponds to the *S. cabotii* Upper P.C. Zone of Tournaisian (TN3) age in the western Europe (Martel et al., 1993). These ages correspond with a European transgressive highstand in Latest Famenian time at the Devono/Carboniferous boundary (Bless et al., 1988). Similar transgressive curves were obtained from the sedimentological and fossil records from Sauerland, Germany (Bless et al., 1993). A recent study by Bless (1993) used the ostracode species *Pseudoleperditia* gr *venulosa* to construct a eustatic sea-level curve from Belgium to compare with those from France for this same time period. The sea-level curve from that study shows the acme of marine transgression at about the latest middle Tournaisian (TN3).

Transgressive and Regressive Cycles

Giles (1981a) compared the transgressive and regressive cycles of the Windsor Group with those of western Europe (Ramsbottom, 1979). The coarse sandstone and conglomerates of the Horton Group were excluded from that study because of the lack of marine evidence and inferred terrestrial origin (Giles, 1981a). It may be that the sedimentary cycles of the Horton Bluff Formation correspond to one of the earlier transgressive events in Dinantian strata in western Europe (Ramsbottom, 1979). In this scenario, the overlying fluvial strata, including the Cheverie Formation and the basal un-named conglomerates of the Horton Group represent regressive sequences. Both the transgressive curves of Bless et al. (1993) and Ramsbottom (1979) roughly correspond to the time of deposition of the BBM dated by miospores (Fig. 6.5). In any event, where did the source of the marine waters come from?

Speculation of the Marine Source

The Albert Formation and the Strathlorne Formation are located north and northeast of the HBF respectively. Both coeval formations occur on the northern side of the Chedabucto Fault Zone. Sedimentologically, these formations resemble the HBF. The Albert Fm, however, contains more chemical sediments and petroliferous oil shales. The Strathlorne on the other hand, is located in the somewhat more rugged terrain adjacent the Cape Breton Highlands and contains more siliciclastics. Curiously enough the sedimentological and paleontological characteristics of these deposits resemble those expected in a fluvio-lacustrine nonmarine setting. Regardless of the interpretations for these deposits, it is unlikely that marine water entered the catchment basin of the Horton Bluff Formation via these potentially interconnected basins.

Giles (1981b) postulated that the marine carbonates from the Mahone Bay area, south of the Windsor Subbasin (Fig. 1.1), may represent a restricted opening along the southern shore of present day Nova Scotia. This concept is problematic as there is no evidence of Tournaisian marine rocks south of Nova Scotia, however, they may lie somewhere under our present day continental shelf. Alternatively, the Meguma and

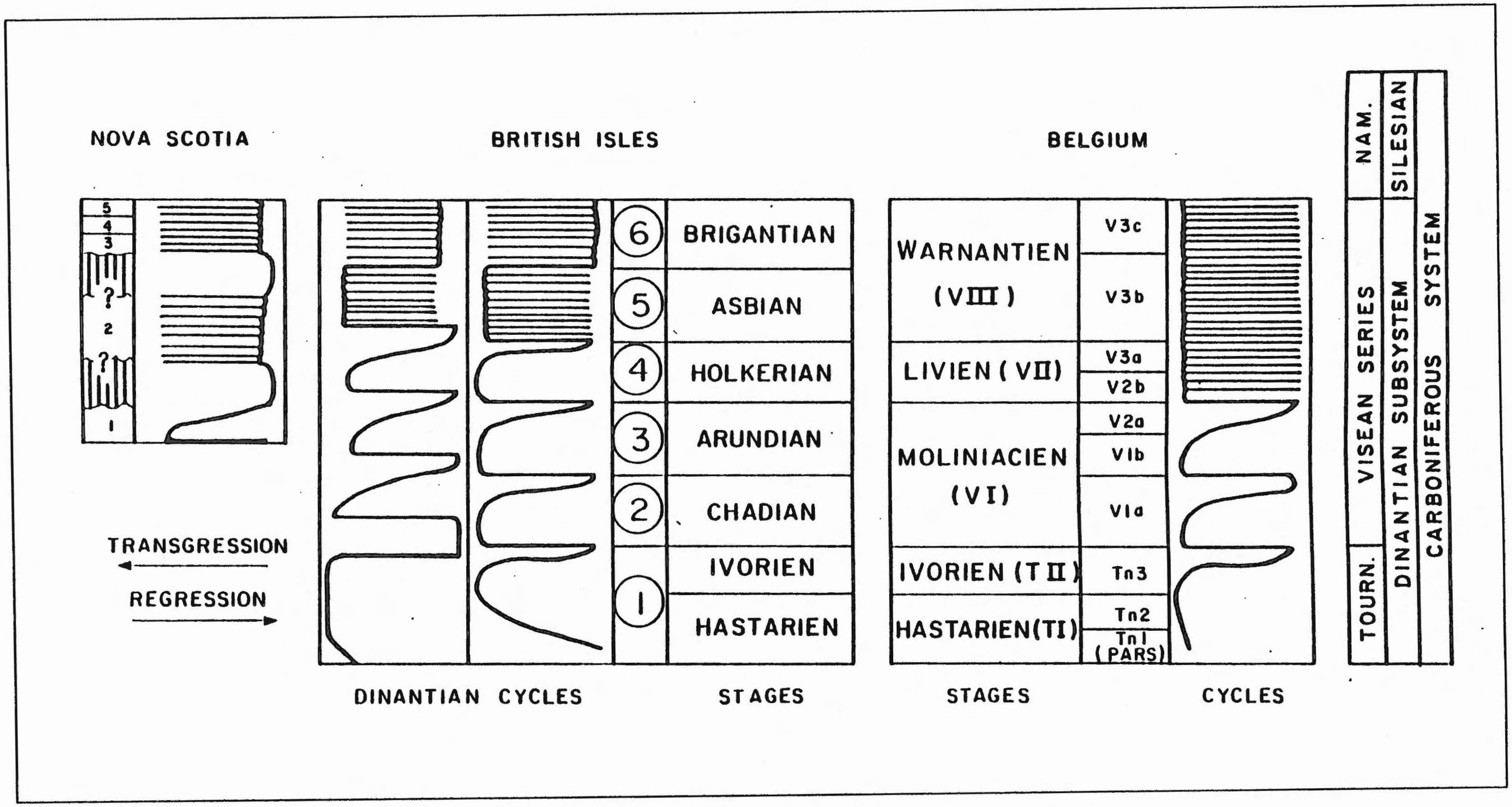


Figure 6.5 Correlation of the transgressive and regressive cycles from Nova Scotia, the British Isles, and Belgium (after Giles, 1981a). Note that the Blue Beach Member corresponds to the Tn2/Tn3 zone dated by miospores (Martel et al., 1993). This corresponds to transgressive peaks in the maritimes and western Europe. This is also in agreement with recent sea level curves from Belgium and Germany surrounding the Carboniferous Devonian boundary (Bless et al., 1993; Bless, 1988; Bless, 1993).

granite clasts in the HBF sediments, the north-easterly paleoflow trends (Martel and Gibling, 1991, 1996), and the northward thickening cycles towards the Cobequid Chedabucto Fault (Fig. 1.1) suggest a south-westerly source from perhaps the present location of the Bay of Fundy.

It is unknown as to how much Carboniferous cover has been eroded post deposition of the Horton, Windsor, and Mabou Groups in the Maritimes Basin. Estimates are upwards of 4 km since Permian times (Grist et al., 1995). Given that the Horton Bluff Formation is a fault bounded half Graben and roughly parallels the Chedabucto Fault Zone (Fig. 1.1), this deposit probably represents a remnant of Tournaisian strata that once probably covered mainland Nova Scotia prior to uplift and erosion. Further research will be necessary before this problem can be resolved. In any case, the marine ostracodes and glauconitic sediments indicate at least period influxes of marine waters at about the same time as transgressive events in western Europe (Ramsbottom, 1979; Bless, 1993, 1988; Bless et al, 1988).

6.4 DEPOSITIONAL MODEL

The BBM had 3 main phases during deposition. The underlying strata of the Curry Brook Member represent the initial phase of ponding on the alluvial plain in response to tectonic subsidence, basinal compaction, and a rise in relative base level. Fluvio/lacustrine deposition predominated while fish and conchostracans lived in the fresh water shallow ponds (Phase 1 Fig. 6.6). As sealevel continued to rise the coastal ponds were inundated introducing a largely marine ostracode population (Phase 2). The deeper areas of the basin contained a relatively diverse brackish/marine population (A4) (see Fig. 5.2). At the acme of marine transgression, glaucony grains formed on the sandy substrate of the outer lagoon in water depths in excess of 60 m. The more nearshore areas during the lagoonal phase contained a mixed marine/freshwater component of paraparchitaceans, beyrichiaceans, and

Depositional Model for the Blue Beach Member

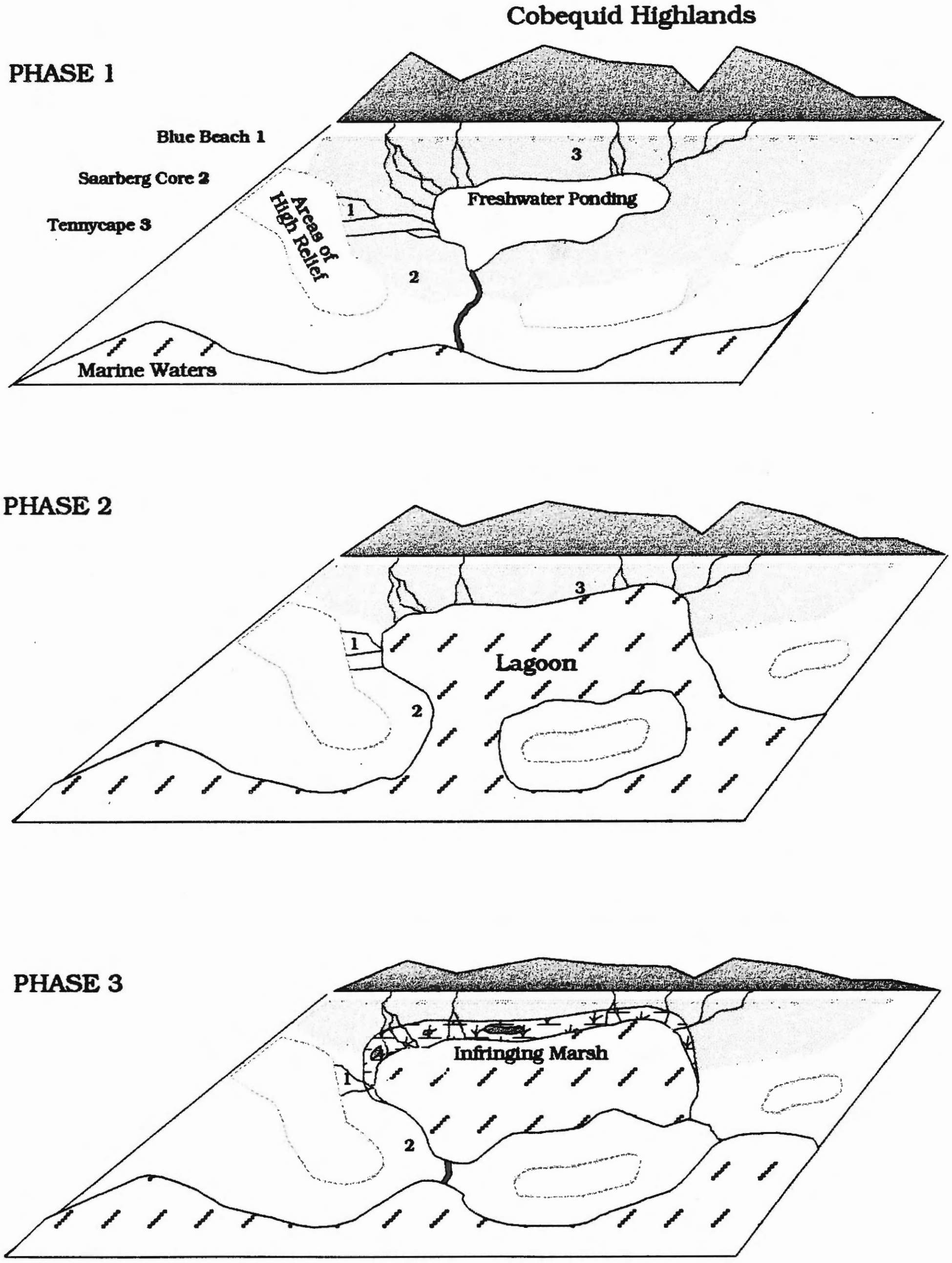


Figure 6.6 Tectonic subsidence outpaces sedimentation causing ponding and fluvial (interdistributary) deposition (Phase 1). Marine inundation introduces a eurytopic ostracode fauna which thrive in the quiescent waters of the restricted lagoon. At the acme of marine transgression (Phase 2) low sedimentation rates promote the glauconitisation of clays at the lagoon mouth, while stagnant waters of the shallow inner bay are conducive for the formation of pyrite. The oxygenated high energy littoral zone comprises a mixed opportunistic paraparchitacean (euryhaline) and allochthonous carbonitacean ostracode assemblage. Regression ensues isolating the bay (Phase 3) from marine waters. Extensive marsh facies develop at the bay head. Foraminifera thrive in the shallow pools surrounded by the plant *Lepidodendropsis*. Tetrapods wallowed in the shallow muddy waters.

carbonitaceans (A1, A2a,b, and A3). During periods of increased fluvial recharge, large populations of freshwater carbonitaceans were transported into the shallow higher energy littoral zone. *Carbonita* would therefore be analogous to modern *Darwinula* and *Candona* as seen in the Pontocaspian region in Europe.

Plants were relatively sparse in the saline waters of the littoral zone. Energy levels were moderate as suggested by the hummocky cross-stratification. Shallowing during the second depositional phase was brief. Density driven silt and sandstone sheets draped the deeper areas of the basin. Eventually, the lagoon became restricted and periodic stagnation of the basin resulted. At this time tabular penecontemporaneous dolomite formed in the shallow subsurface of the muddy sediments. Pyrite also formed during these periods of dysoxia. At times, when bottom waters became anoxic, the benthic ostracode community was killed (Fig. 6.7). Eventually, the free swimming fish of the upper oxygenated waters were also killed, indicated by the articulate fish horizons and associated petroliferous shale.

Phase three saw the onset of lagoonal termination and infilling. Diversity decreased and shallowing was more frequent indicated by the increase in pedoturbated green mudstones, mudcracked horizons, and carbonate nodule horizons. Marsh foraminifera, associated with plant rich mudstone horizons, are common (A5). Ostracodes, however, became less frequent, represented mainly as post mortem death assemblages. It is important to acknowledge the hyperhaline assemblage of this study as it occurs in the uppermost beds of the Blue Beach Member/Harding Brook Member transition. The near monospecific population of small, thin shelled paraparchitaceans (*Chamishaella sp.* and *Shemonaella tatei*) that occur in thin muddy cycles, suggest elevated salinities (A2c) (*Shemonaella tatei* and *Chamishaella sp.* probably occupy the same niche of the modern genus *Cyprideis* in modern saline lakes). During this period the lagoon became isolated from its marine source and experienced a high amount of evaporation. All of the stenohaline and oligohaline genera were decimated leaving only the true euryhaline opportunists. A few abraded *Carbonita* indicate the proximity to shallow fresh water pools of the infringing marsh. Deposition of the Hurd Creek Member lacustrine/infringing marsh begins. The only microfossils are arenaceous foraminifera that are better suited to the increased acidity in the muddy swamp (A5). Tetrapods flourished along the rapidly fluctuating shallow muddy shores of the diminished lagoon. Finally, regression led to the rapid erosion and infilling of the basin until the next transgressive pulse, the Macumber Facies and Ships Cove Formations, during Visean times (see Schenk et al., 1994).

6.5 ANOXIA, EVOLUTION, AND PETROLEUM SOURCE ROCKS

A curious problem arises with the presence of organic rich shale in the Horton Bluff Formation. Previous workers overlooked these horizons as they were covered with scree and boulders. However, the last several periods of freezing and thawing have left them exposed along with several beds of ostracodes and palaeoniscid fish. Analysis of the microfossils and vertebrate fossils reveals interesting relationships.

Hydrocarbon Producing Environments

Anoxic silled basins usually occur in landlocked systems where marine recharge exceeds fresh water influx, creating a negative water balance. This commonly occurs during transgressive events (Demaison and Moore, 1980). Often a chemocline develops and the basin becomes stratified. Under a normal positive water balance mixing usually results in well-oxygenated bottom waters. During periods of stratification, however, there is high productivity in the upper oxygenated zone and a high amount of particulate organic matter settles into the unmixed profundal zone. It is at this time when respiration exceeds the supply of oxygen and anoxia results. The black shales of the BBM have many similarities with this model.

Biologic Features

Filter feeding ostracodes dominate over deposit feeders during periods of low oxygen (kenoxia) (Lethiers and Whatley, 1994). Modern filter feeders pass nutrient rich water through the cuticle of their ventral surface. In the process, more oxygen is obtained from the water thus enabling them to tolerate diminished oxygen levels. Lethiers and Whatley (1994) postulated that straight hinged Paleozoic ostracodes, beyrichiaceans and paraparchitaceans, were filter feeders. The diversity of these families are highest at the Devonian/Carboniferous boundary when there was widespread deposition of organic rich shale attributed to anoxia of the worlds ocean. In addition to the filter feeding, beyrichiaceans incubate their eggs in brood sacks and retain early instars within the carapace, better enabling successful maturation of their offspring.

Both the beyrichiacean, *Copelandella novascotica,* and the paraparchitaceans, *Shemonaella spp.* and *Chamishaella sp.*, occur in the organic rich shales of the BBM. It is interesting that directly overlying the ostracode beds, containing almost an exclusive population of *Copelandella novascotica,* there are thin 5 cm zones of petroliferous oil shale and articulate palaeoniscid fish remains (Fig. 3.21). Although, the lateral extent of these organic-rich horizons are undetermined, these sedimentary layers probably represent low oxygen events. The ostracode assemblages contain a complete growth series of both juvenile and adult molts indicating low energy biocoenosis. The ostracodes disappear completely from the sediments probably when complete anoxia in the water column was achieved. The fish in the stratified water column probably depended on the ostracode population for a large portion of their nutrient intake, especially during low oxygen events, and suffered greatly with the diminution of the ostracode fauna. Eventually, if conditions causing oxygen depletion in the profundal zone persisted, there would have been a reduced oxygen level for fish living in the neritic zone and they themselves would die off. An event of this nature would explain the petroliferous shale and palaeoniscid beds that are intercalated with the ostracode layers.

The Late Devonian Biotic Crisis

The geologic record demonstrates a Late Devonian biotic crisis. This crisis has been attributed to lowering oxygen levels in the oceans and changing climatic shifts, possibly in relation to the development of vascular land plants and well-developed soils (Algeo et al., 1995). Also, transgressive events around the Devonian/Carboniferous boundary in European strata are well documented (Bless et al. 1993; Bless, 1993). Bless et al. (1994) suggested that coeval Hangenberg Black Shale from Sauerland, Germany represents a period of short lived transgressions or a stillstand that caused anoxic black shale to develop. Poor monotonous fossil assemblages indicated unfavourable ecological conditions. Bless et al. (1994) postulated that it is during these times that opportunistic species, such as ostracode filter feeders, can survive intolerable conditions and radiate into new species. Lethiers and Whatley (1994) demonstrated that the diversity of ostracode filter feeders that spanned the Carboniferous/Devonian boundary was relatively high and can be correlated with global eustatic transgressive and regressive cycles. With the evolution of the atmosphere and positioning of the continents at mid-tropic latitudes (Ziegler, 1988; Scotese and McKerrow, 1990), global oceans may have seen reduced oxygen levels or at least poor circulation which led to an increase in opportunistic species that could survive low oxygenic bottom waters. If this transgressive/stillstand period were prolonged enough, perhaps over several hundred thousand years, would not the semiaquatic vertebrates (Tetrapods) selectively encroach upon a new uncharted terrestrial habitat? In any case, the HBF displays interesting patterns leading to the development of anoxia and hydrocarbon rich black shales that may correspond to such sea-level fluctuations and oil shale formation in Europe.

CHAPTER 7 SYSTEMATIC PALEONTOLOGY

Taxonomy

Systematic classification for the agglutinated rhizopods is at the generic level and follows Loeblich and Tappan in Moore (1964). The Ostracode taxonomy follows after Dewey and Fahraeus (1987).

Order ARCELLINIDA (Kent)

Centropyxis? sp. (Ehrenberg)

Plate 1, Fig. 12; Plate 10, Fig. 10

Description: The test is agglutinated and circular in cross-section. The aperture is invaginated.

Occurrence: Sparsely distributed but more frequent in upper cycles usually occurring with fresh/brackish ostracodes.

Stratigraphic Range: Mississippian to Recent

Dimensions (µm): Width: approximately 90 µm

Remarks: Wightman (1993) did not assign a name to this taxa. Because these mitotic organisms seem to have changed little since their probable early Paleozoic origins, these earliest thecamoebians can be compared to recent genera. The specimens occur in shales, usually in the 65-125 µm size fraction. They span the Carboniferous-Recent strata with these specimens representing the earliest identified to date. These are the only agglutinated rhizopods that consistently span the lacustrine to brackish zone in recent ecosystems (high marsh tidal zone or mangrove).

Difflugia? sp. (Ehrenberg)

Plate 1, Fig. 9

Description: The arenaceous tests are variable and they are commonly have a sac-like appearance. They usually have a cylindrical neck with a terminal, circular aperture.

Occurrence: Only a few poorly preserved specimens in a couple of samples.

Stratigraphic Range: Mississippian to Recent

Dimensions(µm): Length: 100 Height: 80

Remarks: Specimens are hard to distinguish as they are most likely flattened. Mississippian-Recent. Modern representatives occupy freshwater/brackish marshes.

Order FORAMINIFERA (Eichwald)

Trochammina sp. (Montagu)

Plate 1, Figs. 1-6

Description: Tests free, trochospiral with globular chambers that increase in size. The final largest chamber has an interiomarginal aperture. The agglutinated wall is comprised of medium to coarse silt sized grains.

Occurrence: Present in many samples usually associated with coarser lithologies and mudstones in cycle tops.

Stratigraphic Range: Cambrian to Recent.

Dimensions: Width of test ranges from 90-250 µm.

Remarks: Although most specimens are rather compressed they are easily recognised. Wightman (1993; 1994), Wightman et al., (1994), and Thibaudeau and Medioli (1987) all found numerous specimens associated with paralic coals in the Late Carboniferous Sydney Basin, Nova Scotia. They occupy the middle to low paralic marsh in recent settings.

Ammobaculites sp. (Cushman and Brönnimann)

Plate 1, Fig. 8

Description: These specimens are poorly preserved. They comprise elongate tubes containing several chambers, the first 3 or 4 forming a tight coil. They are composed of medium size silt grains. No apertures have been observed.

Occurrence: This morphotype is most commonly associated with the shales lower in the cycles at Blue Beach, specifically it is locally abundant at the base of cycle 2.

Stratigraphic Range: Mississippian to Recent

Dimensions: Most specimens occur in the 90-250 µm size fractions.

Remarks: This morphotype has been reported from numerous sites in the Sydney Basin Late Carboniferous strata. All are associated with lower salt marsh facies as indicated by modern representatives.

Ammotium sp. (Cushman and Brönnimann)

Plate 1, Figs. 7, 10

Description: This morphotype is poorly preserved. It is comprised of medium sized silt grains. The basal coil is larger than observed in *Ammobaculites* and the uncoiled stage is more robust. There may be a "lip-like" structure at the termination of the last chamber that may represent an aperture.

Occurrence: These specimens are most commonly associated with the shales lower in the cycles at Blue Beach.

Stratigraphic Range: Mississippian to Recent

Dimensions: Most specimens occur in the 90-250 µm size fractions.

Remarks: This morphotype has been reported from numerous sites in the Sydney Basin Late Carboniferous strata (See synonymies for refs.). All are associated with lower salt marsh facies as indicated by modern representatives.

Ammodiscus sp. (Schmid)

Plate 1, Fig. 11

Description: A single chamber that consists of one equal planispiral coil. The agglutinated wall is composed of fine to medium sized silt.

Occurrence: Black shale

Stratigraphic Range: Mississippian? to Recent

Dimensions: Width of test ranges from 200-250 μm.

Remarks: Several specimens were observed both under the scanning electron microscope and in the sample residues. This morphotype has been documented in modern and ancient near shore shelf environments as follows: the Westphalian strata in the Netherlands (Bless and Pollard, 1973); Cretaceous pelagic limestones in the Mediterranean (Kuhnt, 1990); and Permian strata from north-western England. They are commonly associated with *Hyperammina*, *Textularia*, and *Trochammina*.

Class OSTRACODA Latreille, 1806
Order PALAEOCOPIDA Henningsmoen, 1953
Suborder BEYRICHIOMORPHA Henningsmoen, 1965
Superfamily BEYRICHIACEA Matthew, 1886
Family BEYRICHIIDAE Matthew, 1886
Genus ***Copelandella*** Bless and Jordan, 1971

Diagnosis: see Bless and Jordan, 1971

Type Species: *Beyrichia novascotica* Jones and Kirkby, 1884

Occurrence: Tournaisian/ Dinantian and Visean strata of both Nova Scotia, Newfoundland, Europe, and Russia.

Stratigraphic Range: Tournaisian-Visean

Remarks: Dewey (1983) and Dewey and Lahraeus (1987) documented several poorly preserved specimens of this genus in Visean strata of Newfoundland and Nova Scotia. The lobation, however, is poorly preserved.

Copelandella novascotica (Jones and Kirkby)

Plate 2, Figs. 1-8

Beyrichia novascotica nov. sp. JONES and KIRKBY, 1884, p. 358, pl. 12, figs 5, 6.
Beyrichia hibernica nov. sp. JONES and KIRKBY, 1896, Pl. 12, figs. 7-15.
Beyrichia sp. DAWSON, 1897, p. 256, fig. 78c.
Jonesina novascotica (Jones and Kirkby).- BELL, 1929, no plate
Hollinella ? novascotica (Jones and Kirkby).- BELL, 1960, Pl. 21, figs. 1, 5, 6, 7.
Copelandella novascotica (Jones and Kirkby).- BLESS and JORDAN, 1971, p. 188, figs. 1, 2.

Description: This medium sized quadrilobate ostracode has a distinct swollen dorsal anterial lobe. An elongate pre-adductoral sulcus (S1) separates the dorsal anteral lobe from the other lobes. The mid-dorsal lobe (L2) lies behind the upper regions of the anterial lobe (L1).The syllobium (the lobe complex behind the main sulcus (S2) comprises a dorsal lobe (L4) and a horizontal elongate posterio-ventral lobe (L3). The adductor pit (S2) lies slightly behind the median area of the carapace and separates L2 from L4. The posterial dorsal spine is short and stout with a sulcus (S3) separating it from the syllobial lobes. A velate ridge surrounds the ventral margin terminating at the anterior and posterior dorsal areas. The velum with radiating vertical striate are most prominent in the anteroventral area. The dorsal margin is straight with a the "hooked" (cusp-like) anterior cardinal area which fuses with the velum. The surface of the carapace is coarsely reticulate.

Males: Males are generally more flattened and lack a swollen "pouch" or anterior lobe and have a thinner velum. The anterior lobe is confluent with the anterodorsal regions of the syllobium.

Females: The swollen anterial lobe (L1) forms a pouch. Spherical calcareous "eggs" ranging in size from 50-90 µm are finely reticulate. The calcareous spheres, observed in thin section, occur within the anterioventral pouch.

Juveniles: The juveniles lack swollen anterial lobes. The youngest being the most confluent. The sulci become more prominent with the progressively larger instars. Spines are evident in even the smallest instars but also become larger with successive instars. L2 and L4 are the most prominent lobes in the early series.

Occurrence: Blue Beach near Hantsport, Nova Scotia, Canada, near Cultra Ireland, the Fife limestones, Scotland, and the Moscow Basin, Russia.

Dimensions: All measurements are in microns. Growth series shown in Figure 7.1.

Specimen	**Length**	**Height**	**Width**
Female LV	1,025	775	548
Male	1,225	675	575
Juvenile	825	475	312
Female LV	1,325	875	572
Female	1,800	1,225	

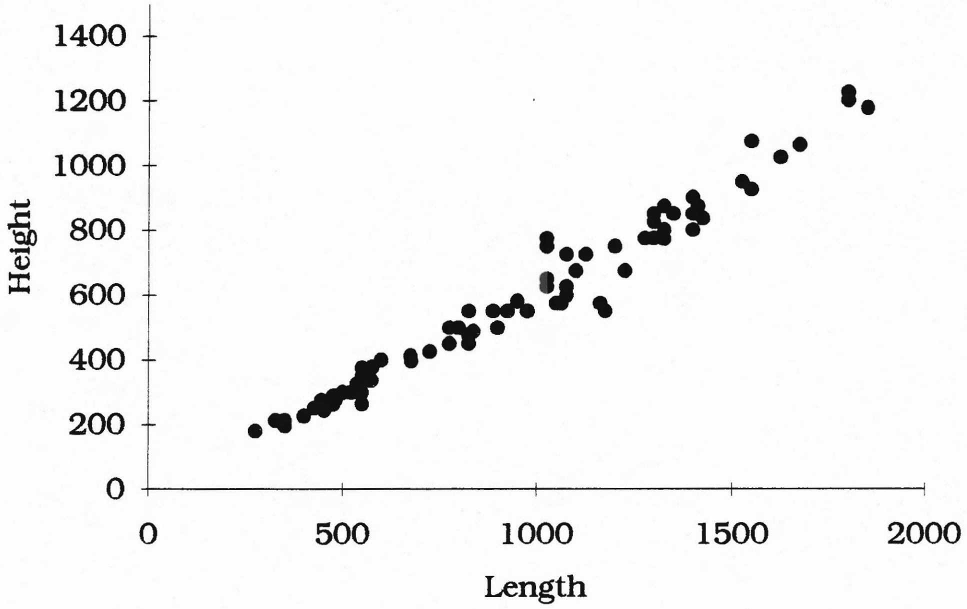


Figure 7.1 Growth series for *Copelandella novascotica.*

Remarks: Bless and Jordan (1971) erected this genus based on it distinct lobation and velate structure. Bell (1960) suggested this species belong to *Hollinella* based on the lobation, however, the anterior swelling is not indicative of the generally confluent anteroventral lobation in most Hollinids. The "brood" pouch allies this species with the super-family of Beyrichid ostracodes.

Suborder indet.
Superfamily YOUNGIELLIACEA Kellet, 1933
Family YOUNGIELLIDAE Kellet, 1933
Genus ***Youngiella*** Jones and Kirkby, 1886

Diagnosis: Carapace extremely minute, elongate, straight taxodont hinge. Smooth or reticulate.

Type-species: *Youngia rectidorsalis* Jones and Kirkby, 1886

Stratigraphic Range: Late Devonian-Upper Pennsylvanian.

Youngiella sp. (Jones and Kirkby)
Plate 3, Figs. 1-4

Youngia nov. gen. JONES and KIRKBY 1886, p. 515, figs 5-7.
Youngiella nom. nov. JONES and KIRKBY 1895a (*pro Youngia* Jones and Kirkby, 1886; *non* Lindstorm)

Description: The poorly preserved specimens are small and elongate with a distinct "canoe shape". The hinge is straight taxodont type. The cardinal angles are obtuse. The anterior margin is more rounded than the posterior. There is distinct tapering at both the anterior and posterior ends of the carapace, almost pointed. The left valve overlaps the right but there are no marginal rims. Some of the better preserved specimens are finely reticulate. One specimen is partially replaced with microcrystalline pyrite.

Occurrence: This species occurs in only two samples, S4-08 in the core and BB65 where they comprise 40 and 51 specimens respectively. They serve as excellent biostratigraphic markers.

Dimensions (μm): Growth series shown in Figure 7.2.

Specimen	**Length**	**Height**	**Width**
Carapace	787	380	275
Carapace	750	350	230
Carapace	650	362	225
Carapace	600	300	250
Valve	875	375	

Remarks: There are very few specimens, however, they represent another normal marine component occurring with *Shemonaella*, *Chamishaella*, and *Geisina* articulate juveniles. This species resembles *Youngiella rectidorsalis* reported by Dewey (1991) except for the tapering of both the anterior and posterior ends of the specimens from this study. Dewey and Fahraeus (1987) described a similar *Youngiellia* morphotype in the overlying Windsor Group. This morphotype is distinguishable from *Carbonita* by the short straight hinge with no dorsal swelling.

Order PODOCOPIDA Sars, 1866

Suborder indet.

Superfamily CARBONITACEA, Sohn, 1985

Family? CARBONITIDAE, Sohn, 1985

Genus ***Carbonita*** Strand, 1928

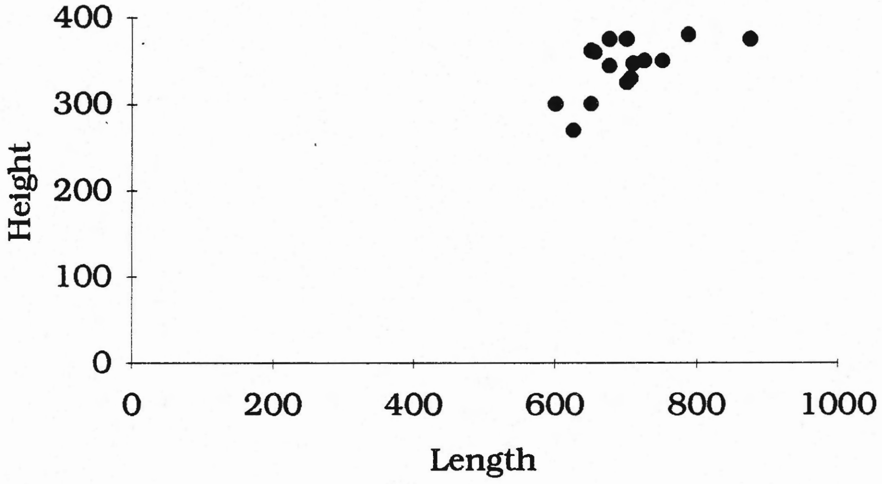


Figure 7.2 Growth series for *Youngiella sp.*.

Diagnosis: The diagnostic features of this genus were emended by Anderson (1970). In general the carapaces are small to medium size, smooth to finely punctate, and often display pitted surfaces. The hinges are generally straight to convex demonstrating dorsal swellings. Dimorphism is common. The right valve commonly overlaps the left along the venter and there is a calcified inner lamella. The anterior is usually more narrow and pointed with the greatest width just behind the center. The muscle scar if present is usually a circular adductor pit that encloses several small circular muscle scars. See Bless and Pollard (1973); Anderson, (1970); and Pollard, (1966).

Type Species: *Carbonia agnes* (Jones, 1870); designated by Bassler and Kellet, 1934, p. 237.

Stratigraphic Range: Tournaisian, Westphalian/Stephanian?, and Earliest Permian.

Remarks: The author follows the classification scheme of Sohn (1985) who erected the above superfamily and family names to encompass the genus *Carbonita* (Strand). Of the species identified, there are many in the Late Carboniferous of Nova Scotia, some of which have been examined by the author. These include *Carbonita altilus* from Westphalian strata of western Cape Breton Island and Joggins of the Cumberland Gp. Copeland (1957) reported many of these species which were included in the past revisions of this genus (Anderson, 1970; Bless and Pollard, 1973; Pollard, 1966).

Carbonita scalpellus (Jones and Kirkby)

Plate 4, Figs. 1-4

Carbonia scalpellus nov. sp. JONES and KIRKBY, 1879, p. 36, Pl. 3, figs. 14-17.
Carbonia subula JONES and KIRKBY 1879, p. 35., Pl. 3, figs, 9-13
Candona? elongata , JONES and KIRKBY, 1884, p. 361, Pl. 12, fig. 10.

Cythere? spp. indett., JONES and KIRKBY, p. 361, 1884, Pl. 12, fig. 11.
Carbonita subula (Jones and Kirkby).- BELL, 1960, p. 10, p. 119, Pl. 21, figs. 2,3,4,8, 9.- ANDERSON, 1970, p. 119 Pl. 18, figs. 78-80.
Carbonita scalpellus (Jones and Kirkby).- COPELAND, 1957, p. 73, fig. 10.- ANDERSON, 1970, p. 117 Pl. 27, figs. 71, 72.
Carbonita cf. *scalpellus* (Jones and Kirkby): BLESS and POLLARD, 1973, p. 33, text Fig. 7, Pl. 2, figs, 6-8.

Description: This species is characterised by a high length to height ratio. The equivalved elongate "scalpel shaped" carapace is smooth and thin with the greatest width in the anteromedian area. The dorsal margin is broadly convex while the ventral margin is gently concave. The left valve overlaps the right corresponding to the areas of maximum concavity just behind the median. The outer surface may be finely pitted. A narrow inner lamella surrounds the inner surface with the greatest thickness occurring along the ventral margin at the anterior and posterior ends. The hinge comprises approximately 2/3 the total length with a minor dorsal swelling. Some specimens have a distinct anterodorsal slope.

Occurrence: Horton Bluff Fm (Horton Gp), Cumberland, Mabou, and Morien Gp strata of the Maritimes Basin (Westphalian), and western European coal measures (Late Carboniferous).

Dimensions (µm): Growth series shown in Figure 7.3.

Specimen	**Length**	**Height**	**Width**
Valve	838	337	
Valve	708	312	
Female	900	375	300
Male	800	450	200
Juvenile	350	150	120

Remarks: *Carbonita scalpellus* is distinguishable from other Carbonitaceans by its elongate equivalved carapace and straight to concave ventral margin. The specimens of

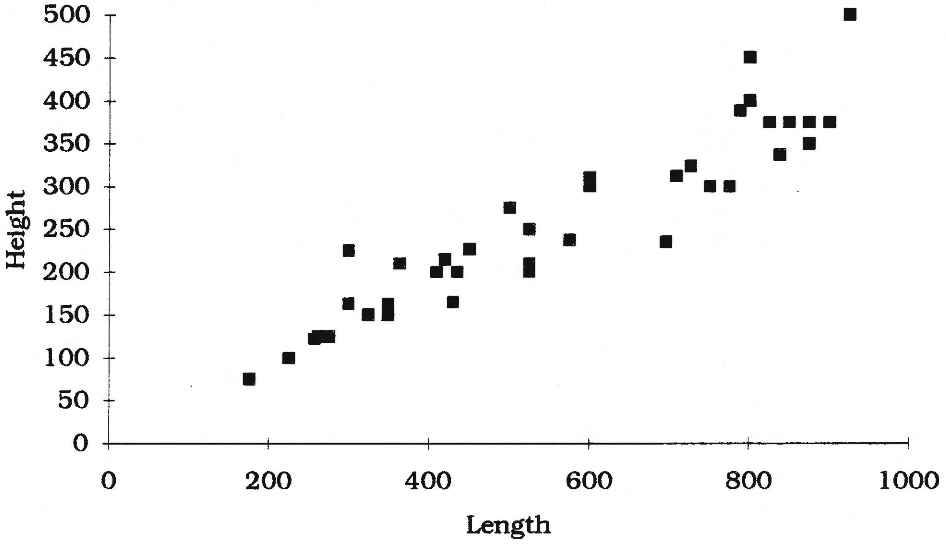


Figure 7.3 Growth series for *Carbonita scalpellus.*

this study appear to be slightly longer and thinner than those depicted by both Anderson (1970) and Bless and Pollard (1973). Bell (1960) noted the "nearly imperceptible" concave ventral margin and the medial adductor pits and absence of complete carapaces, reporting only calcite casts and internal molds. Both Bell (1960) and Anderson (1970) classified *C. scalpellus* as the notably smaller *C. subula* (Jones and Kirkby) reported by Latham (1933) from the Fife limestones and sandstones in Scotland. It is probable that these specimens were juveniles of the *C. scalpellus* or some other elongate Carbonitacean. Copeland (1957) notes that this species is larger than *C. rankiniana* and is equivalved.

Carbonita rankiniana (Jones and Kirkby, 1879)

Plate 5 Figs. 1-8

Cythere rankiniana JONES AND KIRKBY, 1867, p. 217 (reported only)
Carbonia rankiniana (JONES AND KIRKBY, 1879) p. 34, Pl. 3, figs. 1, 6, 7.
Carbonia salteriana JONES AND KIRKBY, 1890, p. 140, figs, 11, 12.
Candona salteriana (Jones and Kirkby).- COPELAND, 1957, p. 67, Pl. 1, fig. 4.
Carbonita rankiniana (Jones and Kirkby).- ANDERSON, 1970, p. 117, Pl. 17, figs. 61-63.
Carbonita salteriana (Jones and Kirkby).- ANDERSON, 1970, Pl. 17, figs. 61-69.
Carbonita aff. *salteriana* (Jones and Kirkby).- BLESS and POLLARD, 1973, p. 35, fig. 8, p. 47, Pl. 2, figs. 1-5.
Bairdiocypris sp. 2 sensu CRASQUIN, 1984, p. 350, Pl. 1, Fig. 4.

Description: The carapaces are oblong and small to medium in size. The dorsal margin is broadly convex with the hinge comprising approximately one third the total length. The sub-circular muscle pit is located in the mid-anterior. Adults have well-rounded anterior and posterior margins with the latter being more pronounced; juveniles demonstrate this even more so. The ventral margin may show a gentle concavity with left valve overlap and reversal common in mature specimens. The inner surface of the valves has a thin calcified inner lamella and is coarsely reticulate (pores spaces?).

Occurrence: Horton Bluff Fm (Horton Gp), Cumberland, Mabou, and Morien Gp strata of the Maritimes Basin (Westphalian); Fife limestones, Scotland; North Tyne, England; western European coal measures from Late Carboniferous: the Latest Mississipian strata from Virginia in the Appalachians of the United States; and the Russian Platform.

Dimensions (µm): Growth series shown in Figure 7.4.

Specimen	**Length**	**Height**	**Width**
Carapace	950	500	125
Carapace	825	425	125
Juvenile	550	325	75
Juvenile	375	175	100
Juvenile	275	162	125

Remarks: Specimens of this study resemble the descriptions given by Anderson (1970) for *Carbonita rankiniana* which occupy the same stratigraphical position in Scotland as the Horton Bluff Formation. Anderson's (1970) distinction between *Carbonita salteriana*, and *C. rankiniana* was based on simple variations between lateral outlines, specifically the more rounded anterior and posterior margins of the former. The author does not feel these differences warrant separate taxonomic designations. In light of this, the author also places *C. salteriana* from Bless and Pollard (1973) and Copeland (1957) in the synonymy. Bless and Pollard (1973) noted that *C. salteriana* has a slight concavity and the lower length to height ratio than other Carbonitaceans. Distinction between *C. rankiniana* and the morphologically similar *C. evelinae* are based almost solely on the presence of horizontal striations and the marked antero-dorsal slope of the latter. Robinson (1978) reported *Actiangulata aequalis* from Britain and noted its occurrence in brackish water shales in Russia, which occupy the same stratigraphic position as the ostracodes of this study. *Carbonita scalpellus* is recognisable from

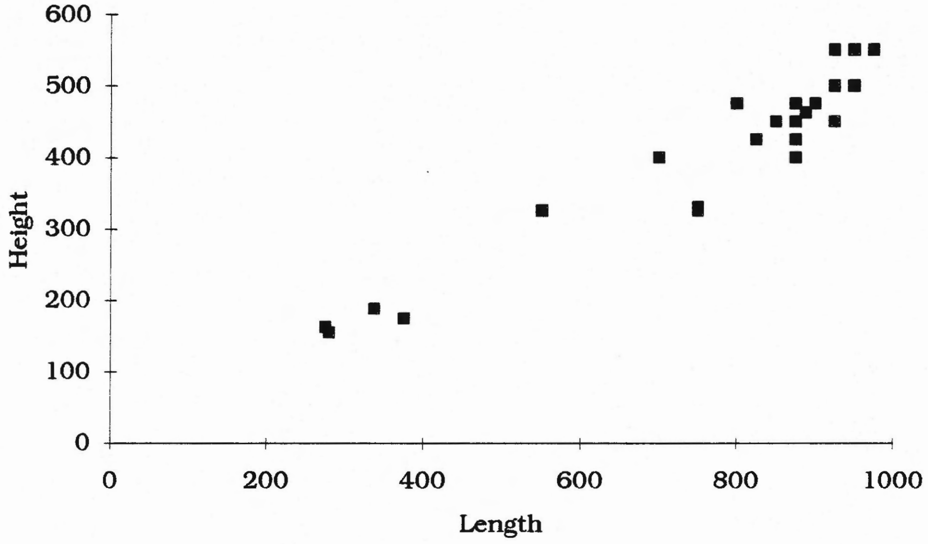


Figure 7.4 Growth series for *Carbonita rankiniana.*

C. rankiniana by its absence of dorsal swelling of the left valve, the lower length to height ratio, a more evenly rounded anterior, and a broadly rounded posterior.

Discussion: This species occurs exclusively with *Shemonaella scotoburdigalensis* and *Carbonita scalpellus* low in the sedimentary cycles. The specimens are articulate and well-preserved, demonstrating a poor growth series suggesting low energy biocoenosis. In Russia and Britain the similar morphotype *Actiangulata aequalis* it is considered to be a true brackish water genus (Robinson, 1978). Its association with Paraparchitaceans and post mortem *Carbonita scalpellus* favours a similar paleoecological interpretation for the specimens of this study.

Suborder PARAPARCHITICOPINA Gramm, 1975

Superfamily PARAPARCHITACEA Scott, 1959

Family PARAPARCHITIDAE Scott, 1959

Genus ***Shemonaella*** Sohn, 1971a

Diagnosis: These paraparchitaceans are distiguishable by their straight dorsal margin, and well-defined cardinal angles often flattened. The dorsal margin may be slightly swollen almost appearing incised. This swelling hides the diagnostic *Shemonaella* straight hinge. Dorsal swelling is not as prominent as is seen in the genus *Chamishaella*.

Type-species: *Shemonaella dutroi* Sohn, 1971a

Stratigraphic range: Middle Devonian to Pennsylvanian (mainly Tournaisian/Courceyan)

Shemonaella tatei (Jones)

Plate 7, Figs. 1-8

Beyrichia tatei JONES, 1864, no figure.
Bernix tatei (Jones).- JONES, 1884, Pl. 2, figs. 5, 6.- ROBINSON, 1969, Pl. 1-4.

Diagnosis: Elongate; slight overreach along the dorsal margins; gentle convex free margin; appears to have almost rounded cardinal areas but inner dorsal margin shows well-defined obtuse angles; bifurcating radial reticulate patterns on inner molds; distinct ovate central muscle scar and anteroventral mandibular scar.

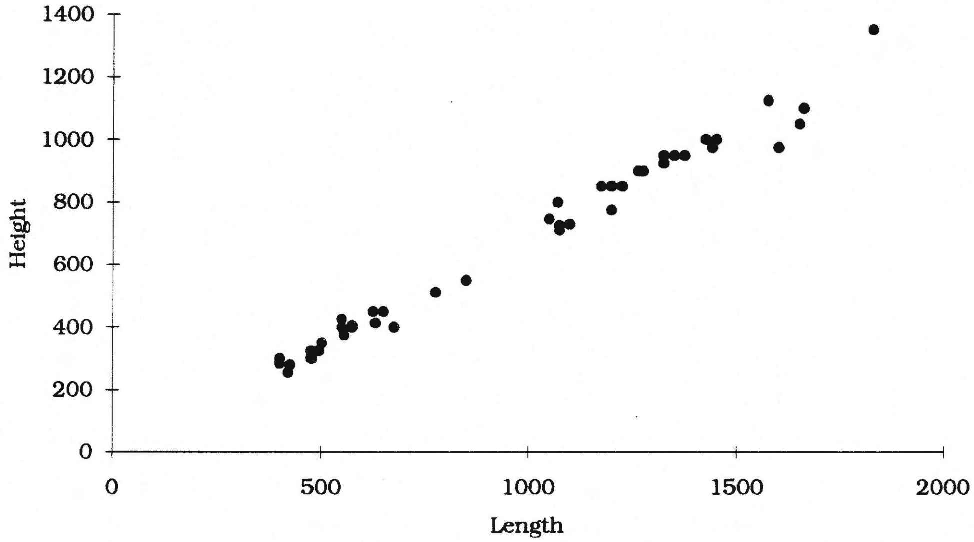
Description: This smooth, elongate, and equivalved ostracode carapace has a moderately large size. The straight dorsal margin has a slight overreach resembling an invagination or groove. The long adont hinge, approximately 3/4 of the total length, is shorter in the posterior. The cardinal angles are obtuse with the anterior being the largest. The greatest height is in the anterior, the greatest width is median. The medial adductor muscle scar comprises a series of crudely circular impressions (approximately 100) that form slightly elongate ovate patterns with the greatest width oriented upwards towards the anterior resembling the muscle scars depicted in the Treatise (Scott *cited in* Moore, 1961, page Q30 fig. 2). The crescent shaped mandibular scar lies obliquely below the adductor scar in the median/anterior region indicating the preplete nature of this species. The wide calcified inner lamella narrows posterodorsally. There are bifurcating patterns radiating away from the central adductor scar in a sinuous series of progressively smaller depressions almost resembling reticulation commonly seen on the outer carapace of many ostracode species. The smallest instars appear to have a convex dorsal margin that become less evident in the last instars and adults. Dimorphism is not immediately evident indicated by the width/length growth series, however, some adults appear to have slightly swollen anterior.

Occurrence: Tournaisian strata from the Maritimes and the Dinantian strata of Britain.

Dimensions (µm): Growth series shown in Figure 7.5.

Specimen	Length	Height	Width
Adult	1,825	1,350	752
Adult	1,100	730	507
Juvenile	900	375	300
Juvenile	550	425	240
Juvenile	425	280	150

Remarks: The major questions that arose from this commonly abundant species in the Fife limestone and oil shale series, first described by Jones (1884), was the almost polygonal network of pits on the molds of these specimens. Robinson (1969) discusses the taxonomic history of this particular species noting that the previous taxonomic uncertainties are likely due to these patterns on the casts. Because of the straight dorsal margin, large smooth carapace, and adductor and mandibular scars the author places this species in the genus *Shemonaella.*. Robinson (1969) and Sohn (1971a) postulated that *Bernix tatei* probably belonged to the Paraparchitacea. Sohn (1971b) describes *Shemonaella dutroi* from Upper Mississippian Brooks Range Alaska. The specimens of *S. tatei* from this study match the generic description given by Sohn (1971a, b) with the exception of the dorsal swelling. The major differences between *S. dutroi* and *S. tatei* are the absence of the well-preserved inner features. Further evaluation of the internal characteristics for *S. dutroi* may reveal its synonymy. *S. tatei* is distinguishable from *S. scotoburdigalensis* by the slight dorsal overreach or slightly



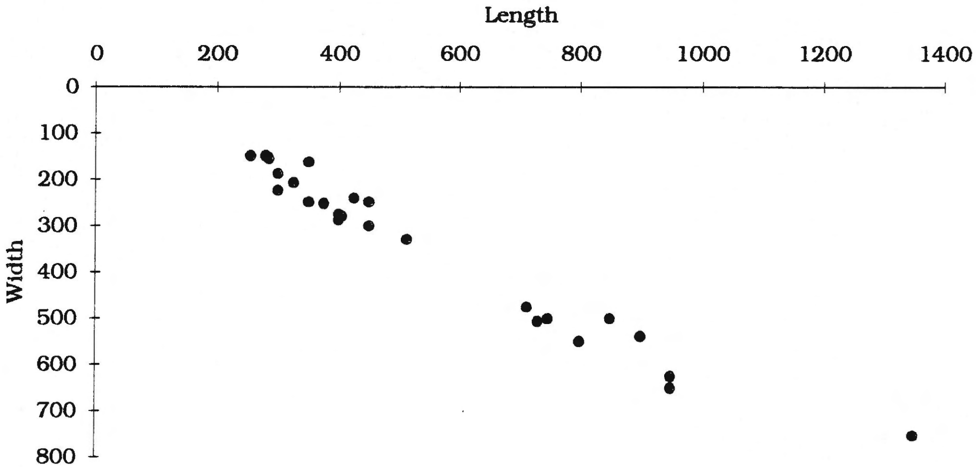


Figure 7.5 Growth series for *Shemonaella tatei.*

invaginated hinge area. Also, the cardinal angles are not as flattened as those observed for *S. scotoburdigalensis*. In general *S. tatei* is much smaller, thinner, and narrower than *S. scotoburdigalensis*.

Paleoecological Discussion: It is curious that the *Bernix tatei*, identified through out Tournaisian strata in northern England and Scotland, occur in cycles of coarsening-up shales where they dominate almost exclusively the total numbers, *Carbonita* being the only other genus of ostracode comprising at most 15 percent of the sample (Robinson, 1969). Robinson speculated that a oligotypic fauna could only represent a restricted brackish water environment. The associated fauna include *Lingula*, lamellibranchs, and palaeoniscid fish remains all associated with organic rich and true oil shale. Robinson (1969) notes that they usually occur within several meters below coal seams. The other ostracode assemblages in the Fife sediments contain abundant marine species associated with foraminifers. Given the resemblance of the assemblage A2 (a, b, and c) in this study, *S. tatei* probably represents a true marginal marine brackish organism and possibly even hypersaline, indicated by the exclusion of most other marine and fresh water euryhaline forms in quiescent, shallow, and isolated ponds at the bay margins.

Shemonaella scotoburdigalensis (Hibbert)

Plate 8, Figs. 1-6

Cypris scotoburdigalensis HIBBERT, 1836, p. 179.
Leperditia okeni var. *scotoburdigalensis* (Hibbert).- JONES and KIRKBY, 1884, p. 357, Pl. 12, figs. 1, 2.
Leperditia okeni (Munster).- JONES and KIRKBY, 1884, p. 356, Pl. 12, fig. 3.- JONES and KIRKBY in Dawson, 1896, p. 318, fig. 1.- JONES and KIRKBY, 1898, p. 202, Pl. 11, figs. 8-10.
Leperditia scotoburdigalensis (Hibbert).- JONES and KIRKBY, 1898, p. 203, Pl. 11, fig. 12.
Paraparchites scotoburdigalensis (Hibbert) LATHAM, 1933, p. 354, fig. 2.- COPELAND, fig. 3-3.1957, p. 73, Pl. 4, fig. 5

Limnoprimitia ? hortonensis nov. sp. BELL, 1960, Pl. 19, figs. 1-8.
Shemonaella scotoburdigalensis (Hibbert).- ROBINSON, 1978, p. 149, Pl. 10, fig. 4a, b.- DEWEY, 1983, Pl. 15, figs. 1, 2.- DEWEY and FAHRAEUS, 1987, Pl. 7, figs. 4, 5.- DEWEY, 1993, p. 85,
Shemonaella sp. CRASQUIN, 1984, Pl. 1, fig. 8.

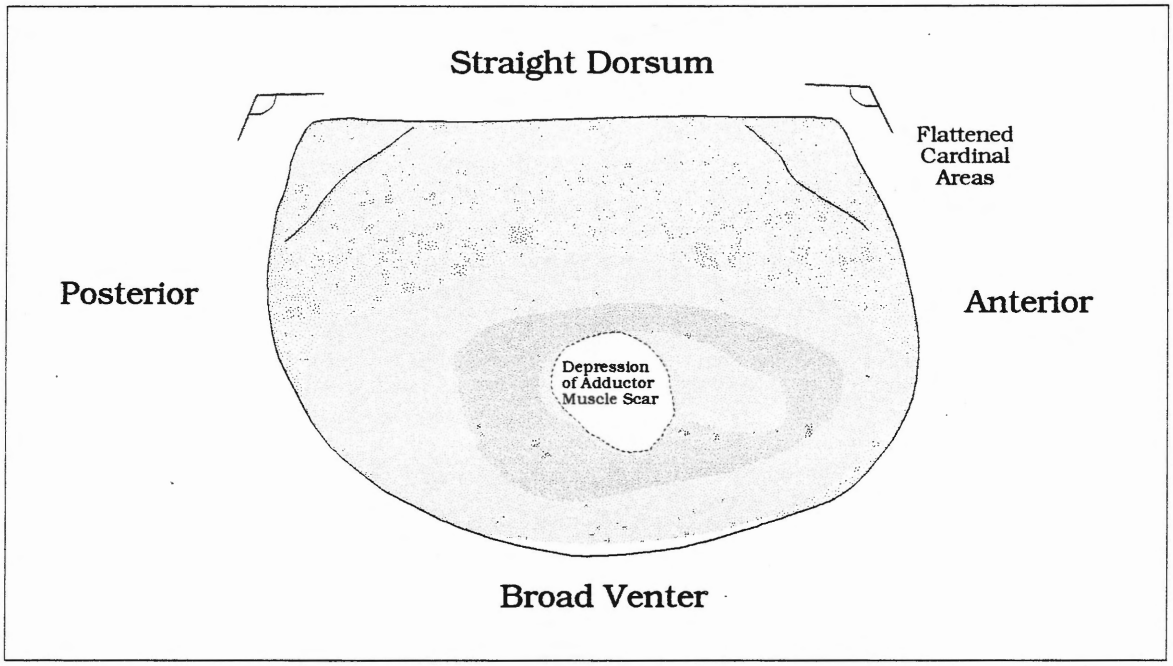
Description: *Shemonaella scotoburdigalensis* is easily recognised by its large smooth carapace, long straight dorsal margin, flattened cardinal areas where the angles are obtuse (the anterior more so), and a wide calcified inner lamella around the entire free margin (Fig. 7.6). The greatest height and width are medial. The adductoral pit is in the median area and comprises a series of circular pits agglomerated into a subcircular pattern. The mandibular scar occurs below and to the anterior of the adductor. Dimorphism is present with females demonstrating anteroventral swelling. Juveniles do not develop swelling and are more subcircular.

Occurrence: Horton Bluff Fm, Cultra Ireland, Mabou Gp N.S., Windsor and Codroy Groups of Nova Scotia and Newfoundland, Fife, Peel Burn, Deadwater, North Tyne, and Northumberland of Northern England and Scotland.

Dimensions (μm): Growth series shown in Figure 7.7.

Specimen	**Length**	**Height**	**Width**
Cara[ace	3,250	2,250	1,550
Carapace	2,700	1,975	1,350
Male	2,900	2,350	1,050
Juvenile	660	497	305
Juvenile	480	375	350

Remarks: This species is by far the most abundant in the Horton Bluff Fm. Most of the carapaces are disarticulated but are in good condition suggesting week hingement. Given the abundance of this marine species in the Dinantian of the Northern British Isles it is conceivable that a follow-up study would reveal a biostratigraphic correlation.



Shemonaella scotoburdigalensis

Figure 7.6 The diagnostic characteristics for *Shemonaella scotoburdigalensis*.

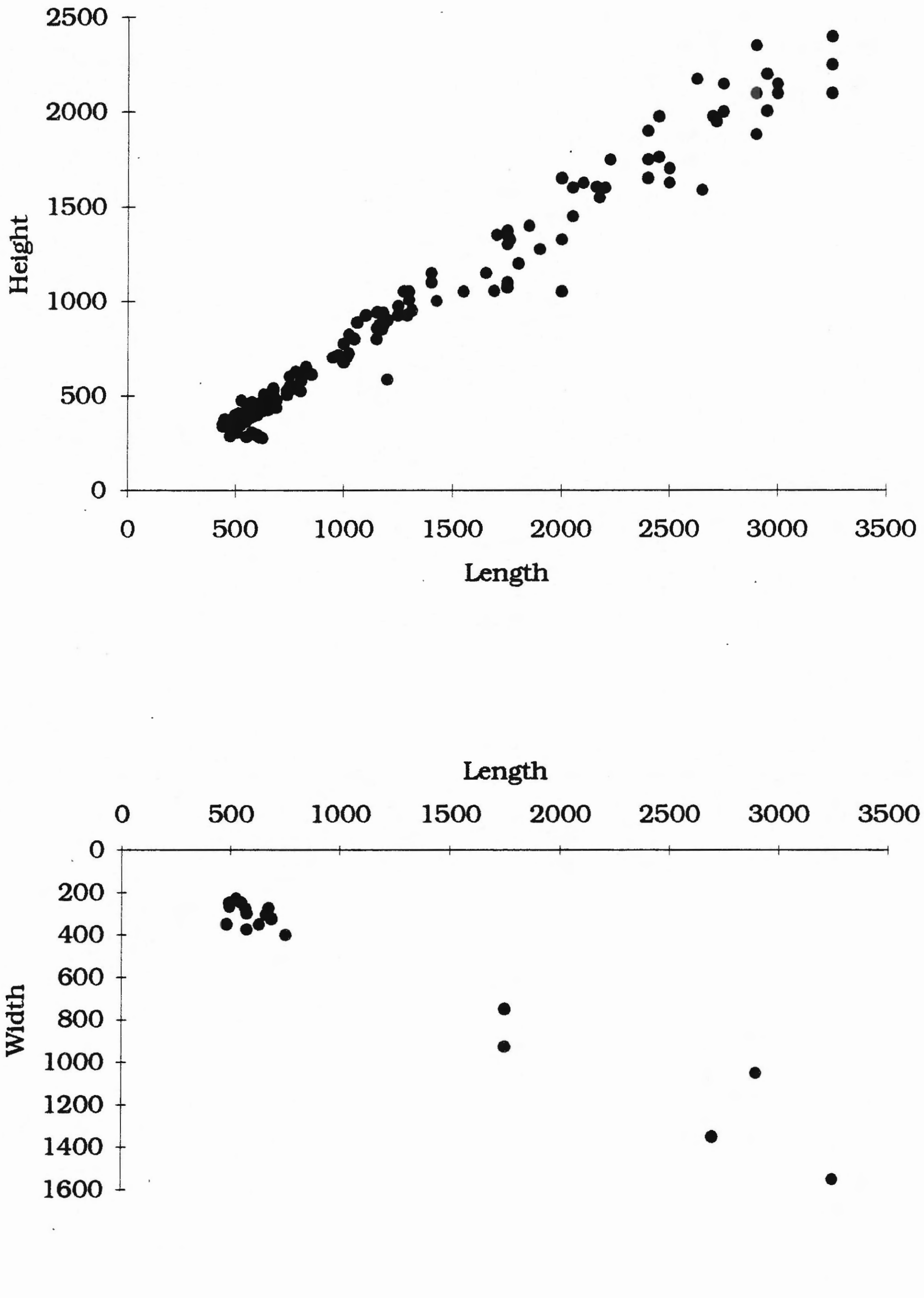


Figure 7.7 Growth series for *Shemonaella scotoburdigalensis.*

Genus ***Chamishaella*** Sohn, 1971

Diagnosis: See Dewey and Fahraeus, 1987

Type-species: *Chamishaella brosgei* Sohn, 1971

Stratigraphic Range: Tournaisian to Visean

Chamishaella sp.

Plate 9, Figs. 1-6

Diagnosis: Large smooth subovate to subcircular carapace; thin with no observable dimorphism; prominent dorsal swelling with overreach of the smaller left valve; the right valve overlaps the left along the ventral margins; hinge straight to slightly convex; cardinal angles are obtuse with the posterior the larger of the two; posterior margin more broadly curved; juveniles are more sub-circular in lateral outline and do not display the prominent dorsal swelling and ventral overlap.

Description: In general this species appears almost flattened in comparison with others of the same genus. The carapace is somewhat thinner than most Paraparchitacea, specifically *Shemonaella scotoburdigalensis* of which this species is commonly associated with. More importantly, *Chamishaella sp.* occurs frequently with the thinner, more elongate *Shemonaella tatei*, suggesting they have similar affinities; they both occur in muddy shales comprising over 90% of the total numbers in an assemblage. The thinner shells may reflect rapid fluctuations in either hypo or hypersalinity. There is a complete instar succession where most of the valves are articulate, although they are somewhat laterally compressed suggesting a low energy biocoenosis.

Occurrence: Tournaisian strata of the Horton Bluff Formation Nova Scotia

Dimensions (µm): Growth series shown in Figure 7.8.

Specimen	**Length**	**Height**	**Width**
Valve	2,500	1,575	
Male	1,878	1,400	255
Female	1,715	1,075	425
Valve	812	587	
Juvenile	375	266	212

Remarks: After a careful review of the literature the author cannot determine the specific name to which this ostracode belongs. This new species is placed in the genus *Chamishaella* because is a large smooth paraparchitacean lacking spines and the right valve overreaches the left via a prominent dorsal swelling. One valve overlaps the other along the free margin. This species differs from both *Chamishaella suboriculata* (Dewey and Lahraeus, 1987) and *Chamishaella brosgei* (Sohn, 1971a) as it is more elongate, thinner, and has a more prominent dorsal swelling in the adults.

Genus ***Paraparchites*** Ulrich and Bassler, 1906

Diagnosis: see Sohn, 1971a

Type-species: *Paraparchites humerosus* Ulrich and Bassler, 1906

Stratigraphic Range: Devonian to Permian

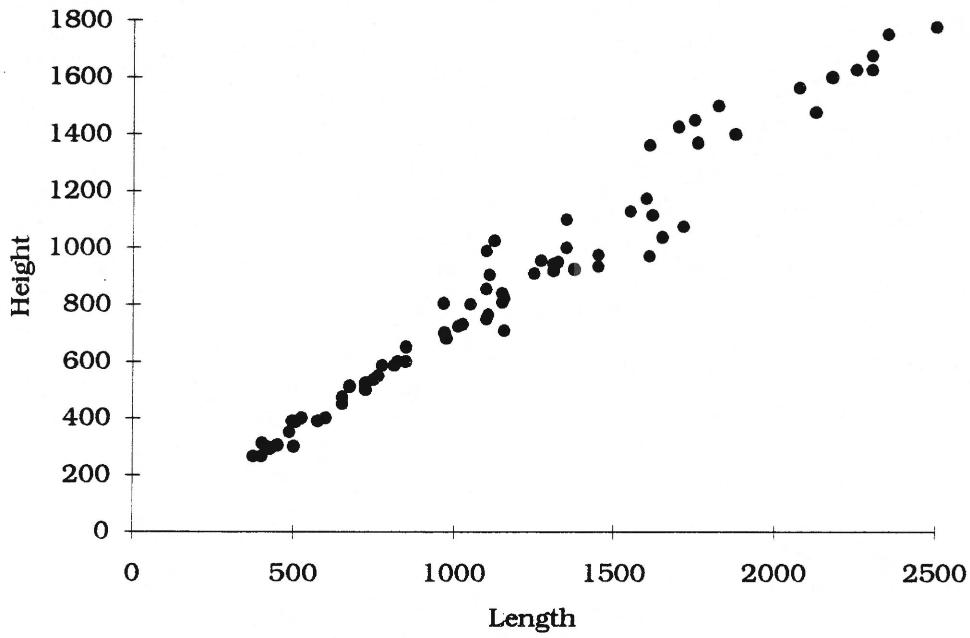


Figure 7.8 Growth series for *Chamishaella sp.*.

Paraparchites sp.

Description: Given the size and smooth thick carapace, this species is included with the paraparchitaceans. The specimens have high length to height ratio. The ventral margin is gently convex. There appears to be a calcified inner lamella characteristic of paraparchitaceans. Only a few broken specimens were recovered.

Remarks: Further work on these specimens will undoubtedly result in their proper taxonomic position in the Paraparchitididae.

Paraparchitacean #1

Plate 10, Fig. 4, 7

Description: A subovate to subcircular carapace with a broad ventral margin. There are 3 to 4 vertical furrows along the venter.

Remarks: Only a few incomplete specimens were found associated with other Paraparchitaceans. The outline resembles that of either *Shemonaella* or *Chamishaella*. Several complete specimens would be required to either designate or erect a generic and specific name.

Suborder BAIRDIOCOPINA Grundel, 1967

Superfamily BAIRDIACEA Sars, 1888

Family BAIRDIIDAE Sars, 1888

Subfamily BAIRDIINAE Sars, 1888

Genus ***Bairdia*** McCoy, 1844

Diagnosis: see Sohn, 1954

Type-species: *Bairdia curtis* McCoy, 1844

Stratigraphic Range: Ordovician to Recent

Bairdia pruniseminata (Sohn)

Plate 10, Figs. 1, 2

Bairdia? pruniseminata nov. sp. SOHN, 1954, p. 4., Figs. 1a-d, Pl. 1, Figs 1-7.

Description: Most of the 50 specimens are steinkerns making specific designation difficult. The diagnostic feature of this species is the convex broadly arched dorsal margin that becomes concave terminally especially the posterior. The venter is straight in middle portions of the carapace but has a broadly rounded anterior. The juveniles lack a well-developed terminal concavity. The specimens from Blue Beach are generally smooth and small with most specimens approximately 650 µm long and 475 µm in height. They are most commonly associated with *Copelandella sp.* low in the cycles at Blue Beach in the black shales and siltstones (33 specimens). They are relatively abundant (16 specimens) in sample S4-08 from the Saarberg Core.

Occurrence: Horton Bluff Formation, Nova Scotia and the Permian of Texas.

Dimensions: Length: 650 µm; Height: 475 µm; Width: undetermined

Remarks: Sohn (1954) provided a sketch of 4 instars of which both shape and size resemble the specimens from the BBM, specifically in figures 1a and 1b (two early instars). Sohn (1954) notes that the short carapace restricts designation of this species to the genus *Bairdia* which are typically longer and thinner. However, given the classic "bairdian" outline of the juvenile specimens the author feels this species belongs to the designated genus. The majority of the Blue Beach bairdiaceans appear somewhat smaller and may represent juveniles not fully developed. Because the fossils are mostly steinkerns, they have probably been reworked destroying the finer characteristics of the carapaces. Although Jones and Kirkby (1896) do not figure any of the specimens of *Bairdia sp.* from Ireland, they refer to them as acute/ovate, short, and thick. Latham (1933) refers to Jones and Kirkby (1867) and provides a similar description for *Bairdia sp.* from both the Calciferous Sandstone Series and Lower Limestone Series in Carboniferous strata in Scotland. Dawson (1868) depicted a specimen from Joggins, Nova Scotia that vaguely resembles those of this study and notes the similarity to *Bairdia*, however, this family has not been formally identified in Horton strata to date. Its occurrence is significant as it is generally considered a family of normal marine affinities. The bairdiacean family is the longest ranging ostracode genus ranging from Ordovician to Recent (Benson et al, 1961).

Genus ***Bairdiacypris*** Bradfield, 1935

Diagnosis: see Bradfield, 1935

Type-species: *Bairdiacypris deloi* Bradfield, 1935

Stratigraphic Range: Devonian to Permian

Bairdiacypris striatiformis Dewey and Fahraeus

Plate 4, Figs. 5-7

Bairdiacypris striatiformis nov. sp. DEWEY and FAHRAEUS, 1987, Pl. 4, figs. 5-9.

Description: An elongate subovate striated carapace with an acutely pointed anterior and a blunt posterior. The dorsal margin is moderately arched with the ventral margin slightly less convex.

Occurrence: The Horton Bluff Fm of this study, and the Codroy Gp of the Port au Port Peninsula, western Newfoundland.

Dimensions: Length: 750 µm; Height: 600 µm

Remarks: This species was reported as *Actiangulata* nov. sp. by Dewey (1983) in his doctoral thesis. Dewey and Fahraeus (1987) established this "trapezoidal" species of bairdiacean based on its small size, shape, striations, and steep posterodorsal slope. Only a few poorly preserved specimens were extracted associated with *Shemonaella spp.*, *Chamishaella sp.*, *Copelandella novascotica*, *Geisina sp.*, and *Bairdia pruniseminata* suggesting this species preferred moderate hydrologic energy and near normal or slighlty brackish salinity.

Order PLATYCOPIDA Sars, 1866

Suborder KLOEDENELLOCOPINA Scott, 1961

Superfamily KLOEDENELLACEA Ulrich and Bassler, 1908

Family KLOEDENELLIDAE Ulrich and Bassler, 1908

Genus ***Geisina*** Johnson, 1936

Diagnosis: See Johnson, 1936

Type-species: *Jonesina gregaria* Ulrich and Bassler, 1906

Stratigraphic range: Devonian-Permian

Geisina sp. Dewey and Fahraeus

Plate 3, Figs. 5-8

Geisina sp. DEWEY and FAHRAEUS, 1987, p. 105, Textfig. 14, Pl. 5, figs. 1-3.

Description: The anterior is inflated, the posterior is compressed, and there is a medial "pinch" evident in dorsal view. The subquadrate unequivalved carapace displays a distinct reticulation. Cardinal angles are rounded and the posterior has a sharp taper. Instars are more quadrate in outline and generally less swollen. There is a distinct kloenedellid dimorphism; heteromorphs have a swollen anterior lobe and tecnomorphs are more elongate and the lobation is not as pronounced. An incomplete growth series demonstrates the variability of height between the males (shorter) and females. The anterior right lateral lobe is located in the dorsal regions extending slightly over the left valve. The adductoral sulcus is located medially and separates the anterior from the less pronounced mid posterior sulcus. Right valve overlaps left. with wide ventral overlap more pronounced in the anterior.

Occurrence: Restricted to a 40 specimens in the Saarberg core near Falmouth (S4-08). Occurs in the overlying Windsor Group, Nova Scotia.

Dimensions (µm): Growth series shown in Figure 7.9.

Specimen	**Length**	**Height**	**Width**
Female	900	575	425
Female	925	550	375
Male	775	375	350
Juvenile	650	400	275
Juvenile	450	288	107

Remarks: Dewey and Fahraeus (1987) present a new unnamed species of *Geisina* which demonstrates a prominent anterior swelling and flattened posterior most closely matching the specimens of this study. The author feels the many Sansabellid Kloedenellaceans may belong to the designated genus *Geisna.* The genera of *Sansabella* resemble Geisinid forms, however, because of the apparent reversal of overlap numerous authors cited have placed morphologically similar taxa in the Sansabellidae family. Morey's (1935) description of *Sansabella duboi* is analogous with the specimens of this study except for the slight overlap on the free edges and absent reticulation. Sohn (1975) questions the generic emplacement of *Sansabella? duboi* by Morey (1935) because of the lateral outline and the lack of indentation along the dorsal margin both evident in *Geisina sp* from Blue Beach. Sohn (1975) also pointed out that *Sansabella* is restricted to the Pennsylvanian. *Geisina,* on the other hand, has been documented in Devonian deposits, which is in agreement with its occurrence in the Tournaisian strata of the Horton Bluff Formation. McGill (1963) placed *Hypotetragona albertensis* in the Geisinidae family and the author feels the distinct reticulated carapaces, lobation, and lateral outline of *H. albertensis* resembles the specimens of this study.

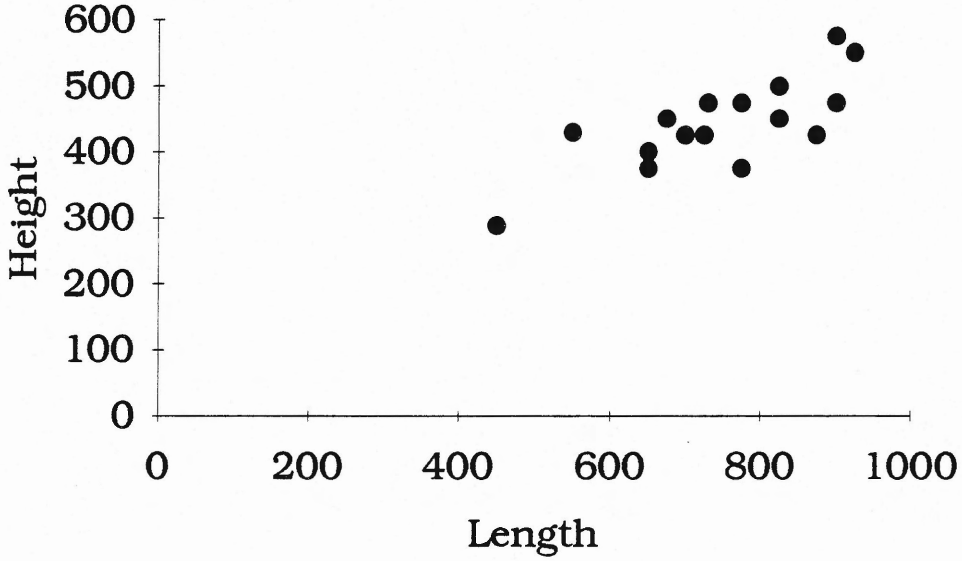


Figure 7.9 Growth series for *Geisina sp.*.

Family CYTHERELLIDAE Sars, 1866

Subfamily CAVELLININAE Egorov, 1950

Genus ***Cavellina*** Coryell, 1928

Diagnosis: See Coryell, 1928

Type Species: *Cavellina pulchella* nov. sp. Coryell, 1928

Range: Devonian-Permian?

Remarks: This genus is exclusively marine, however, its common association with paraparchitaceans and other low salinity indicators suggests a brackish water affinity.

Cavellina lovatica? (Zaspelova)

Plate 6, Figs. 1-8

Cavellina lovatica ZASPELOVA, 1959.- GRAMM, 1972, p. 267, fig. 1.

Description: A short "stubby" carapace with the greatest height in the swollen posterior. The right valve overlaps the left. The dorsal margin is broadly convex and more rounded at the posterior while the ventral margin is straight to gently concave. A dorsal stragular process is evident just past the median towards the anterior. The anterior end is more tapered. The surface is finely reticulate or punctate. Dorsal and ventral views demonstrate the "wedge" shape of the carapace and the right valve overlap along the ventral margin. The inner lamella is narrow and extends around the entire free margin. A small sub-central pit on the external surface indicates the position of adductor muscle scar. Sparse adult females demonstrate posterior swelling forming a brood pouch. A limen is evident on the internal surface. Males are more elongate and flattened. The right ventral inner lamella demonstrates a slight medial thickening. Instars are flattened, more oblong, and display distinct punctation.

Occurrence: Tournaisian strata of Nova Scotia, Britain, and Russia.

Dimensions (µm): Growth series shown in Figure 7.10. Note the scarcity of adult specimens.

Specimen	**Length**	**Height**	**Width**
Female	625	337	250
Male	650	400	162
Female	687	400	325
Male	312	187	88
Juvenile	125	75	

Remarks: The identifying characteristic for the Cytherellidae family is an inner partition (limen) an interior ridge that forms the anterior boundary of the brood chamber (Adamczak, 1991). As a result of this inner partition, Adamczak (1991) places this family in the Kloedenellacean superfamily. These features can be seen on the internal surface as two distinct depressions or via horizontal thin sections. Plate 6, Figure 2 demonstrates the inner surface of a male specimen which clearly displays no depressions, however, this would be expected in most ostracode tecnomorphs. Distinct brood pouches are seen on some of the sparse adult female specimens not figured.

Cavellina lovatica (Zaspelova *in* Gramm, 1975, Fig. 1), resembles perfectly the species in question here as indicated by the central adductor muscle scar, lateral outline, right valve overlap, and posterior swelling in the females. Also, this species occurs in Latest Devonian/Earliest Carboniferous marine strata which is in agreement with the stratigraphic position of the BBM.

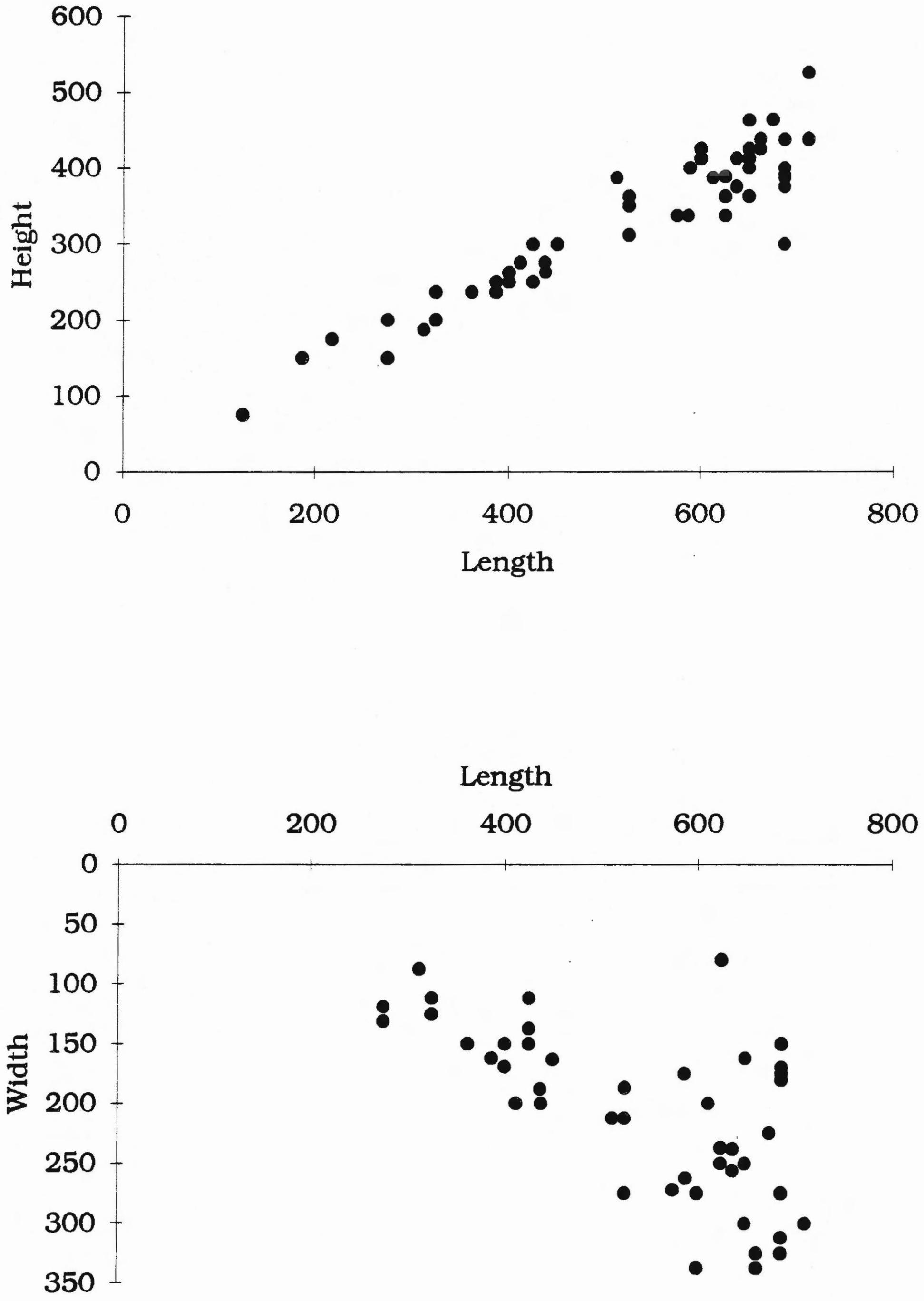


Figure 7.10 Growth series for *Cavellina lovatica?*.

Evolutionary Discussion: *Cavellina* belongs to the Platycope ostracode Family Cavellinidae, a well-documented Paleozoic ostracode documented from Devonian and Carboniferous strata in North America, Russia and western Europe (McGill, 1963; Kellet, 1936; Gramm, 1972; Sohn, 1975; Robinson, 1978; Bless, 1983; Gramm, 1985; Dewey and Fahraeus, 1987). Recent studies yield some interesting aspects of Cavellinid ostracode evolution worthy of mention here.

Muscle Scars: Gramm (1985) demonstrated that the muscle scar pattern in early Cavellinids formed an aggregate in a circular pit, similar to those depicted for the Carbonitaceans (Sohn, 1985). By the late Paleozoic the patterns changed to more ordered biserial to multiserial (distinct vertical rows) patterns similar to Mesozoic Cytherellids. Gramm (1985) suggests these phenotypic changes provide evidence that modern Cytherellids are ancestors of the Cavellinids.

Brood Pouches: Gramm (1972) described *Cavellina lovatica* (Zaspelova) from uppermost Devonian of the Russian Platform. The female specimens of this study contain approximately 24 eggs within the brood pouch resembling modern representative *Cytherella spp.* of the same super family (Gramm, 1972). The modern representatives usually produce up to four eggs. Gramm (1972) suggested there was a evolutionary change in brood rearing, possibly in response to changing ecological parameters. In any event, the brooding of young in modern and ancient ostracodes are a reproductive strategy required to ensure success of a species in stressed environments.

CHAPTER 8 CONCLUSIONS

8.1 INTRODUCTION

This section chapter summarises and clearly states the main conclusions of this study. The final section provides a closing statement concerning ostracode and foraminiferal studies.

8.2 RESULTS

8.2.1 Sedimentology

The sedimentary facies comprise cyclic asymmetrical shallowing-up packages that generally increase in frequency up section. These facies are defined in ascending order as follows:

1. Black shale with an organic content of less than 1% that contains glaucony grains and framboidal pyrite. Fossils comprise ostracodes, serpulid worms, palaeoniscid fish, and foraminifera. This facies is interpreted as a below wave base profundal zone of a low oxygen quiescent lagoon.

2. Alternating siltstone and sandstone where hummocky cross-stratification is common. Fossils include ostracodes representing thanatocoenosis. This facies is interpreted as the littoral zone of the lagoon where higher energies cause traction suspension and wave base bottom interactions.

3. Bi-directional wave-rippled sandstone with flasers, and, clay drapes. Fossils include the ichnogenera., *Skolithos* and *Palaeophycus*, and agglutinated foraminifera, mainly

Trochammina. This facies is interpreted as the waning episodes of an attenuated shoreline.

4. Microcrystalline penecontemporaneous dololutite that contains sparse root traces and fish scales. Tabular beds formed in the subsurface below the shallow water sediment interface. In contrast, nodular dolostones formed in the vadose zone of the fluctuating shoreline.

5. Carbonate mudstones that are pedogenic in origin. Plant detritus and foraminifera indicate the proximity to a terrestrial source but on the outer fringes of the shallow marine embayment.

8.2.2 Faunal Assemblages

The 8,818 ostracodes and 431 arenaceous foraminifera can be divided into five fossil assemblages indicative of specific environmental conditions. These are as follows:

1. Shallow brackish/marine comprised mainly of the spinose lobate beyrichiacean *Copelandella novascotica* which demonstrates brood rearing of their young indicative of an opportunist in an unstable environment. The associated glaucony grains indicate the marine affinities of *C. novascotica.* The reticulate and spinose nature of *Copelandella novascotica* suggests current activity. This ostracode is also associated with pyritic black shale containing articulate palaeoniscid fish. Foraminifera identified in this assemblage include *Trochammina*, *Ammobaculites*, and *Ammotium.* The allochthonous low salinity ostracode *Carbonita* indicates the proximity to a terrestrial source. This assemblages represents the stagnant lagoon during the acme of marine transgression.

2. The restricted nearshore is characterised by paraparchitaceans and high energy indicators. There are three subassemblages. The brackish littoral nearshore is dominated by *Shemonaella scotoburdigalensis* and the allochthonous *Carbonita scalpellus* and *Carbonita rankiniana*. *Copelandella novascotica*, *Chamishaella sp.*, and *Bairdia pruniseminata* are common. Foraminifera include *Trochammina* and *Ammobaculites*. Hummocky cross-stratification is the dominant sedimentary feature. The 2nd subassemblage differs in that it has a high proportion of articulate juveniles of the marine ostracode *Cavellina lovatica?* representing a pathological thanatocoenosis. The third hypersaline subassemblage is characterised by the smaller, thinner shelled paraparchitacean biotypes *Shemonaella tatei* and *Chamishaella*. The paraparchitacean subassemblages represent the rapidly fluctuating physical and chemical parameters in the shallower areas of the lagoon.

3. The upper estuarine assemblage (low salinity) comprises the morphologically similar carbonitaceans, *Carbonita scalpellus* and *Carbonita rankiniana*. The associated paraparchitaceans, bairdiaceans, and *Copelandella novascotica* indicate an adjacent marine/brackish system. In addition to the in situ plant, *Lepidodendrosis*, the marsh foraminifera *Trochammina*, coiled worm *Spirorbis*, and palaeoniscid fish are all locally abundant. Secondary pyrite, desiccation cracks, and pedogenic structures within the carbonate mudstones indicate the shallow nature of the ponds.

4. The stable marine assemblage, the most diverse of the deposit, occurs exclusively in the Saarberg Core in a glaucony rich shale zone. The ostracodes in relative decreasing abundance include: *Chamishaella sp.*, *Shemonaella tatei*, *Youngiella sp.*, *Bairdia pruniseminata*, *Geisina sp.*, and several abraded valves of *Carbonita scalpellus*. The specimens are morphologically small in comparison with those from the coastal section and most carapaces are articulate demonstrating an incomplete growth series where

adults are sparse. The ostracodes accumulated from suspension as a low energy thanatocoenosis. This assemblage represents the distal end of the lagoon mouth where water depths were in excess of 60 m and water chemistry was of a near normal marine consistency at the onset of the transgression.

5. The infringing marsh occurs in silty mudstones associated with desiccation cracks and insitu plants. *Trochammina* predominates and ostracodes include only sparsely distributed carbonitaceans. Tetrapod trackways are exclusive to this assemblage. This assemblage increases in frequency up section. This fossil association represents shallow ponding along the perimeter of the isolated proximal lagoon.

8.3 ENVIRONMENT OF DEPOSITION

The sedimentary features, fossil assemblages, and cyclic nature of the deposit resemble modern and ancient lagoonal embayments. Conditions were relatively unstable at the proximal areas where only opportunistic, faster breeding, brood rearing ostracodes could survive. The deeper areas of the lagoon were more stable, restricted in nature, and short lived. The marsh areas were inhabited by tolerant agglutinated foraminifera that have modern representatives in paralic marsh settings.

8.4 CLOSING STATEMENT

Even after two years of research leading to this thesis, the taxonomic designations of several of the specimens are not completed. This is inevitable as more information comes to light. The literature is immense and there are many synonymies for a given species. Taxonomic problems aside, the strength of these microfossils is their large numbers. Growth series (ontogenetic changes) and the nature of the sample either transported or in situ must be carefully considered prior to interpretation. Unfortunately, this entails much detailed measuring and counting. Nonetheless, if these methodological intricacies are not embraced, paleoecological errors will undoubtedly occur as is so evident in the past.

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PLATE I

Figures 1, 5. *Trochammina sp.* ventral view of the agglutinated test.

Figure 2. *Trochammina sp.* dorsal view demonstrating trochospiral form.

Figure 3. *Trochammina sp.* ventral view showing 6 well-defined chambers.

Figure 4. *Trochammina sp.* ventral view of pyritized test. Note the euhedral pyrite crystals on the last chamber.

Figure 6. *Trochammina sp.* ventral view at a 30 degree angle demonstrating the central depression.

Figures 7. *Ammotium sp.* poorly preserved showing loose coil and large final chamber.

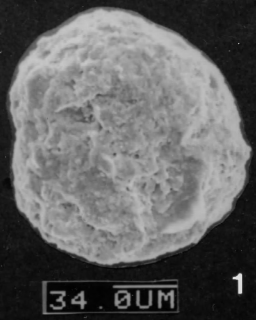
Figure 8, 10. *Ammobaculites sp.* poorly preserved showing small coil and extended apertural neck.

Figure 9. Difflugid thecamoebian demonstrating elongate sac-like shape resembling the modern *Difflugia.*

Figure 11. *Ammodiscus sp.* showing the planispiral single chamber.

Figure 12. Spherical thecamoebian showing an arenaceous test with aperture resembling the modern *Centropyxis.*

Plate I



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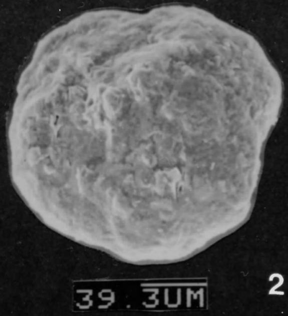

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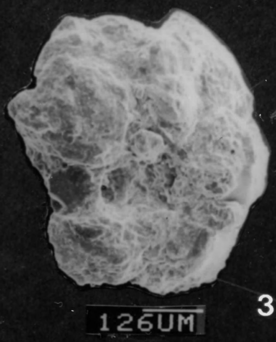

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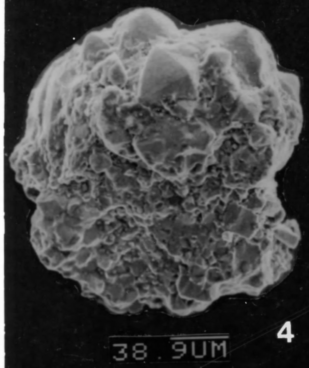

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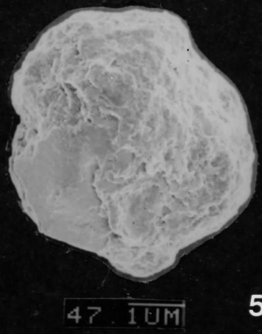

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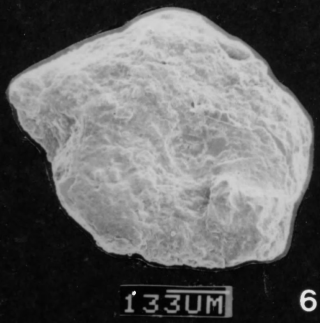

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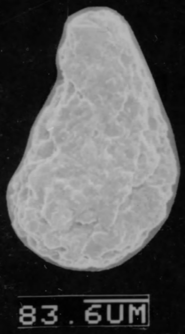

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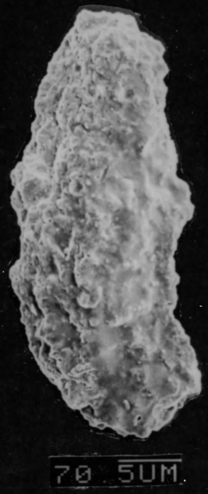

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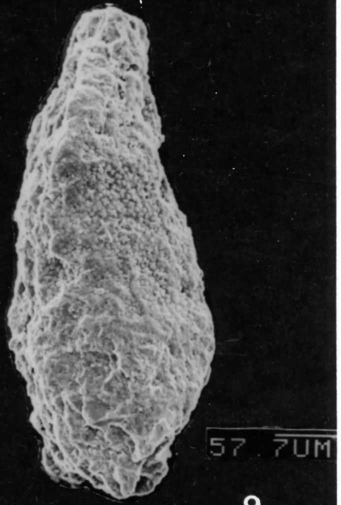

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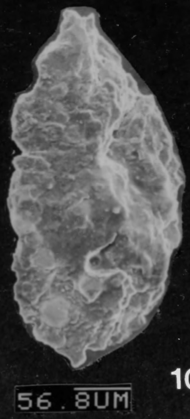

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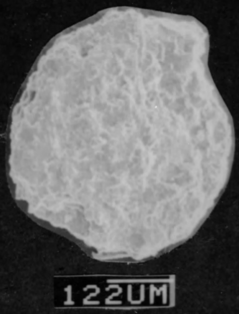

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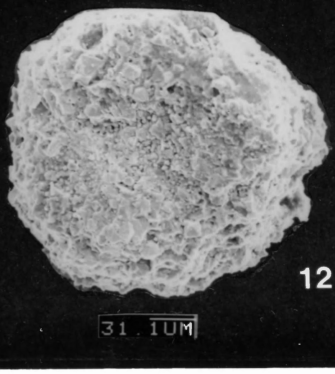

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PLATE II

Figures 1, 3. *Copelandella novascotica* right aspects of adult females demonstrating lobation, reticulation, and the posterior spines. Note the velate frill on figure 3.

Figure 2. *Copelandella novascotica* left aspect of adult female.

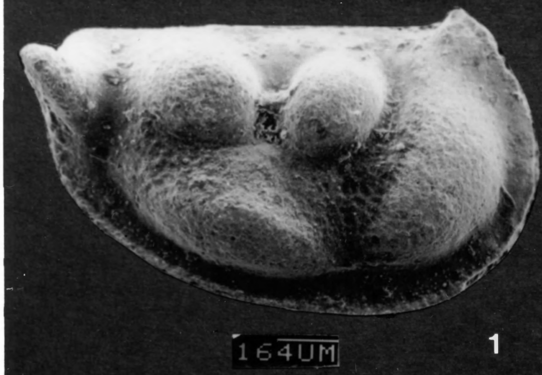
Figure 4. *Copelandella novascotica* juvenile showing reticulation and poorly developed lobation. Note the posterior spine is well-developed at this stage of development.

Figure 5, 6. *Copelandella novascotica* juvenile dorsal and ventral aspects respectively. Note the velate ridges in figure 6.

Figure 7. Early instar of *Copelandella novascotica.*

Figure 8. Calcareous reticulate sphere thought to the egg of *Copelandella novascotica.* These spheres were observed in thin section within the anterior cruminae.

Plate II



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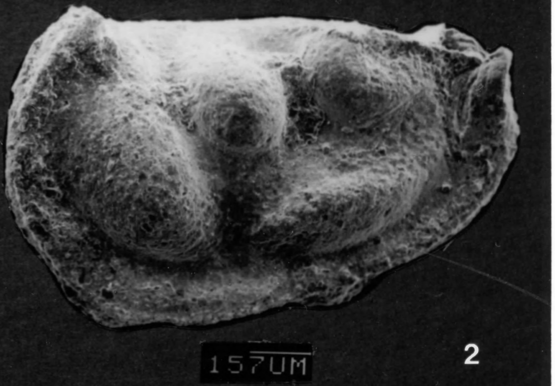

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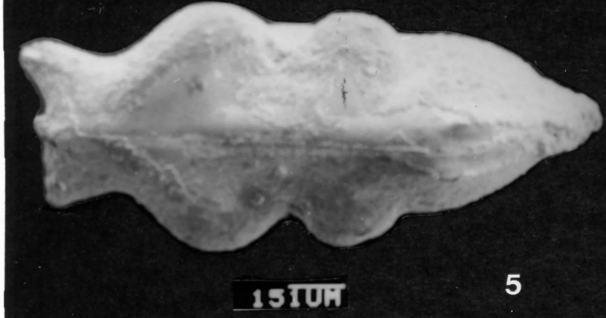

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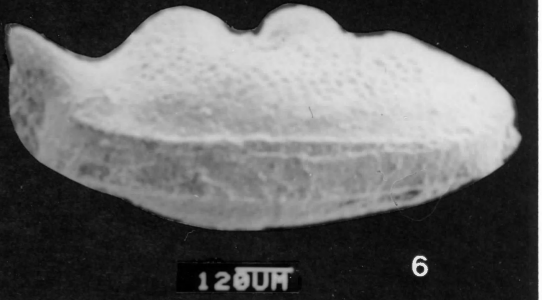

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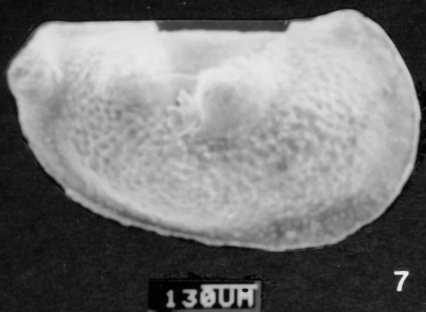

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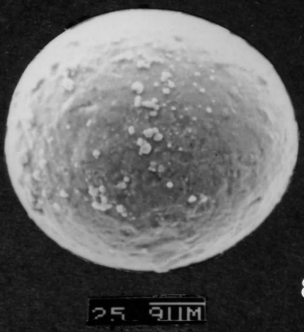

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PLATE III

Figure 1. *Youngiella sp.* internal mold.

Figure 2, 4. *Youngiella sp.* tecnomorph. Specimens are steinkerns.

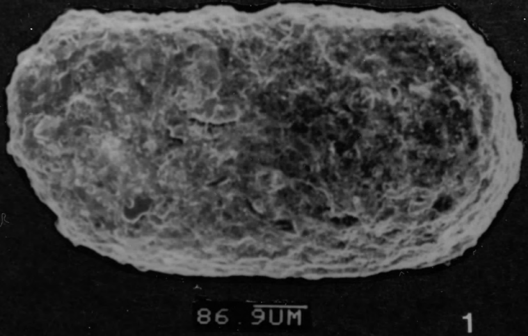
Figure 3. *Youngiella sp.* showing dorsal view.

Figure 5, 6. *Geisina sp.* adult female demonstrating dimorphic swelling and central sulcus. Both left and right aspects are shown.

Figure 7. *Geisina sp.* left aspect of tecnomorph.

Figure 8. *Geisina sp.* ventral view showing overlap and inequality of the valves.

Plate III



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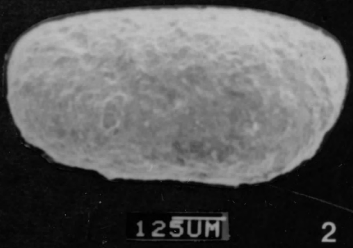

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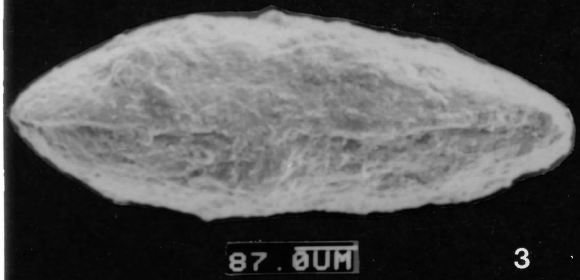

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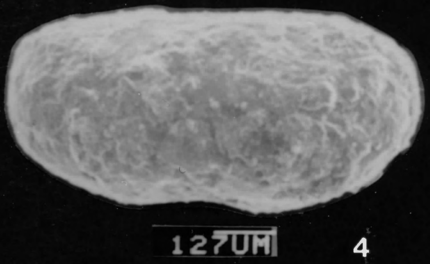

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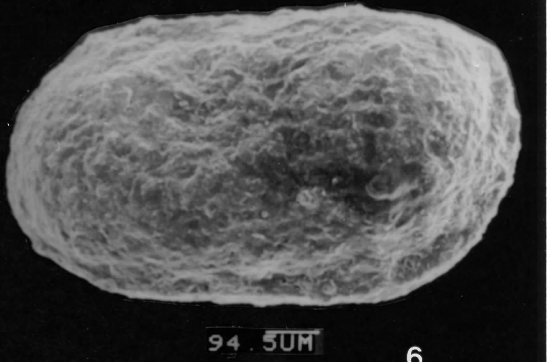

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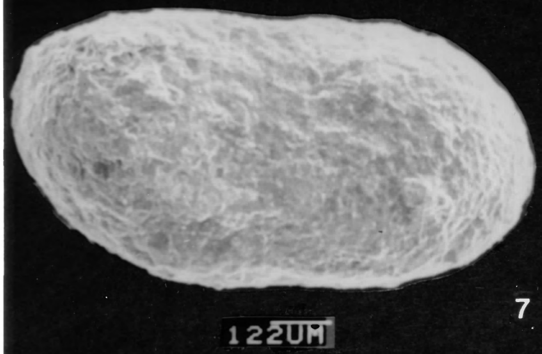

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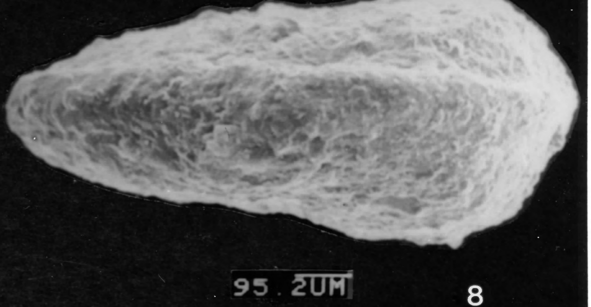

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PLATE IV

Figure 1. *Carbonita scalpellus* right aspect adult.

Figure 2. *Carbonita scalpellus* adult female carapace. The stage is rotated 30 degrees to show the dorsal margin.

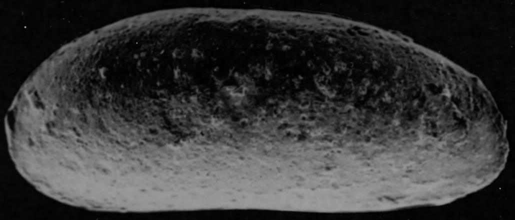
Figure 3. *Carbonita scalpellus* internal mold showing thin inner lamella.

Figure 4. *Carbonita scalpellus* left aspect of an adult female. There is slight swelling in the mid anterior.

Figure 5, 6. *Bairdiacypris striatiformis* left and right aspects.

Figure 7. Enlarged median area of *Bairdiacypris striatiformis* (Fig. 6) showing distinct striations

Plate IV



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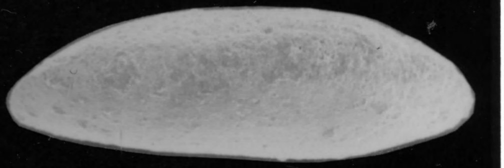

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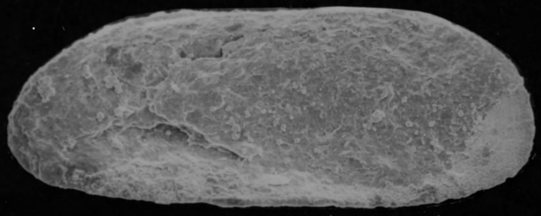

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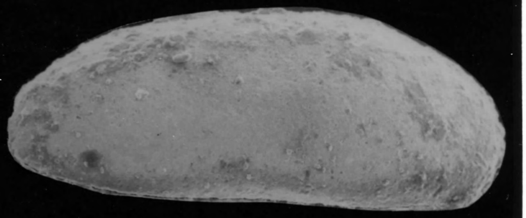

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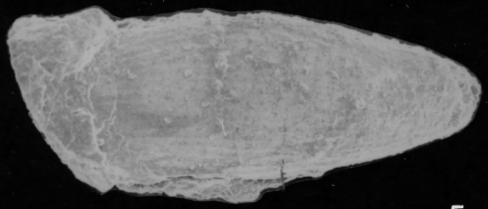

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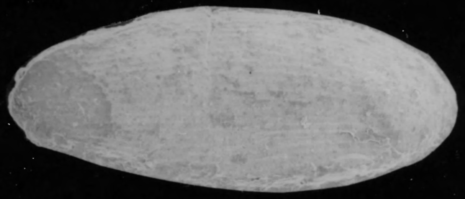

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PLATE V

Figure 1. *Carbonita rankiniana* adult cast.

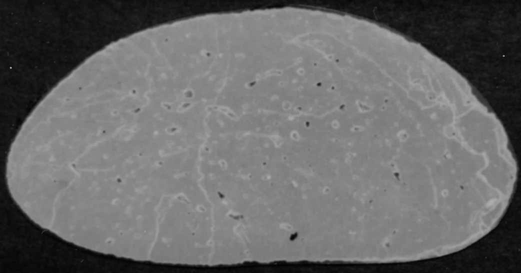
Figure 2. *Carbonita rankiniana* juvenile right aspect.

Figure 3. *Carbonita rankiniana* left aspect adult.

Figure 4, 5, 6. *Carbonita rankiniana* juvenile instars. It is likely that previous researchers identified the smaller instars of this taxa as *Carbonita secans*.

Figure 7, 8. *Carbonita rankiniana* internal cast (7) and its enlarged ventral margin demonstrating the narrow inner lamella (8).

Plate V



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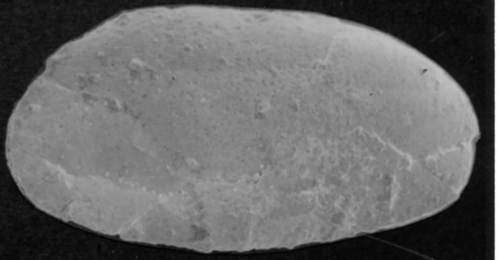

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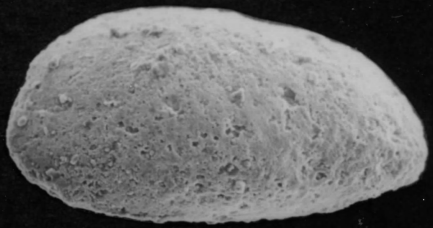

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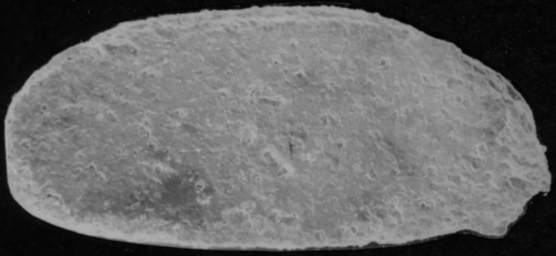

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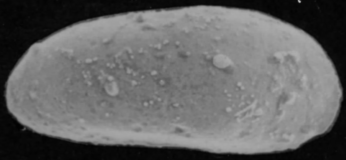

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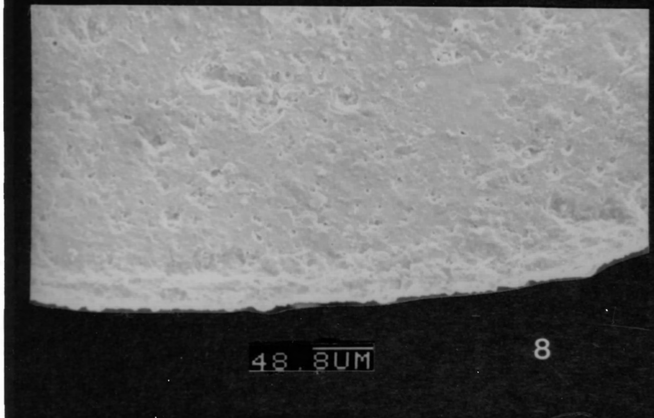

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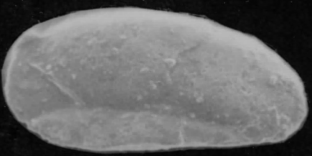

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PLATE VI

Figure 1. *Cavellina lovatica?* left aspect. Note the right valve overlaps left valve.

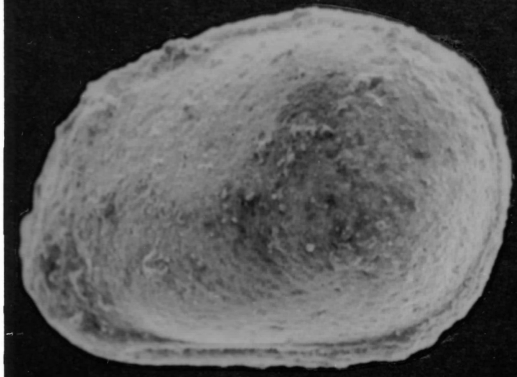
Figure 2. *Cavellina lovatica?* inner surface of the right valve.

Figure 3. *Cavellina lovatica?* right aspect of tecnomorph.

Figures 4, 5, 6. *Cavellina lovatica?* juveniles.

Figures 7, 8. *Cavellina lovatica?* dorsal and ventral aspects respectively. Note the stragular process.

Plate VI



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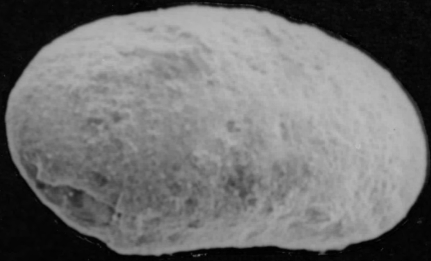

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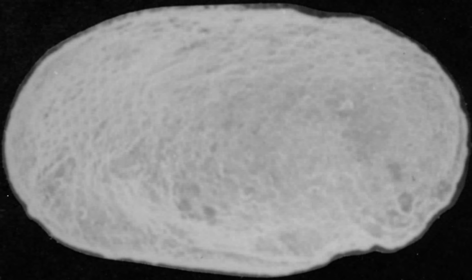

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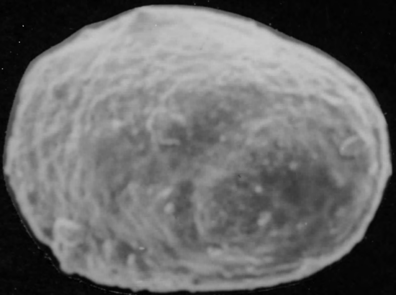

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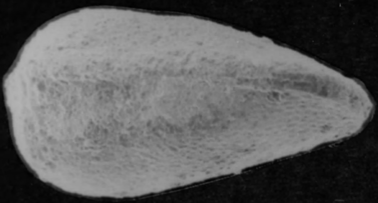

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PLATE VII

Figure 1, 3. S*hemonaella tatei* right and left aspects of adult.

Figure 2, 5. S*hemonaella tatei* inner valve demonstrating the straight dorsal margin often masked on the external aspect due to dorsal swellings. Note the thick calcified inner lamella typical of the Paraparchitaceans.

Figure 4. S*hemonaella tatei* dorsal view showing hinge and slight dorsal swelling.

Figure 6. S*hemonaella tatei* juvenile right aspect. Stage is rotated 15 degrees to show dorsal swelling and the ventral margin

Figures 7, 8. S*hemonaella tatei* internal cast and enlarged area showing well-preserved internal adductor and mandible muscle scars and distinct radiating reticulation.

Plate VII

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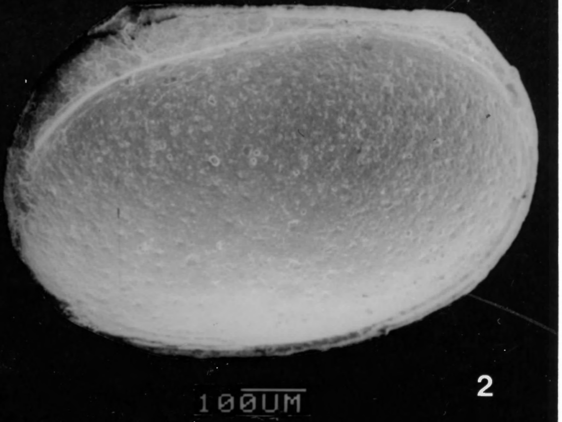

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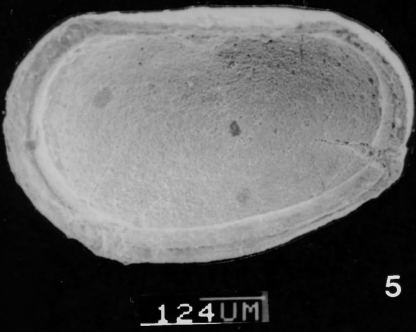

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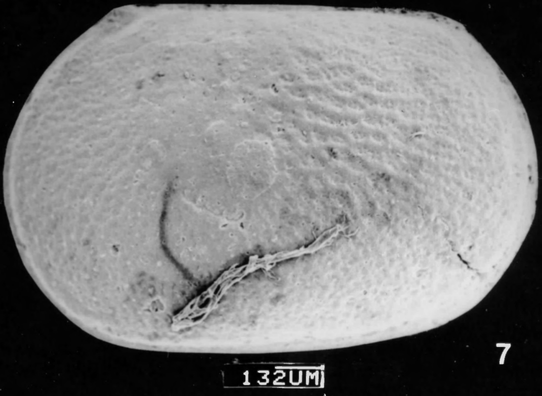

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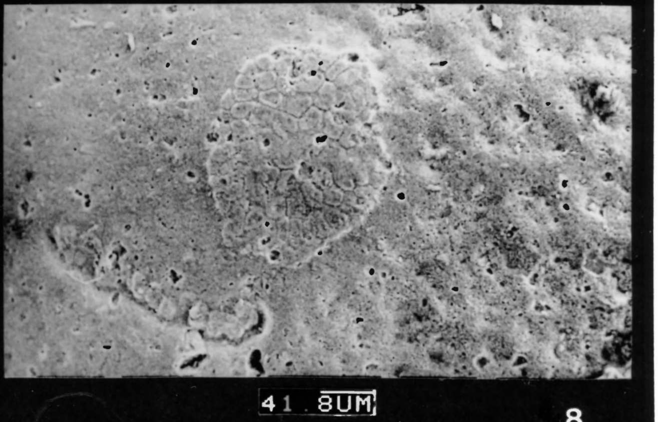

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PLATE VIII

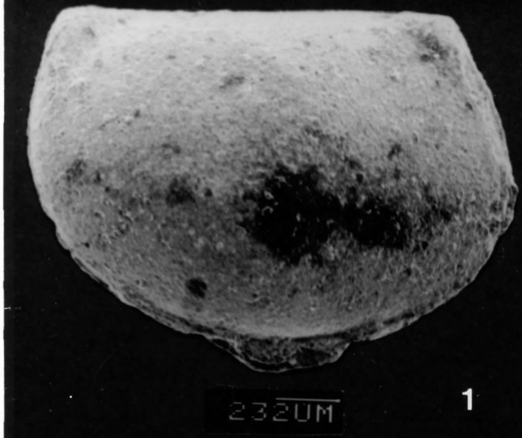
Figure 1. *Shemonaella scotoburdigalensis* adult right aspect. Note the flattened cardinal areas and the straight dorsal margin.

Figure 2. *Shemonaella scotoburdigalensis* inner cast showing wide calcified inner lamella (left valve).

Figures, 3, 4. *Shemonaella scotoburdigalensis* dorsal views of juveniles. Note the absence of dorsal swelling.

Figures 5, 6. *Shemonaella scotoburdigalensis* inner cast and enlarged central area demonstrating the adductor and mandible muscle scars.

Plate VIII



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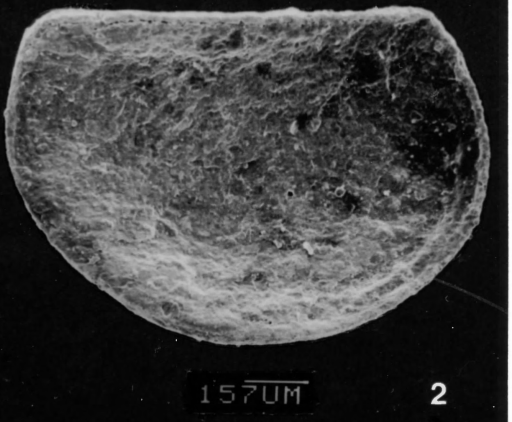

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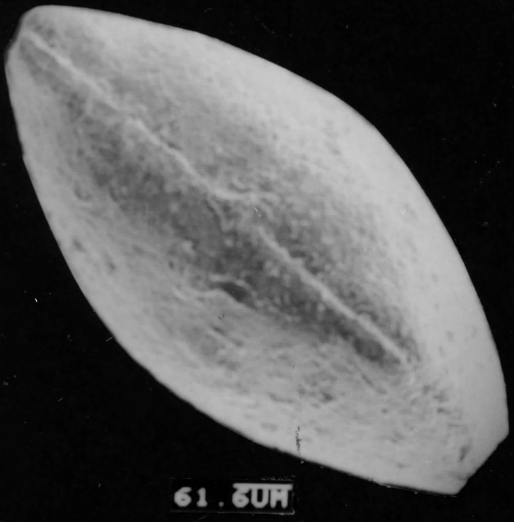

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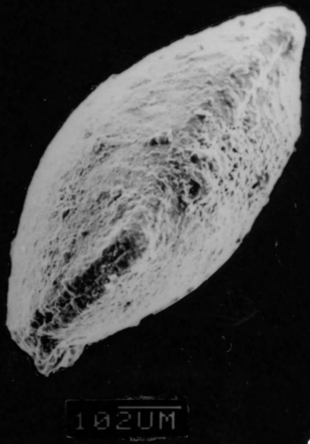

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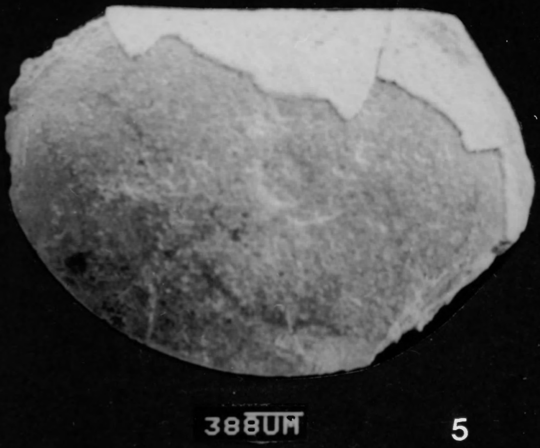

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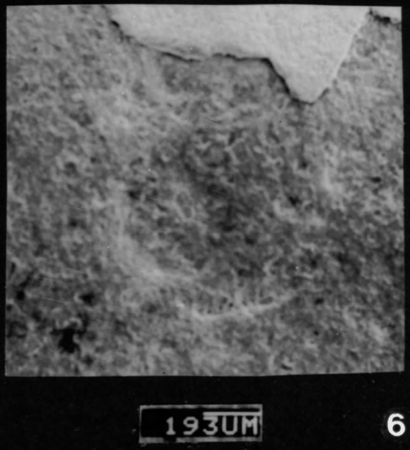

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PLATE IX

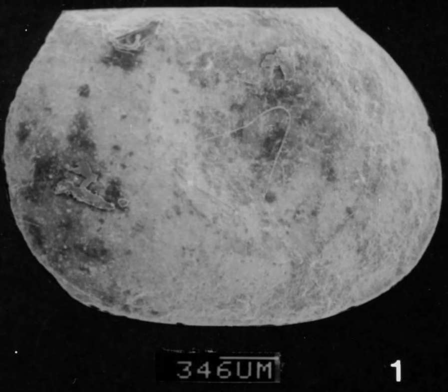
Figure 1. *Chamishaella sp.* left aspect.

Figure 2. *Chamishaella sp.* left aspect. Stage is tilted 20 degrees to show the well-developed dorsal swelling in the an adult valve.

Figure 3, 4. *Chamishaella sp.* left aspects of the late instars. Note the valve overlap on the ventral margin.

Figure 5, 6, *Chamishaella sp.* early instars.

Plate IX



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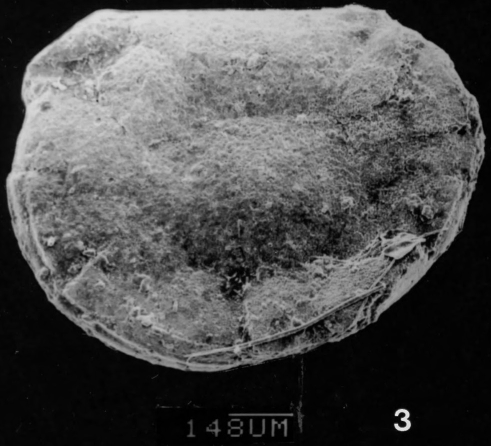

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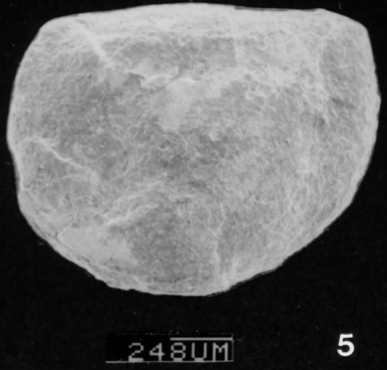

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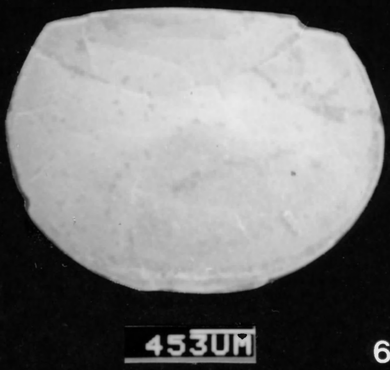

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PLATE X

Figures 1, 2. *Bairdia pruniseminata* late instar and earlier juvenile (steinkerns).

Figure 3. *Cavellina lovatica?* adult carapace soaked in glycerine and photographed using the scanning light microscope. Note the internal subcentral muscle scar.

Figures, 4, 7. Paraparchitacean Genus and Species undetermined. Note the vertical ribbing and the Paraparchitidae ventral outline.

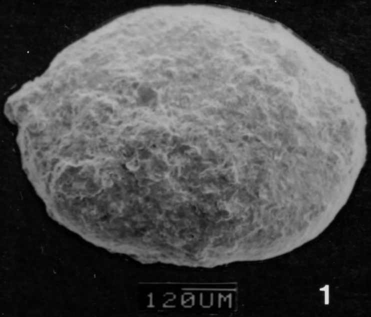
Figures 5, 6, 9. Ostracode gen. and sp. indet.

Figure 8. *Triletes cheveriensis* megaspore.

Figure 10. Enlargement of Plate I, figure 12 of the spherical thecamoebian resembling the modern *Centropyxis.* Note the aperture and angular silt and clay particles comprising the test.

Figure 11. Algal bodies (Chuaria?) in fine siltstone. Note the concentric overlapping margins in the lower right corner of the sample.

Plate X



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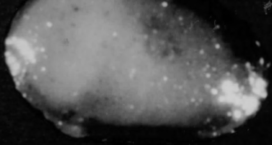

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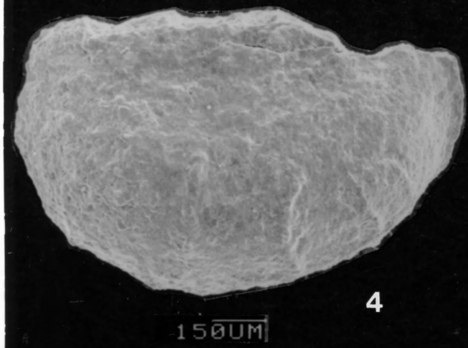

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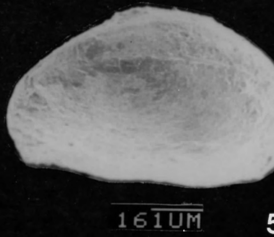

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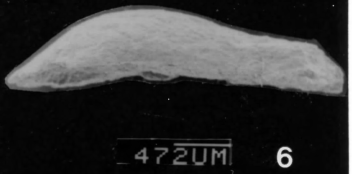

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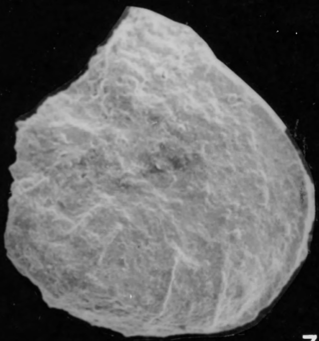

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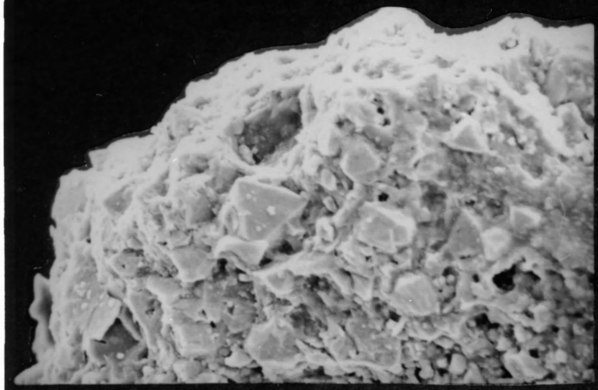

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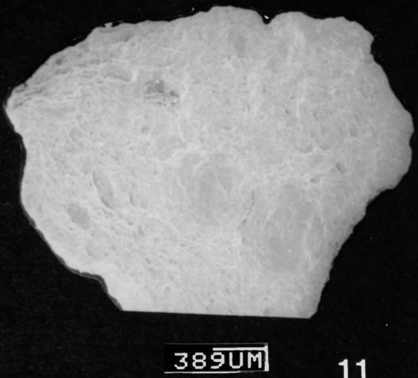

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PLATE XI

Figures 1, 2, 3. Palaeoniscid fish scale and teeth.

Figures 4, 7. *Spirorbis avonensis* coiled serpulid polychaete worm.

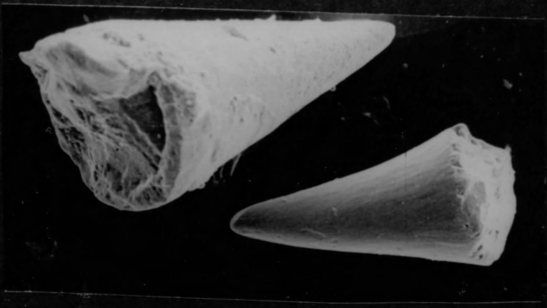
Figure 5. Uncoiled serpulid worm locally abundant in the Saarberg core. Specimens were found erect presumed attached to the benthic substrate.

Figure 6. *Spirorbis avonensis* attached to a valve of *Shemonaella scotoburdigalensis.*

Figure 8. Framboidal pyrite in organic-rich black shale.

Plate XI

1



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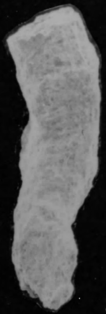

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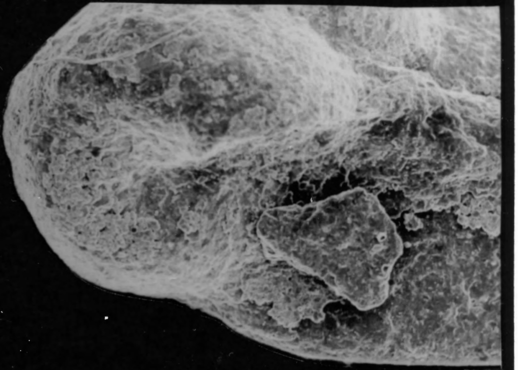

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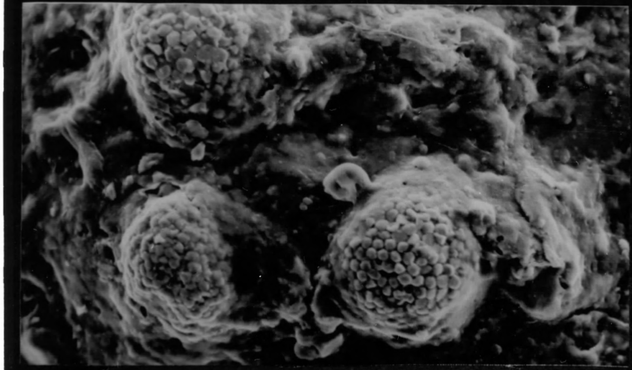

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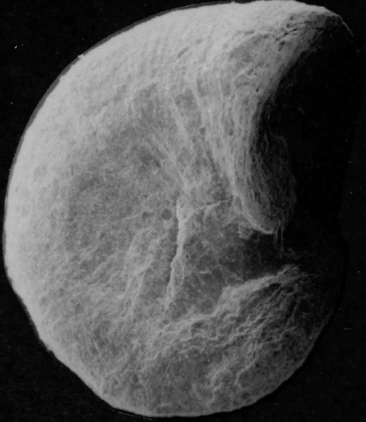

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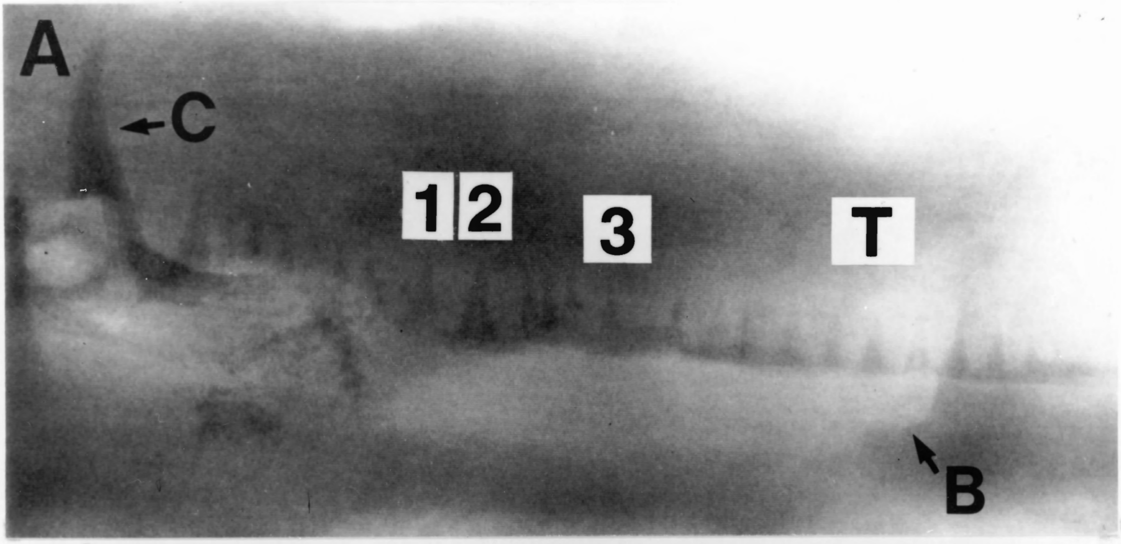
PLATE XII

Rhizodont crossopterygian fish jaw.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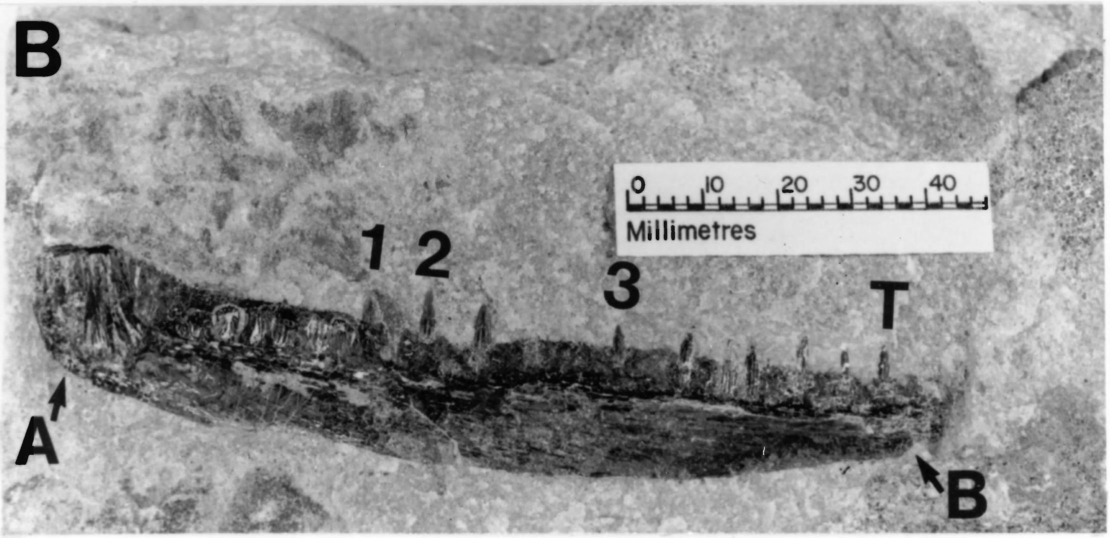
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