Cambrian Multichambered Foraminifera from the Halifax and Goldenville Groups of the Meguma Supergroup, Nova Scotia

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ABSTRACT

Foraminifera in the Cambrian are rare; only ten genera have been recorded and these were all simple tubular and branching unilocular forms found in West Africa. The discovery of an organic lens within the Goldenville Group by amateur collector Colin Corkum and articulate brachiopods within the Halifax Group by Armgard Zentilli, provided sample locations for the study. Both locations yielded multichambered foraminifera. The Halifax Group specimens were made up of *Trochammina* in a monospecific assemblage, with one specimen identified to species level as *Trochammina macrescens* (Brady). The Goldenville Group yielded specimens of *Trochammina* as well as *Ammotium* and *Haplophragmoides*.

The Halifax and Goldenville Group assemblages are not only the oldest foraminiferal community discovered, they also are the oldest multichambered foraminiferal find, existing in the mid-Cambrian some 50–60 million years before *Reophax blackriveranus,* in the mid-Ordovician.

The presence of *Trochammina macrescens*, a shallow marine species, in a formation interpreted on sedimentological grounds as deep sea turbidites requires further investigation.

ACKNOWLEDGEMENTS

I would like to thank, first and foremost, D. B. Scott for his direction and advice, giving me the opportunity to participate in such an intriguing project. I would like to thank Colin Corkum and Armgard Zentilli for reporting their respective finds, without them there would be no project at all. I would like to thank Marcus Zentilli, Milton Graves, Don Fox and Sandy Grist for helping in the understanding of these rocks. I would like to thank Chloe Younger for the processing the sample material, Frank Thomas for the ESEM photography, Gordon Brown for the grain mounts and F. S. Medioli for the instruction and use of his microscope. I would like to thank Martin Gibling for his all of his help and suggestions throughout the past year.

Finally I would like to thank Richie Tobin, who's barstool advice proved invaluable in those crucial last few days, and Lori Anne Cook (OMG) for her endless support, advice, and friendship over the past year.

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CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

Foraminifera are rare in the Cambrian; only ten genera have been recorded and described in the lower and middle Cambrian (Culver 1994). Although foraminifera are widely studied, their evolutionary origin is still unknown. Prior to the discovery presented in this thesis, initially made by amateur collector Colin Corkum, the Cambrian foraminifera that had been recorded were agglutinated, simple tubular or pseudochambered forms of the sub-order Textulariina (Lipps 1992). The discovery of foraminifera in the Goldenville Formation is important since fossils are extremely rare in this rock and the foraminifera are multichambered, exhibiting many modern day morphologies previously unreported (Scott 1996, Scott and Medioli, submitted). This not only dates them as the oldest multichambered foraminifera but it also suggests that multichambered tests were in existence before the species found in this deposit (Scott and Medioli, Submitted). Since the multichambered foraminifera are more complex than the unilocular foraminifera, it is assumed that the unilocular tests evolved prior to the multichambered form. The earliest Cambrian foraminifera found prior to these were well preserved, unilocular species from west Africa (Culver 1991).

Foraminifera are not the oldest animals to have persisted through the Paleozoic. The brachiopod genus *Lingula* has existed since the Early Cambrian virtually unchanged through to the present (Williams *et.al.* 1965), therefore it is not surprising that a species of foraminifera could persist virtually unchanged from the Cambrian.

All of the microfossils in this study are marine, benthic foraminifera with agglutinated tests. They belong to the animal kingdom Protista, subphylum Sarcodina, class Rhizopodea (Loeblich and Tappan 1964). Foraminifera species can be useful paleoenvironmental indicators since they typically exist in certain ranges of pH, salinity, temperature and water depth (Boltovsky and Wright 1976).

Prior to this find, the oldest validated agglutinated multichambered foraminifera was *Reophax blackriveranus*. The sample was discovered in a quarry, located in the mid-Ordovician (~ 450 Ma) Mifflin Formation of the Plattville Group of Illinois (Gutschink 1986). The morphology of the Ordovician foraminifera evolved from that of a simple straight or single branching tubular shape to those with partitions and multichambers (Gutschink 1986).

1.2 PREVIOUS STUDIES

Prior to Culver (1991), there had been no record of undoubted lower Cambrian foraminifera, and only a few species of middle Cambrian ammodiscids (*Hemisphaerammina, Psammosphaeria* and a Thuramminoid) had been recorded (Culver 1994). Lower Cambrian foraminiferal records previous to this had been problematic in some way; the species that were found were rare and therefore subject to interpretation. A good example of such interpretative problems is the description of *Spirosolenites* by Glaessner (1978). This particular sample originates from a single source locality in Norway and is an agglutinated coiled tube (Glaessner 1978). The simple morphology has invited speculation as to whether it is actually a separate species. Rozanov (1983) considers this specimen to be a variation of *Platysolenites.*

The West Africa foraminiferal discovery was the first definite Early Cambrian find (Culver 1991). The specimens had simple, tubular, unilocular morphologies, and confirmed the presence of foraminifera in the Cambrian. However, Culver (1991) only found 18 specimens in the sample location. It may be noteworthy that all the genera in that association are also present in modern sediments.

1.3 PURPOSE

The purpose of this study is to determine whether multichambered foraminifera were present in the sampled material. The specimens will be indentified to at least to the genus level and illustrate the diversity of this fauna as well as comparing the results to those of Scott and Medioli (submitted).

1.4 SCOPE

This study was confined to the Cambrian-Ordovician rocks of the Halifax and Goldenville Groups in the greater Halifax area, and more specifically to the Cambrian section of these rocks.

1.5 ORGANIZATION

This paper is organized in the following manner; Chapter two provides a detailed description of the geological and physical setting of the study, including the sequence of stratigraphy for the area and a detailed description of the rocks under study, Chapter three provides the sample collection, sample preparation, methodology and examination, Chapter four provides the foraminifera results of the study. The discussion of the results occurs in Chapter five and conclusions in Chapter six.

CHAPTER 2 REGIONAL GEOLOGY

2.1 REGIONAL SETTING

The samples were collected at two localities; the Clayton Park samples originate from the Goldenville Group, the Jubilee Road samples from the Halifax Group (Figure 2.1). These two groups are within the Meguma Supergroup (Figure 2.2). The Meguma Supergroup is a thick sequence of siliciclastic rocks which underlies the majority of the southern mainland of Nova Scotia and extends for 200km under the continental shelf. Ranging in age from Late Cambrian to Early Ordovician (Schenk 1996), it was elevated to supergroup status by Schenk (1995). The Halifax and Goldenville Formations are thus being elevated to group status and the members to formations. There are no known equivalents to the Meguma Supergroup in the Appalachian belt. The nearest suggested equivalent is Morocco, North Africa (Schenk 1976). Schenk suggested that the Nova Scotia and Morocco rocks were joined prior to the opening of the Atlantic Basin which occurred in the Jurassic (Schenk 1995).

The first major orogenic event to affect the Meguma Supergroup was the Devonian Acadian Orogeny. The emplacement of the South Mountain Batholith occurred ~ 372 Ma into these low grade metamorphic rocks (Clarke *et. al.* 1997). The metamorphic facies increases from Greenschist facies to Amphibolite facies in the southwest (Schenk 1986).

There is no sharp boundary between the Halifax and the Goldenville Groups; the contact is gradational. It is determined by measuring the sand - slate ratio (Schenk 1986).

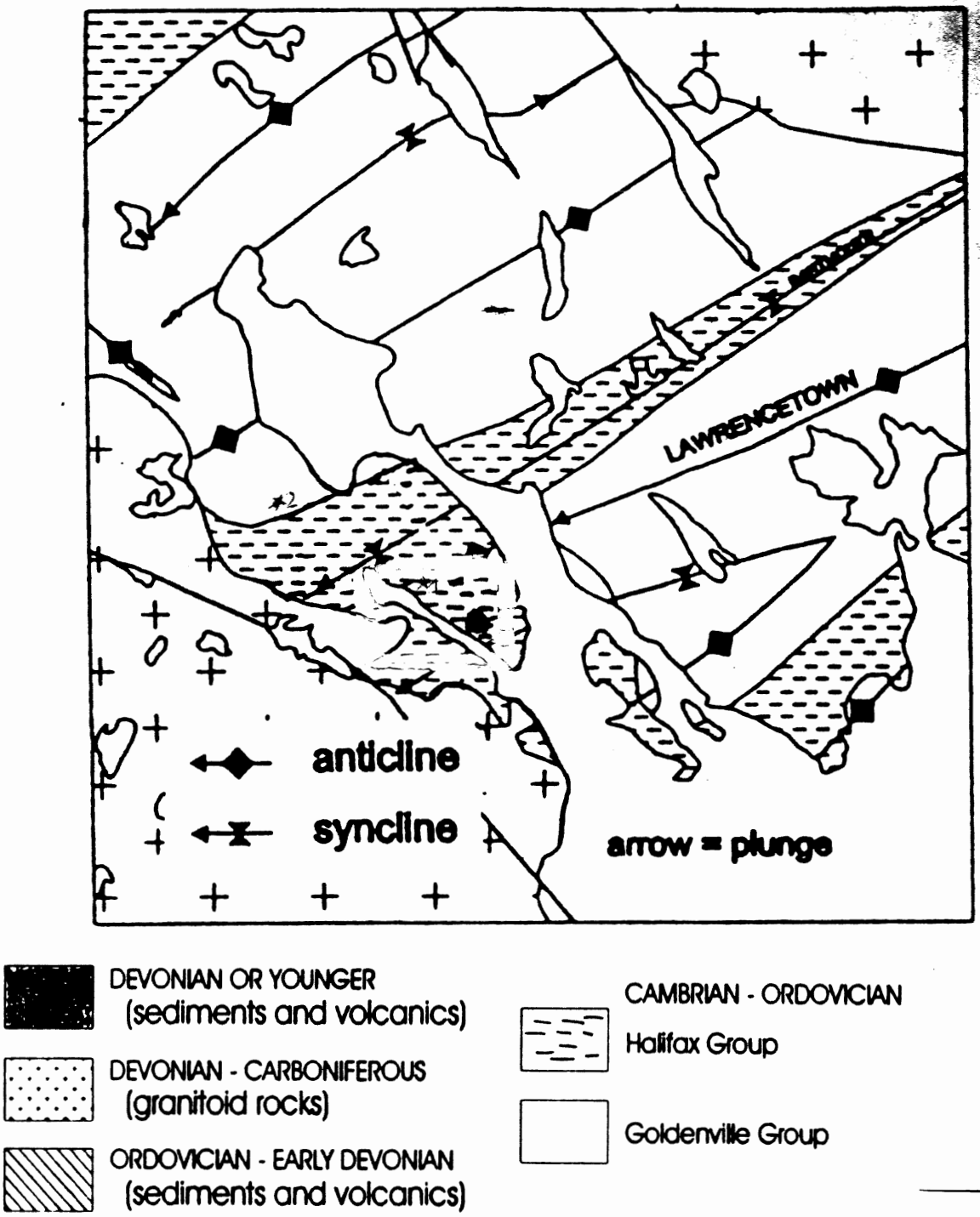


Figure 2.1 Geology map of Halifax. Halifax Group samples denoted by *1, Goldenville Group samples denoted by *2 (after R. J. Horne)

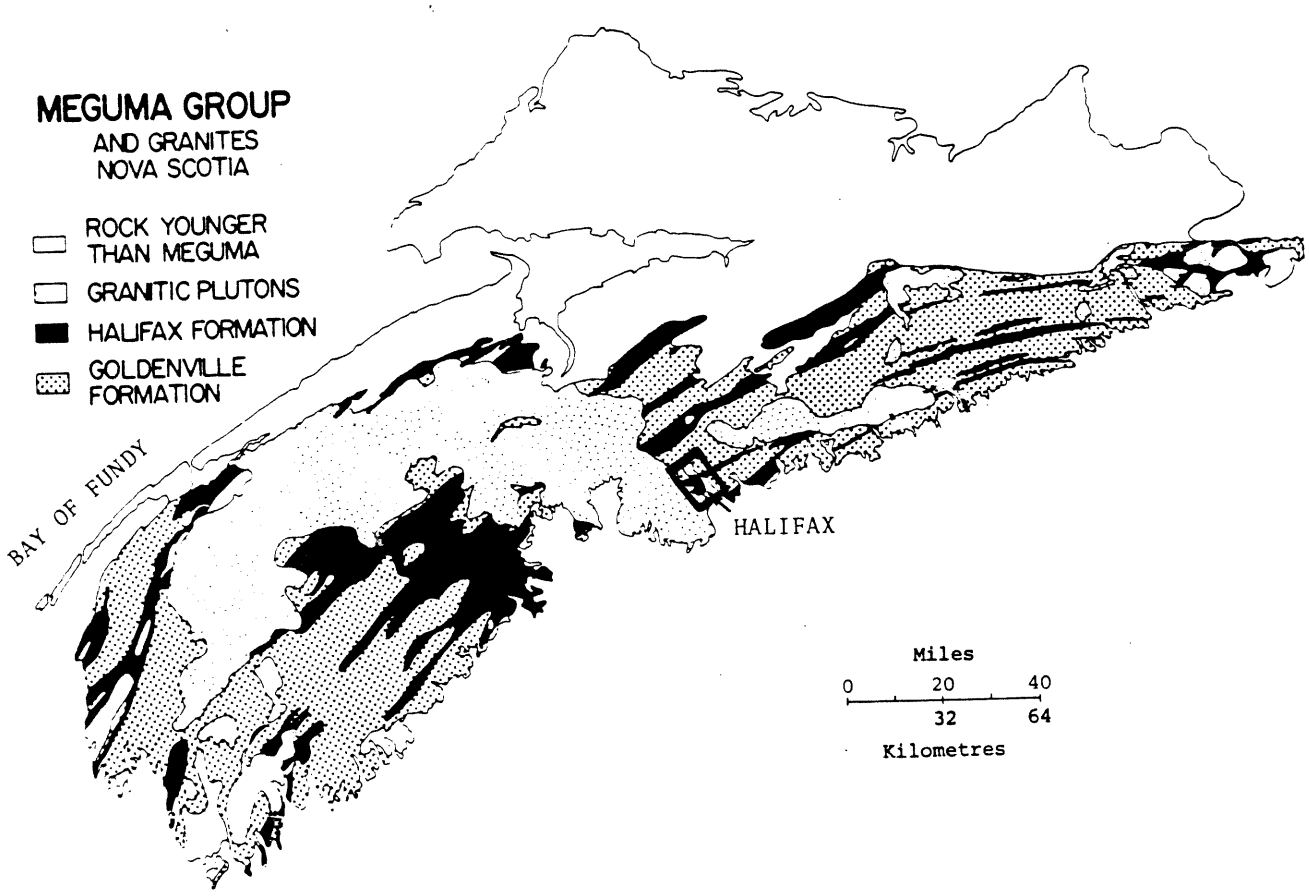


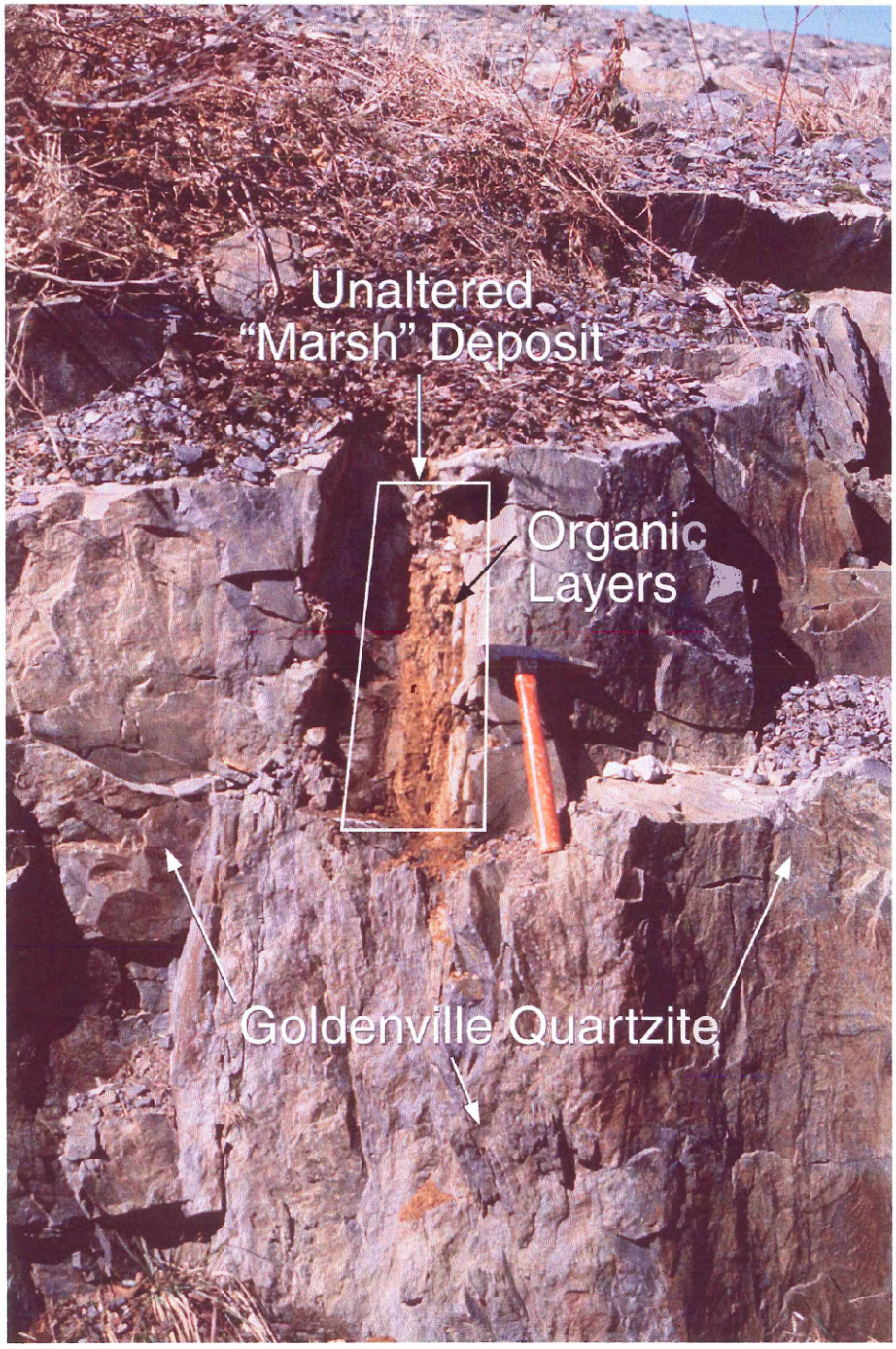
Figure 2.2 Meguma Supergroup outcrop, boxed area represents sample locations (After Schenk 1976)

2.1.1 THE GOLDENVILLE GROUP

The Goldenville Group is the lower stratigraphic unit of the Meguma Supergroup. It is composed mostly of thick beds of gray, fine-grained, metamorphosed sandstone, (Waldron and Jenson 1985). The Devonian South Mountain Batholith is within the region resulting in metamorphism of many of the structures. The Goldenville Group is overlain by the Halifax Group. There is no known base to the Goldenville Group and it has a maximum thickness of 6.7 km near Liverpool (Schenk 1995).

The Goldenville Group is divided into formations in the southwestern region only. The foraminifera were found in the West Dublin Formation, in a lens of yellow material with layers of dark organic material (Figure 2.3). The layer examined in this study was the darker layer, as the yellow layer had previously been examined by Scott and Medioli (submitted). The environment of deposition has been interpreted as a submarine channel levee complex restricted to the southern portion of the Meguma Zone (Schenk 1995). The West Dublin Formation has been interpreted as stratigraphically and lithologically intermediate between deep sea fans and pro-delta siltstones (Schenk 1986). The siltstones and black slates are suggested to be levee and overbank deposits (Schenk 1995). The thicker sandstones represent submarine fan deposits flanked by raised levees, and the thinner sandstones represent shallow channels lacking levees (Schenk 1991). The black slates represent interbank and overbank deposits (Waldron and Jenson 1985).

Figure 2.3 Photograph of the organic lens within the Goldenville Group. Hammer for scale (from Scott and Medioli, submitted)


Unaltered
"Marsh" Deposit
Organic
Layers
Goldenville Quartzite

2.1.2 THE HALIFAX GROUP

The Halifax Group (Figure 2.4) is the upper stratigraphic unit of the Meguma Supergroup. It is fine-grained, thinly laminated and is mostly pyritiferous slate (Schenk 1991). There is no known top over the majority of its exposure. It has a maximum thickness of 11.8 km.

The Halifax Group is composed of five formations, the Mosher's Island Formation, the Cunard Formation, the Feltzen Formation, the Delancey's Formation and the Rockville Notch Formation. The Halifax Group is interpreted as a deep water - continental rise or a prodeltaic wedge that prograded over the Goldenville fan deposit (Schenk 1995). Bioturbation is virtually absent in the Cunard and Mosher's Island Formations (Schenk 1995).

The dominant regional structures of the Halifax formation are the upright chevron folds. These folds have wavelengths of 0.5- 6.0 kilometers (Horne and Culshaw 1994). The Halifax Formation has high concentrations of carbon and oxygen. Studies of the isotopic concentrations of the carbonate concretions in the Goldenville- Halifax transition zone show restricted oxygen and carbon isotope ratios. This demonstrates the importance of the interaction between organic material and minerals during diagenesis (Zentilli and Graves 1988).

Figure 2.4 Photograph of the sample location, Conrose Park, within the Halifax Group.

CHAPTER 3 METHODS

3.1 SAMPLE COLLECTION

The samples were collected from two different locations within the Meguma Supergroup. The Clayton Park samples, from the Goldenville Group, were collected in 1996 by D. B. Scott from an apparent organic horizon. The Jubilee Road samples, from the Halifax Group were collected by R. M. Braund in September 1997.

3.2 FORAMINIFERA EXTRACTION

Due to the large amount of sample material available from the Halifax Group sample location, and the initial difficulties in breaking down the material, many methods of extraction were employed.

3.2.1 DRYING

The samples were placed in an oven at 50°C until they were thoroughly dry (varying between two days and two weeks). This was to remove any of the moisture remaining within the pore spaces of the sample material.

3.2.2 BOILING

Approximately 100ml of the sample material was placed in a beaker of distilled water. The sample was boiled for approximately 40 minutes. Boiling resulting in the break down of the sample material.

3.2.3. OVEN DRYING AND SIEVING

A cursory examination of each of the sample groups began with light crushing with boiling water in a mortar, so as to lightly fracture the material until there is

evidence that the material was breaking down. This was followed by simple washing with hot water and soap through a set of sieves, 500-63μm, the standard size for the processing of foraminiferal material. Any material smaller than 63μm was lost due to processing. This continued until the water ran clear through the sieve. The sample was then dried thoroughly in the oven at 50 °C. The sample was then examined under the microscope for evidence of microfossils. This method was repeated as often as necessary to extract microfossils. The sample was then run through a set of dry sieves (850-250μm, 250-180μm, 180-120μm, <120μm), and each sieve fraction was examined separately under a binocular microscope.

3.2.4. SODIUM THIOSULPHATE

This method was modeled after that of Wightman (1993). The material to be processed was heated thoroughly in the oven at 50 °C for 24 hours. In a fume hood, the sodium thiosulfate (Kodak ® fixer) was combined with enough distilled warm water, maximum 80°C, to cover the sample. Sodium thiosulfate was added until the solution was super saturated (beginning to precipitate out of solution). The solution infiltrates pore spaces when supersaturated. The sample was allowed to soak in the solution over night in a covered vessel, then the sample was removed from the solution and allowed to dry thoroughly in the oven at 50°C. Crystals begin to form, forcing the sample to disaggregate. The sample was examined under the microscope for evidence of microfossils. The process was repeated until there was sufficient breakdown of the material. The sample was then washed through a set of sieves (500-63μm) repeatedly until the water run off was clear.

3.3 FORAMINIFERA EXAMINATION METHODS

3.3.1 SAMPLE PREPARATION

The samples were washed, dried, and divided in size fractions through a series of dry sieves (800μm, 250μm, 180μm and <120μm). This was done to facilitate observation of the material. The selected specimens were mounted and glued with Gum Tragacanth to a partitioned, 60 cell slide. Forty- five specimens selected for Environmental Scanning Electron Microscopy (ESEM) were removed and mounted to an ESEM stub.

3.3.2 SCANNING ELECTRON MICROSCOPE EXAMINATION

The analysis of the sample material from the ESEM was based on the examination of photomicrographs. The Environmental Scanning Electron Microscope (ESEM), located at the Bedford Institute of Oceanography (BIO), was used to examine the specimens with a water vapour environment.

3.3.3. LIGHT MICROSCOPE EXAMINATION

Samples were examined dry, in the sieved fraction under reflected (dissecting scope) and transmitted light microscopes (Ultraphot® in this department). Samples were examined at 20x, 40x, and 80x with the reflected light microscope, and photographs were taken at 100x and 400x, with the transmitted light microscope. The specimens were also examined and photographed immersed in glycerin on a glass slide with transmitted light. Pictures were taken only with ESEM and transmitted light. Reflected light photography would have produced

out of focus pictures because of depth of field problems. The samples were too small to utilize the scanning light microscope.

3.3.4. GRAIN MOUNTS

Grain mounts were produced by placing grains on a slide covered in epoxy and then grinding them down to a thickness of 30μm. The slides were then analyzed through a transmitted light microscope and photographed on Fuji® 64T color slide film.

3.3.5 ENERGY DISPERSAL SPECTROMETRY

While mounted on the ESEM stub, the specimens were bombarded with electrons which recorded the frequency of the elements present in the sample by measuring the frequency of 'hits' on a specific electron shell. This occurs by the ionization of the sample by an electron beam, exciting the valence electrons of the sample. Inner shell electrons replace the excited valence shell electrons to regain stability. The energy is released through this transition as x-rays, which are measured and recorded (Welton 1984). This method cannot give a precise chemical composition but records a qualitative frequency of the elements occurrence.

CHAPTER 4 RESULTS

4.1 INTRODUCTION

Two sample areas yielded foraminifera after processing. The first was a small lens of dark organic material in the Goldenville Group which was surrounded by a protective chert coating, which appears to have protected the lens from complete alteration. The surrounding country rock is quartzite, which is bedded in the same direction as the soft organic lens. This suggests that the two layers were emplaced at virtually the same time.

The second sample location is in the Meguma Supergroup, at the foot of Connaught Avenue in Conrose Park, stratigraphically at the base of the Halifax Group. This location is slightly younger than the Goldenville Group samples.

The Goldenville Group has been dated as Middle Cambrian using a trilobite discovery (Pratt and Waldron 1991) therefore providing a time constraint for the samples in question. Brachiopods found in the second sample location appear to be from the primitive articulate brachiopod genus, *Kutorgina* which is restricted to the lower-middle Cambrian (Scott, pers. com. 1998).

4.2 HALIFAX GROUP SPECIMENS

The Halifax Group samples were examined by light microscopy and ESEM analysis. Examination of the samples found two distinct test textures, although both types are clearly Trochammina (Parker and Jones 1859). The first textural type was an amber colored, translucent, flattened, glassy material, which had no remnant trace of agglutinated material; it had all been recrystallized.

The second textural type was a lighter brown material, distinctly agglutinated. The bulk of specimens were found in the <120μm and 180-120μm size fraction. The species discussed below have been selected as the best representatives.

Specimen 1 is composed of a translucent amber material that exhibits very little relief. The trochospiral coil arrangement and six collapsed chambers can be seen under reflected light allowing identification as Trochammina. However, under the ESEM (Figure 4.1, 1), none of these features are visible as the specimen is glassy with little relief. Under transmitted light (Figure 4.2, 1b.) the spiral direction is visible but the chambers are not visible. Under reflected light this specimen is indistinguishable from the modern species Trochammina macrescens (Scott, pers. com. 1998). This specimen was found in the <120μm size fraction.

Specimen 2 is light brown and has retained its agglutinated appearance. Under the SEM, four chambers are visible as well as three sutures (Figure 4.3, 1). This specimen is also trochospiral. The transmitted light micrograph of specimen 2 illustrates two of the chambers (Figure 4.2, 3b.). This specimen was found in the <120μm size fraction.

Specimen 3 (Figure 4.1, 6) is composed of translucent glassy material. Under the reflected light microscope, intact and collapsed chambers and sutures are visible. The specimens chamber arrangement is trochospiral. Under the ESEM, the glassy material has preserved two of the sutures. This specimen was found in the 180-120μm size fraction.

Specimen 9 (Figure 4.4, 2a.) is composed of translucent amber material. Under the reflected light microscope this appears to be a fragment of a larger *Trochammina*,

Figure 4.1 Specimens under Scanning Electron Micrographs (SEM) (100x). Specimens 1-9,11 and 12 are composed of the translucent amber material. Specimen 10 is composed of the light brown agglutinated material.

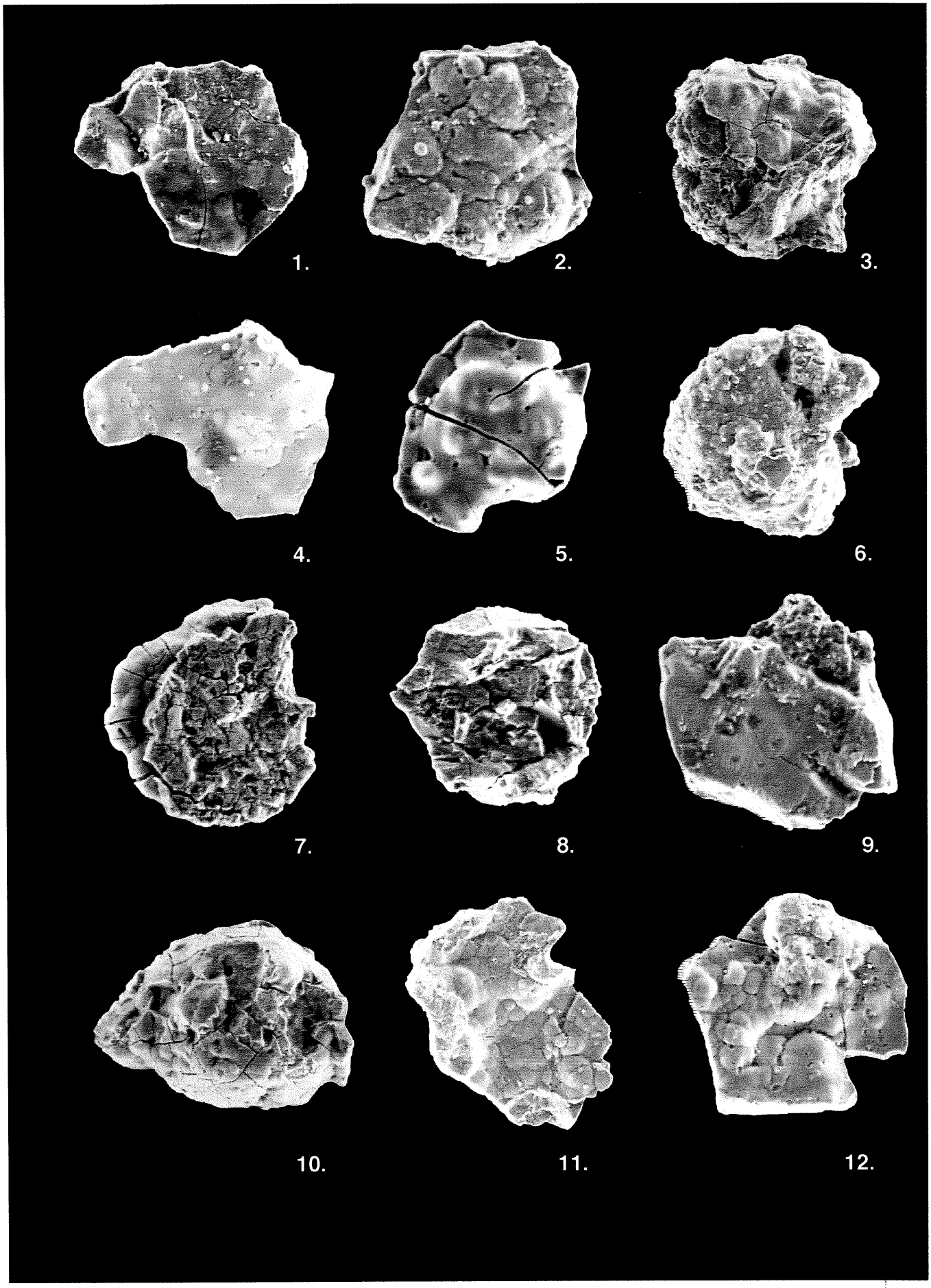
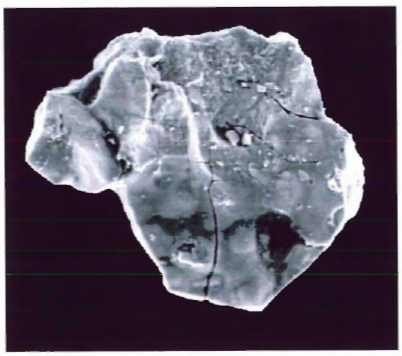
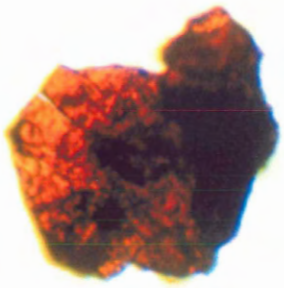

1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.

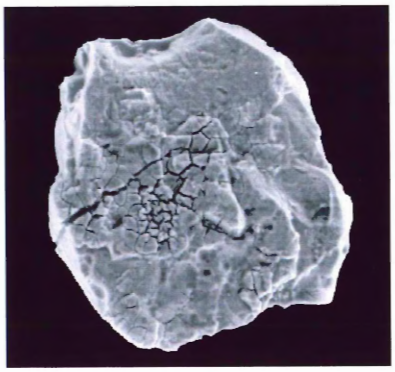
Figure 4.2 Specimens under SEM and transmitted light microscope (100x). 1. Under reflected light specimen 1a. was indistinguishable from *Trochammina macresens* but under the ESEM (1a.), only a vague outline of the basic shape of the genus was distinguishable. Under the transmitted light microscope (1b.), the outline was again visible, and the arrows denote the faint outline of a chamber. 2. Specimen is composed of the amber material which was difficult to photograph by ESEM (2a.) due to the lack of relief and transmitted light. Under transmitted light (2b.) the umbilicus of the specimen is highlighted. 3. Specimen is composed of the light brown material. The ESEM photograph (3a.) clearly illustrates three chambers that can be seen as light shadows in the transmitted light photograph (3b). 4. Specimen is composed of the light brown material, ESEM very effective in illustrating the coiling pattern of the specimen and two chambers (4a.) however, the transmitted light photograph is ineffective in illustrating either the chamber arrangement or the basic outline of the species(4b.).



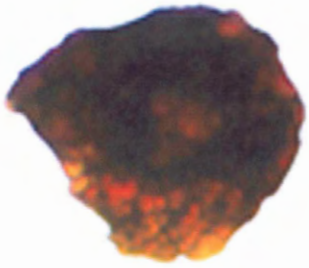
1a.



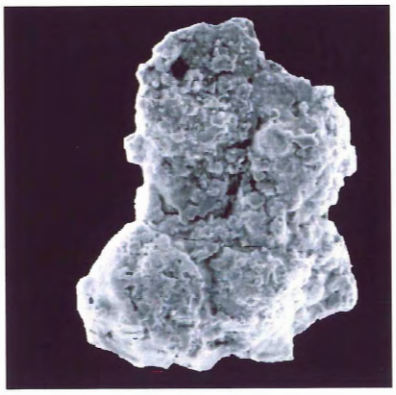
1b.



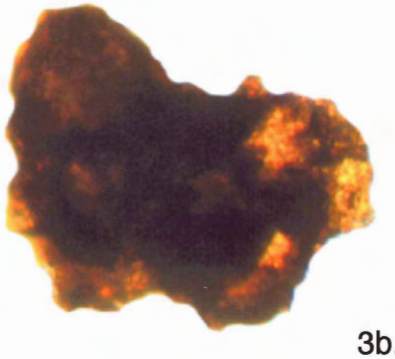
2a.



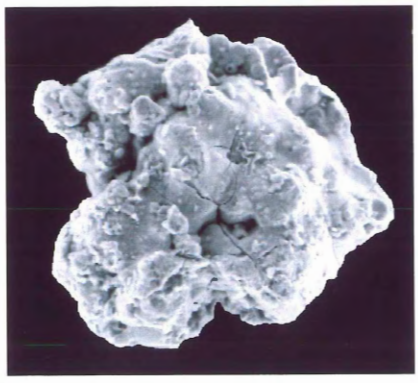
2b.



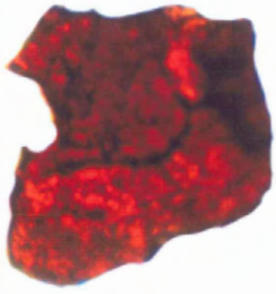
3a.



3b.

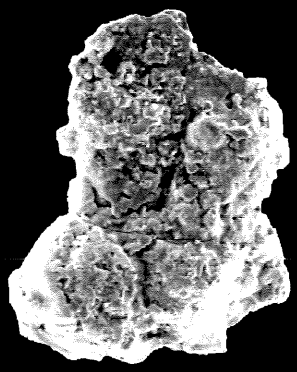


4a.



4b.

Figure 4.3 Agglutinated light brown material under the SEM, 1-7a are 100x, 7b is 400x. 1. Four chambers are visible as well as three sutures, *Trochammina*. 2. No chambers are visible, however, three 'holes' are present in the umbilicus region. These are characteristically organic in nature. 3. *Trochammina* morphology, two chambers are visible as well as a broken chamber. 4. *Trochammina* morphology, broken chambers reveals suture line. 5, 6. No morphology visible under the SEM. 7a. Umbilicus of this specimen visible, under higher magnification (7b.) numerous 'holes' can be seen within the umbilicus.



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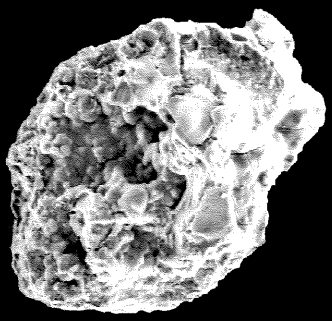

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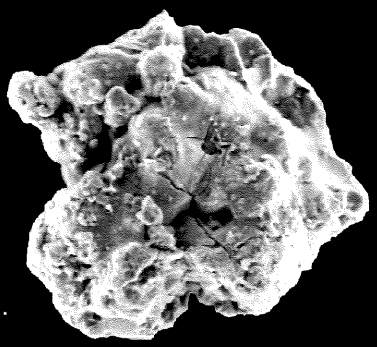

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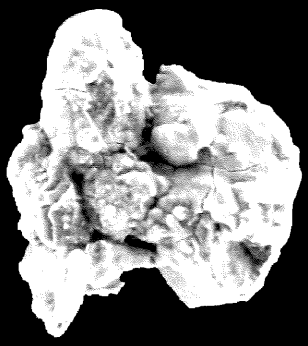

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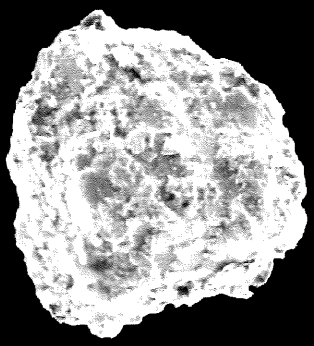

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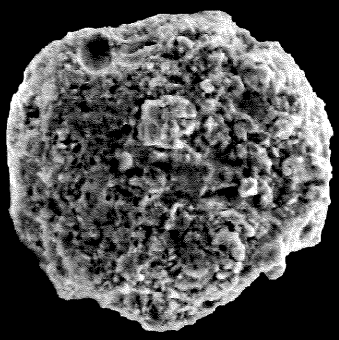
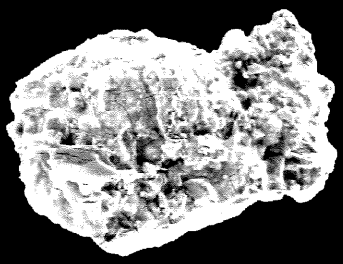
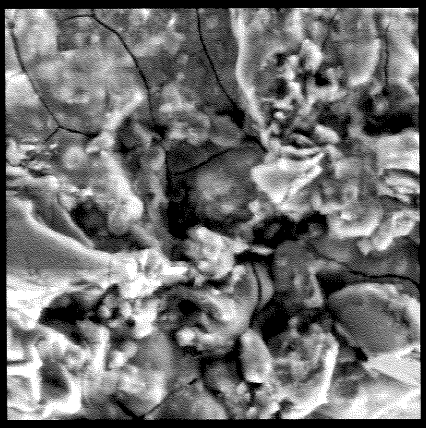


6.

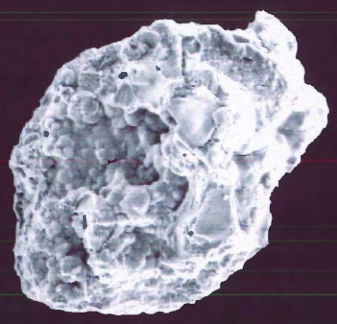


7a.

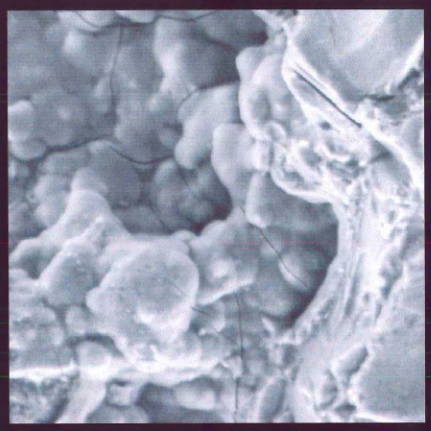


7b.

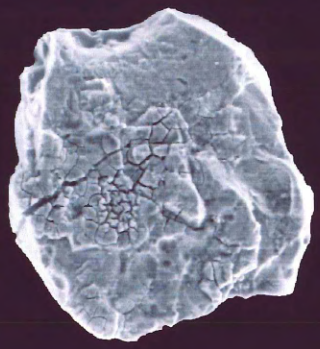
Figure 4.4 ESEM of agglutinated and light brown material. 1a. Agglutinated material (100x), 1b. Enlargement of the umbilicus of the specimen (400x). Three concave cavities are visible and suggest that these are definitely organic. 2a. Amber material under reflected light it appeared to be a fragment of a larger *Trochammina*, (100x), 2b. Enlargement of the center of the specimen shows a coiling pattern, (400x). 3a. Translucent amber material, specimen has been identified as Trochammina, side view (100x). 3b. Enlargement of broken fragment of the specimen clearly illustrates the recrystallization of the specimen (400x). 4a. Light brown agglutinated material, broken chamber (100x). 4b. Enlargement of the broken chamber illustrates the wall structure of the agglutinated material, the suture, and the foramen (400x).



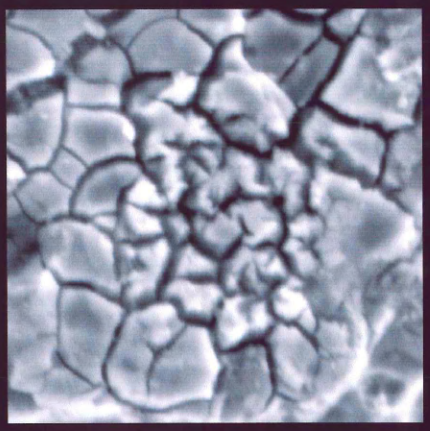
1a.



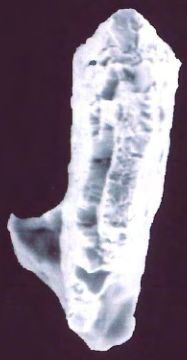
1b.



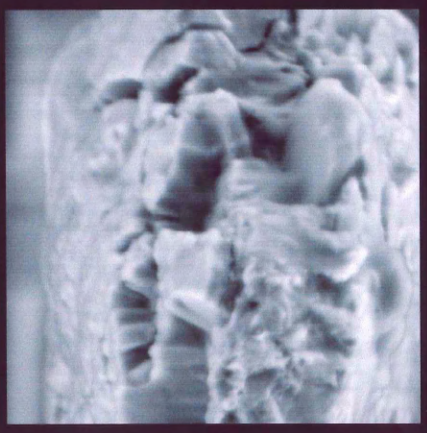
2a.



2b.

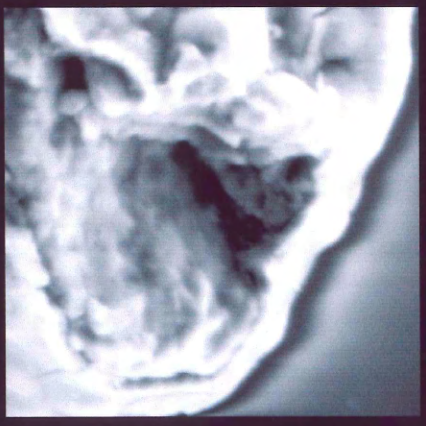


3a.



3b.

4a.



4b.

however under the SEM, none of the partial chambers are visible due to the lack of relief of the sample. Cracks visible under higher magnification show a definite spiral form. This specimen was found in the 180-120μm size fraction.

Specimen 19 (Figure 4.4, 3a) is composed of translucent amber material. Under the light microscope it is *Trochammina*-like in shape. It was photographed on its side to illustrate the recrystallization of the original material. Figure 4.4 (3b) shows an enlargement of a broken chamber. The lateral placement of the crystals is clearly visible. This specimen was located in the 180-120μm size fraction.

Specimen 21 is interesting because it seems to have preserved a cast of the foraminiferal test. Four chamber-like features are clearly visible under the ESEM (Figure 4.1, 5). This specimen is composed of translucent amber material and was found in the <120μm size fraction.

Specimen 25 (Figure 4.4, 1a.) is composed of the lighter brown agglutinated material. It was found in the 180-120μm size fraction. Under the ESEM the umbilicus is visible (Figure 4.4, 1b.) and is composed of three 'holes', which are all characteristically organic.

Specimen 30 (Figure 4.3, 4) is composed of the lighter brown agglutinated material. It was found in the 180-120μm size fraction. Its trochospiral form and three chambers are visible in both reflected and transmitted light. An enlargement of the lower right part of the specimen (Figure 4.4, 4b.) reveals a broken chamber, the suture and the chamber wall are visible within.

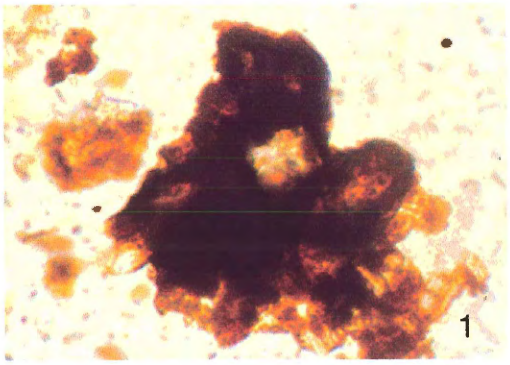
Specimen 44 (Figure 4.3, 3) is composed of the light brown agglutinated material, found in the 180-120μm size fraction. Under the ESEM, chambers arranged trochospirally are visible, however, under transmitted light (Figure 4.2, 4b.) the specimen appears entirely translucent.

Photography of the specimens was problematic in that it did not clearly illustrate all of the features that were visible under reflected light. Under reflected light, specimens with low relief are easily observed with the light source at a high angle. The amber material had exceptionally low relief and as a result amber specimens, especially specimen 1, were easily recognized as *Trochammina* under the reflected light. However, under the ESEM, features such as the collapsed chambers and sutures were not visible. The ESEM is useful in finding the apertures and sutures on foraminiferal tests. It also allows for the accurate magnification of minute details. Its use is restricted to surface features and it is not effective in recording low relief features, such as those in the amber material, or internal structures that can only be seen with an optical light source.

4.3 THE GOLDENVILLE GROUP SPECIMENS

The Goldenville Group material was examined in grain mounts with the transmitted light microscope. The photography was done at 100x and 400x. The grain mounts were composed of the dark layer within the lens. The lighter material was previously examined by Scott (1996), Scott and Medioli (Submitted). The grain mounts of the dark material were too thick (30 μm) to obtain sections thin enough for photography, which made it difficult to identify the foraminifera. Many of the specimens photographed were selected on the basis of the apparent chambers, although often disordered, as in the case

Figure 4.5 Grain Mounts from Goldenville Group (100x). Photographed under transmitted light. 1. Disordered arrangement 2. Apparent fragment of amber colored material 3,6,8. Disordered chamber arrangement 4. Arrows show apparent chambers in the specimen 5,7.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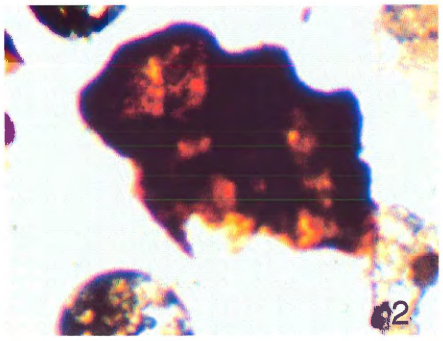
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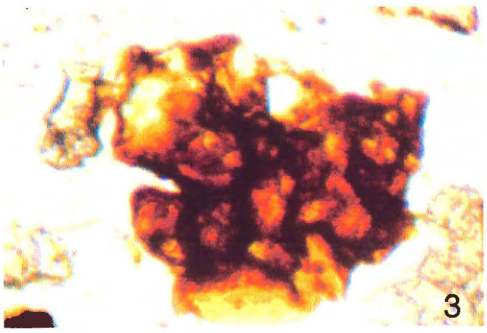
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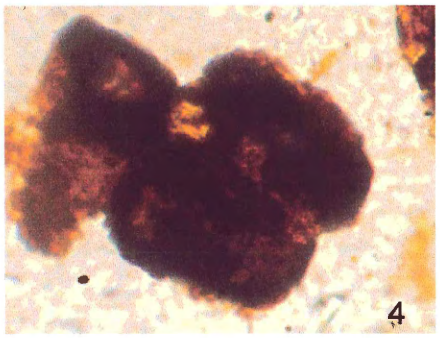
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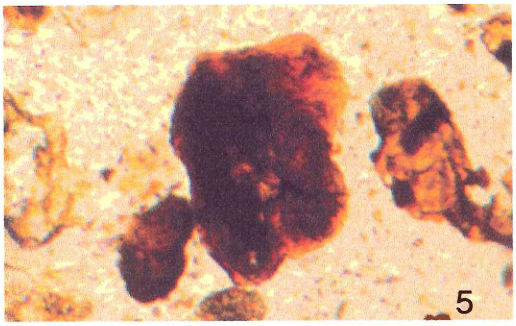
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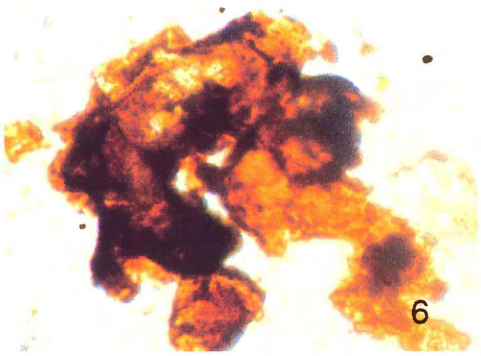
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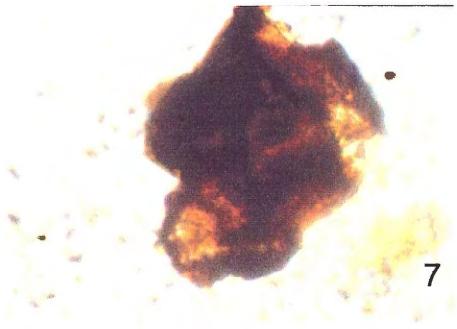
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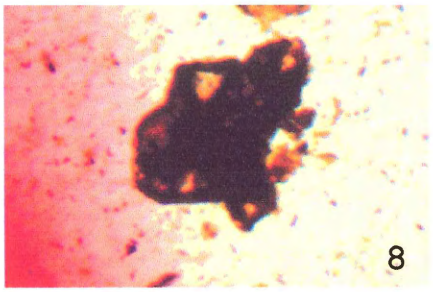

8

of specimen 5 (Figure 4.5). The specimens photographed by Scott and Medioli (Submitted) from the yellow layer are distinctly foraminifera.

Three different genera are present in the yellow layer, *Trochammina* (Figure 4.6, 1 and 3), *Ammotium* (Figure 4.6, 2) and *Haplophragmoides* (Figure 4.6, 4).

Specimen 1 illustrates a well defined inner and outer whorl. The *Trochammina* morphology is clearly illustrated. Specimen 3 is cut deeper in to the foraminifera and the inner whorl is more well defined. The *Trochammina* morphology is easily identified.

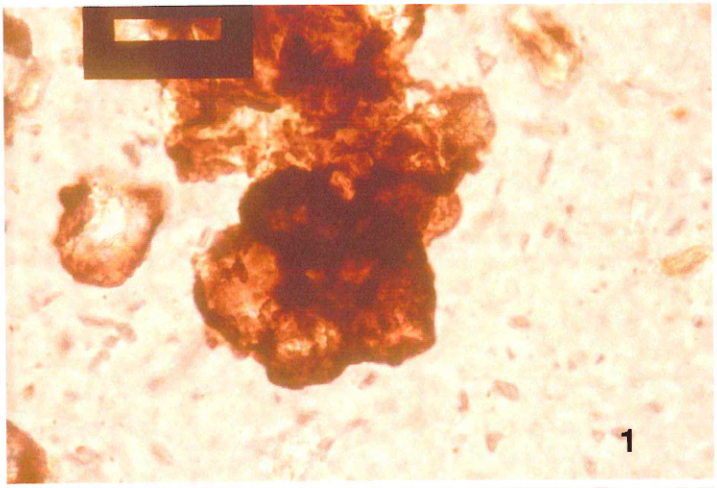
4.4 ELECTRON DISPERSAL SPECTROMETRY

Electron Dispersal Spectrometry applied within the ESEM analysis (Figure 3.1) provided a semi-quantitative chemical analysis for some specimens. In the light brown specimens, the highest frequencies included C, O, Fe, Mg, Si, and Al (Figure 4.7). In the amber material, the highest frequencies were that of C, O, Fe, S, Al, Ca, and Cl (Figure 4.8).

Specimen	Colour	Counts C	Counts O	Counts Fe	Counts S	Counts Si
1	Amber	5200	6600	5700	2500	2200
34	Light Brown	2600	2100	2400	600	900
39	Amber	2000	1500	2200	600	100
42	Light Brown	2400	2100	200	600	2300

Table 4.1 Results of the Energy Dispersal Spectrometry. The counts represent the frequency of the hits on the valence electron shell, providing a qualitative analysis of the composition of the specimens

Figure 4.6 Grain Mounts from the lighter layer within the Goldenville lens (from Scott and Medioli 1997). 1. and 3. are *Trochammina*, the scale bar is 60μm. These specimens have well defined upper whorls. 2. is *Ammotium*, the scale bar is 150μm. 4. is *Haplophragmoides*, the scale bar is 60μm.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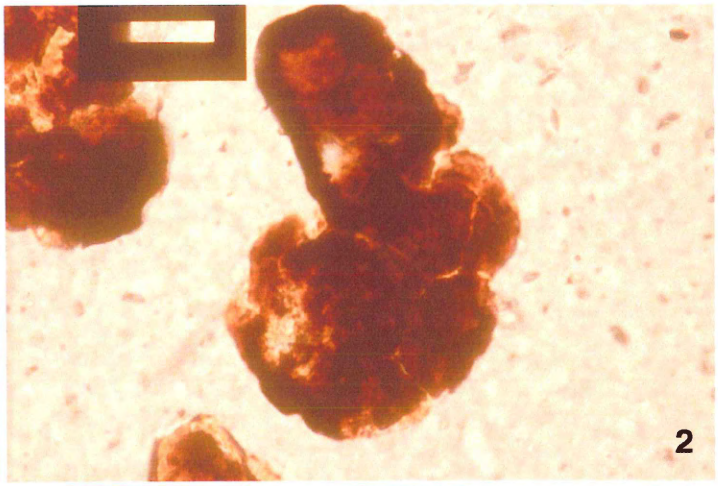
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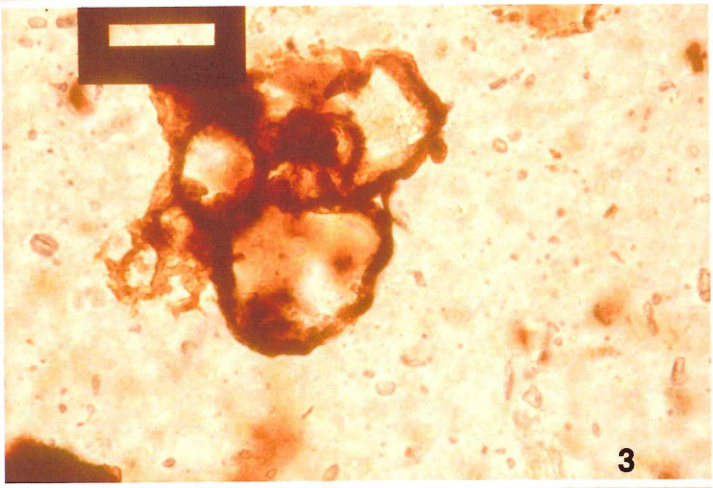
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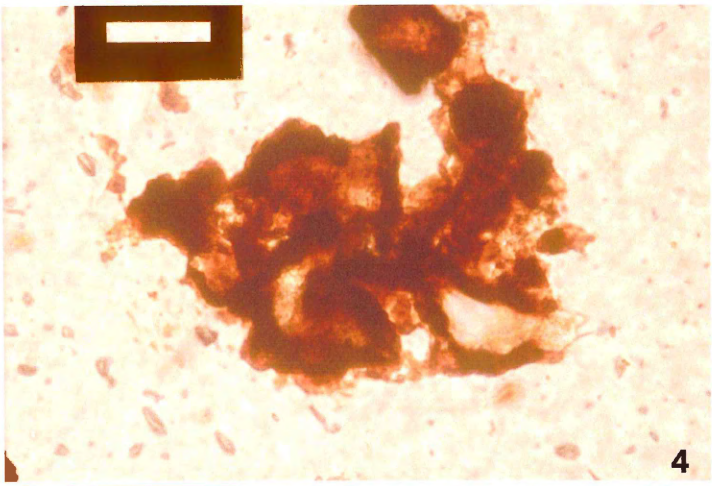
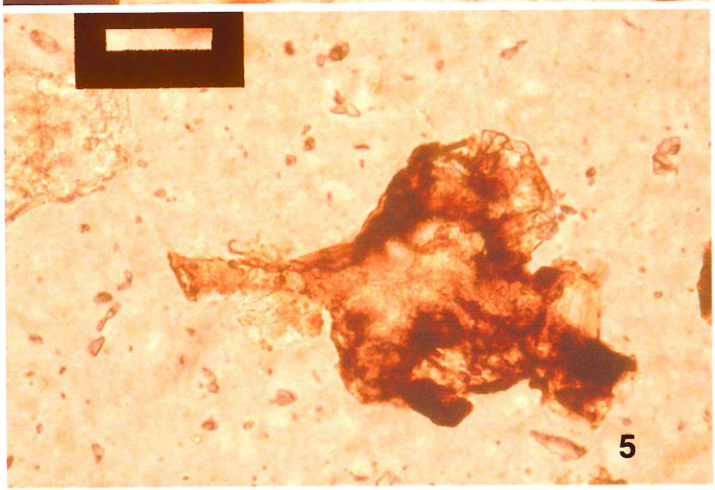
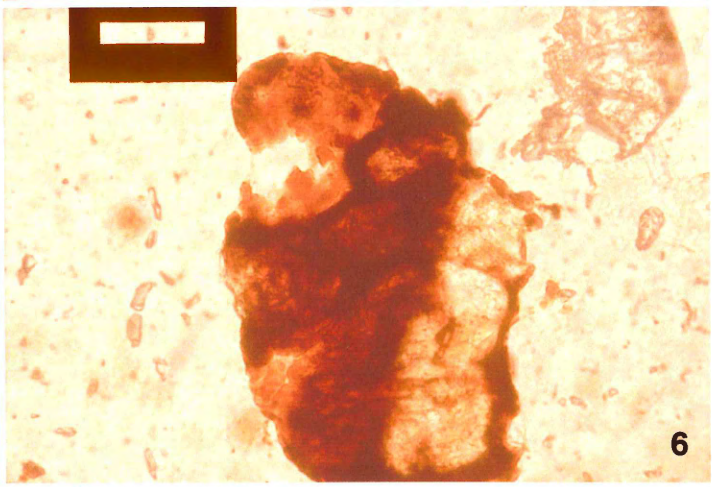

4


5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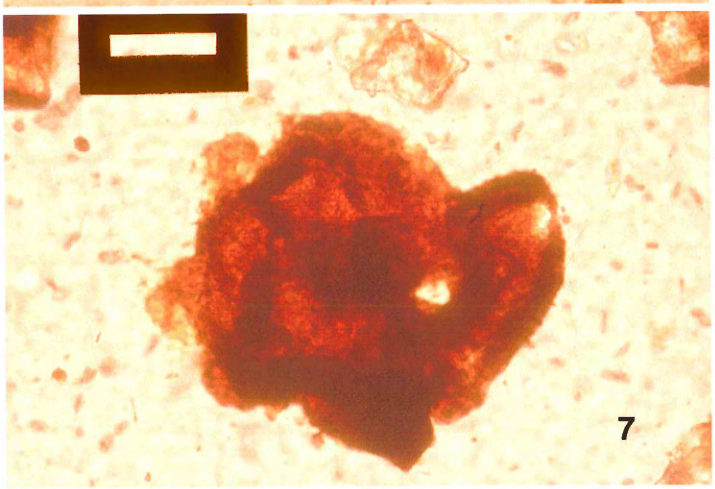

7

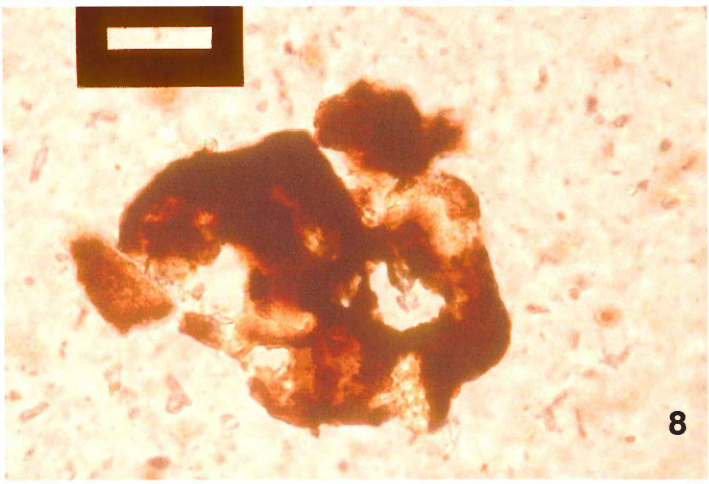
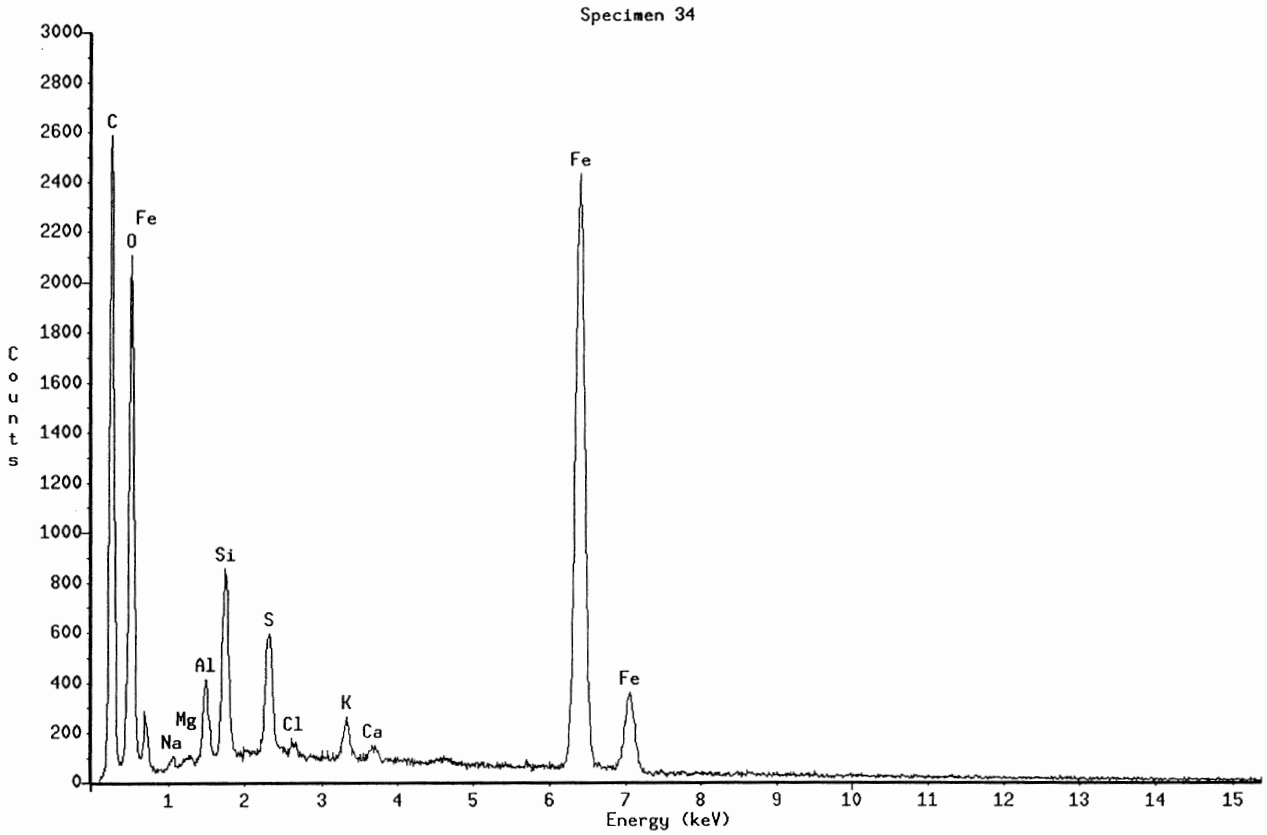

8

Figure 4.7 Results from the Energy Dispersal Spectrometry (EDS) on light brown agglutinated material. 1a. Specimen 34 1b. Specimen 42



Specimen 34

Column	: Column1.Pioneer		
Take-off angle	: 3.93565	Accelerating voltage	: 17.5
Acquisition type	: eds	Magnification	: 465
Creation time	: 98/02/12 14:24	Charge	: 100
Livetime	: 100	Beam current	: 1
Deadtime	: 38.827	Beam spot size	: 0
Channels	: 2048	Beam location	: 0.0
Channel width	: 10	Working distance	: 11.6
Detector type	: Silicon/Lithium	Stage X	: 0
Window type	: norvar	Stage Y	: 0
Window thickness	: 0.3	Stage Z	: 1.6
Coating material	: Al	Stage tilt	: 0
Coating thickness	: 0.04	Stage rotation	: 0
Contact material	: Au	Contamination material	: none
Contact thickness	: 0.02	Contamination thickness	: 0
Crystal thickness	: 3		

File name : /usr/home/voyager/spectra/Thomas/DBScott/spec_34.eds

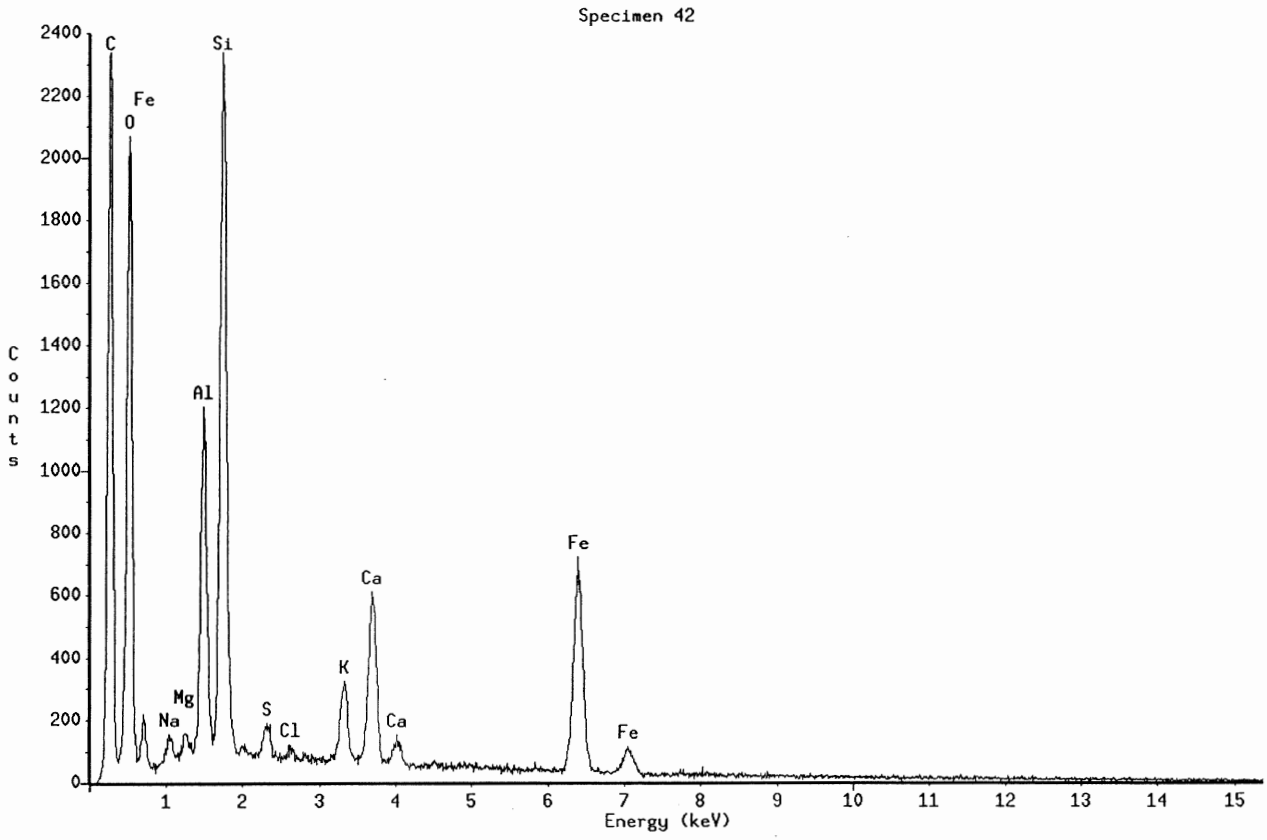
Notes:

Thu Feb 12 14:24:50 1998

Specimen 34

Livetime : 100.0 Sec.
Technique: Least Squares Fit

Elements Present:
C (6), O (8), Fe(26), Na(11), Mg(12),
Al(13), Si(14), S (16), Cl(17), K (19),
Ca(20)
Possible Additional Elements:
Br(35)



Specimen 42

Column	: Column1.Pioneer		
Take-off angle	: 3.93565	Accelerating voltage	: 17.5
Acquisition type	: eds	Magnification	: 465
Creation time	: 98/02/12 14:05	Charge	: 100
Livetime	: 100	Beam current	: 1
Deadtime	: 35.308	Beam spot size	: 0
Channels	: 2048	Beam location	: 0,0
Channel width	: 10	Working distance	: 11.6
Detector type	: Silicon/Lithium	Stage X	: 0
Window type	: norvar	Stage Y	: 0
Window thickness	: 0.3	Stage Z	: 1.6
Coating material	: Al	Stage tilt	: 0
Coating thickness	: 0.04	Stage rotation	: 0
Contact material	: Au	Contamination material	: none
Contact thickness	: 0.02	Contamination thickness	: 0
Crystal thickness	: 3		

File name : /usr/home/voyager/spectra/Thomas/DBScott/spec_42.eds

Notes:

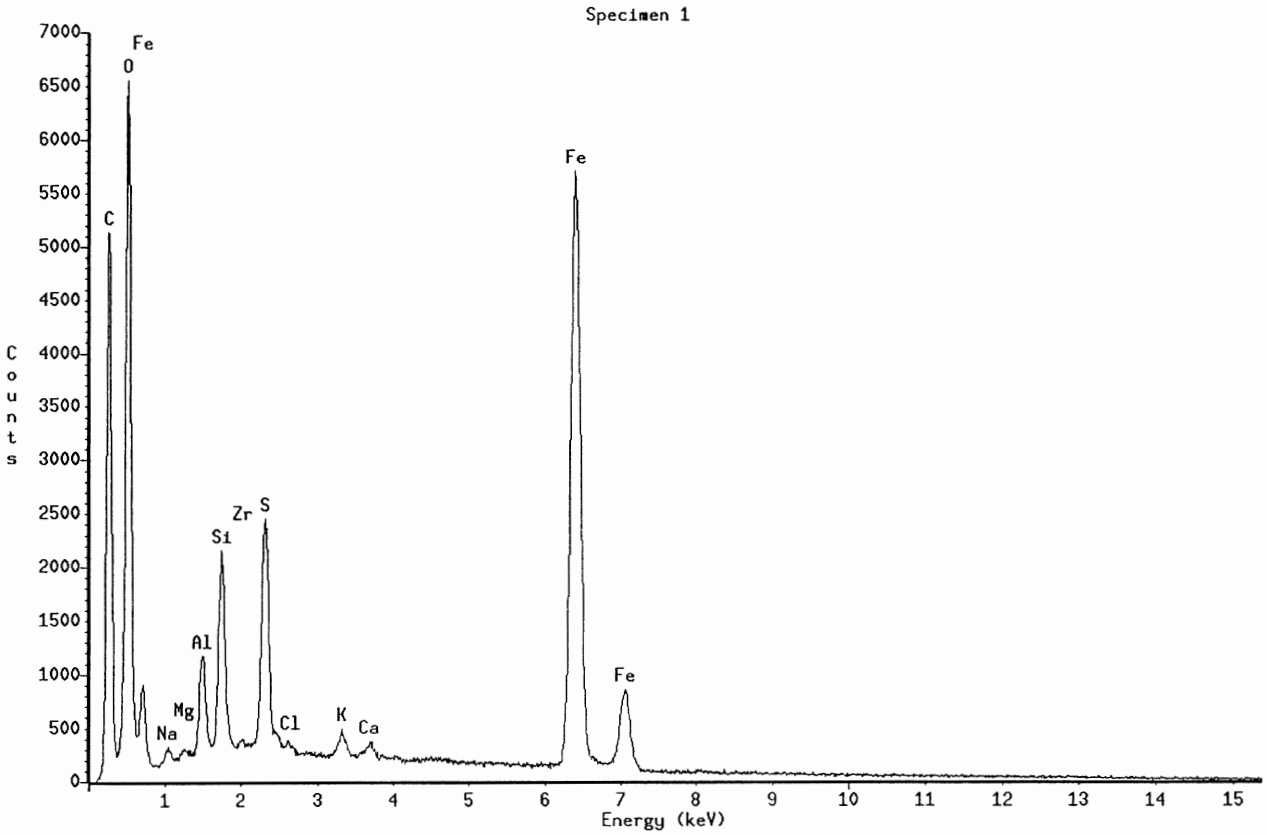
Thu Feb 12 14:06:00 1998

Livetime : 100.0 Sec.
Technique: Least Squares Fit

Elements Present:
C (6), O (8), Fe(26), Na(11), Mg(12),
Al(13), Si(14), S (16), Cl(17), K (19),
Ca(20), Br(35)

Energy	Intensity	Element
0.271	17432	C Ka

Figure 4.8 Results from the Energy Dispersal Spectrometry (EDS) on the translucent amber material. 1a. Specimen 1 1b. Specimen 39



Specimen 1

Column	: Column1.Pioneer		
Take-off angle	: 18.9659	Accelerating voltage	: 17.5
Acquisition type	: eds	Magnification	: 1800
Creation time	: 98/02/12 14:31	Charge	: 100
Livetime	: 100	Beam current	: 1
Deadtime	: 104.209	Beam spot size	: 0
Channels	: 2048	Beam location	: 0,0
Channel width	: 10	Working distance	: 20.1
Detector type	: Silicon/Lithium	Stage X	: 0
Window type	: norvar	Stage Y	: 0
Window thickness	: 0.3	Stage Z	: 1.6
Coating material	: Al	Stage tilt	: 0
Coating thickness	: 0.04	Stage rotation	: 0
Contact material	: Au	Contamination material	: none
Contact thickness	: 0.02	Contamination thickness	: 0
Crystal thickness	: 3		

File name : /usr/home/voyager/spectra/Thomas/DBScott/spec_1.eds

Notes:

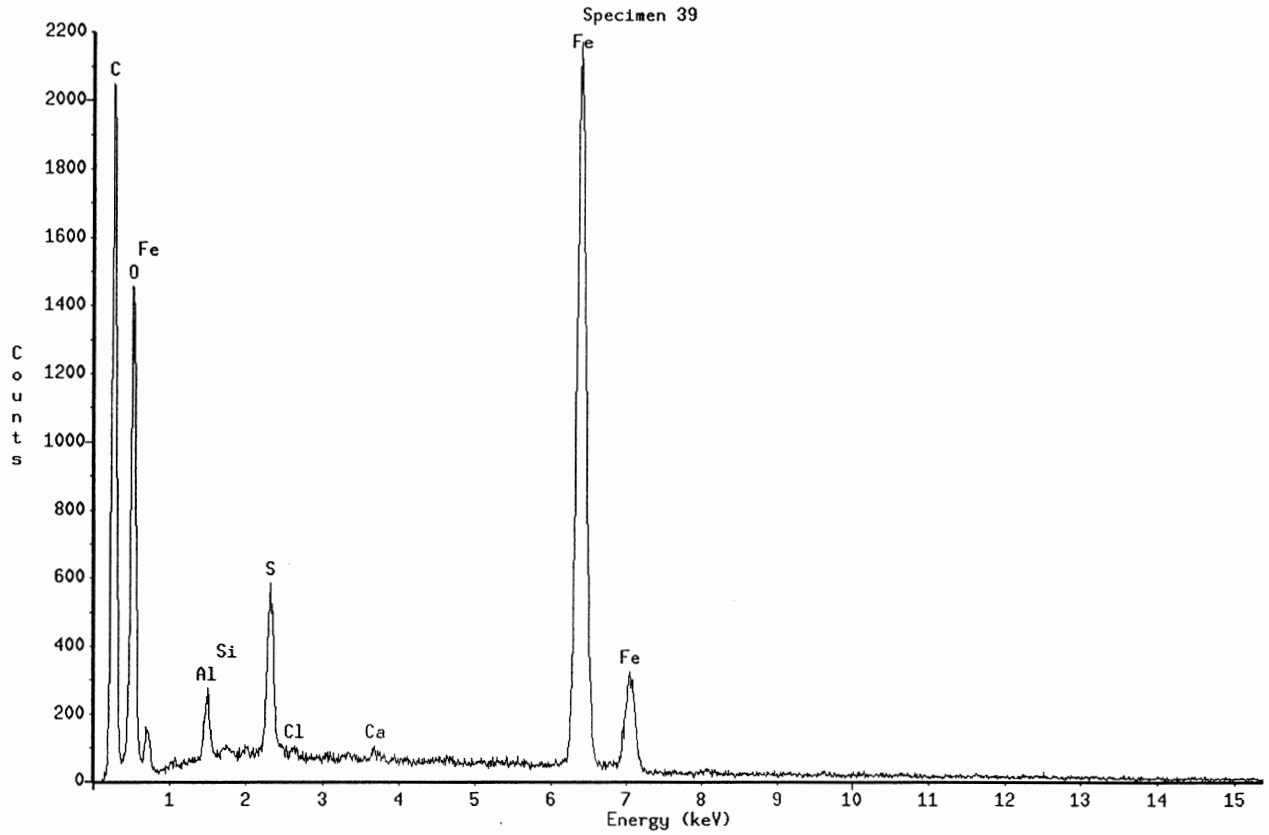
Thu Feb 12 14:31:48 1998

Specimen 1

Livetime : 100.0 Sec.
Technique: Least Squares Fit

Elements Present:
C (6), O (8), Fe(26), Na(11), Mg(12),
Al(13), Si(14), Zr(40), S (16), Cl(17),
K (19), Ca(20), Br(35)

Energy	Intensity	Element
0.271	37949	C Ka



Specimen 39

Column	: Column1.Pioneer		
Take-off angle	: 3.93565	Accelerating voltage	: 17.5
Acquisition type	: eds	Magnification	: 465
Creation time	: 98/02/12 14:15	Charge	: 100
Livetime	: 100	Beam current	: 1
Deadtime	: 31.136	Beam spot size	: 0
Channels	: 2048	Beam location	: 0.0
Channel width	: 10	Working distance	: 11.6
Detector type	: Silicon/Lithium	Stage X	: 0
Window type	: norvar	Stage Y	: 0
Window thickness	: 0.3	Stage Z	: 1.6
Coating material	: Al	Stage tilt	: 0
Coating thickness	: 0.04	Stage rotation	: 0
Contact material	: Au	Contamination material	: none
Contact thickness	: 0.02	Contamination thickness	: 0
Crystal thickness	: 3		

File name : /usr/home/voyager/spectra/Thomas/DBScott/spec_39.eds

Notes:

Thu Feb 12 14:15:25 1998

Specimen 39

Livetime : 100.0 Sec.
Technique: Least Squares Fit

Elements Present:
C (6), O (8), Fe(26), Al(13), Si(14),
S (16), Cl(17), Ca(20)
Possible Additional Elements:
Br(35)

Energy	Intensity	Element

These results indicate that the specimens are carbon based, not minerallic, nor are they simply organic coated quartz grains; although the tests of agglutinated foraminifera may be composed of quartz grains. Each specimen was examined under the petrographic microscope in order to determine that the chambers were in fact chambers.

Chapter 5 DISCUSSION

5.1 INTRODUCTION

Foraminiferal assemblages can be used to define ecological environments. An environmental niche can be defined on the presence of a particular genera and species as well as the nature of the particular test, whether it be agglutinated or calcareous (Murray 1991).

When dealing with fossil material, taphonomic processes complicate the identification of the remains and paleoenvironment interpretation (Boersma 1986). In this particular study, recrystallization and deformation make identification at the species level virtually impossible. Identification is done primarily on the basis of photomicrographs and the external morphology of the test.

5.2 DISCUSSION

The specimens recovered from the Halifax Group were excellent quality specimens. Very few natural phenomenon can destroy agglutinated foraminifera (Scott and Medioli 1980b). Although there are two distinct groups, the lighter brown agglutinated material and the amber-colored glassy material, both are very well preserved. Chamber arrangement and coiling mode were observed in the light brown material, and in the amber material, chambers were visible.

The earliest undoubted foraminifera found prior to this find was in West Africa (Culver 1991). These foraminifera were well preserved, unilocular and only eighteen specimens were found in the sample location. The Halifax samples yielded many

multichambered foraminifera, and the specimens reported here are only a small fraction of the specimens present in sample material.

Prior to this discovery the oldest validated multichambered foraminifera find was in the Mifflen Formation of the Plattville Group of Illinois (Gutschink 1986). These specimens, *Reophax blackriveranus*, have been interpreted to have evolved from a straight or simple branching tubular shape to one with partitions and multichambers (Gutschink 1986). The specimens that were found in the Halifax Group are clearly members of the modern genus *Trochammina*. The morphologies are not as primitive as that of *Reophax blackriveranus* (a partitioned tubular shape), rather they are a complex trochospiral morphology, with the chamber arrangement helicodial, spiraling among more than one plane (Boersma 1986).

The age of Halifax Group specimens also predate the *Reophax blackriveranus* specimens. *Reophax blackriveranus* was discovered within the Mifflen Formation of the Plattville Group of Illinois (Gutschink 1986). The age of this formation is ~ 450 Ma, mid-Ordovician.

5.3 IMPLICATIONS FOR DEPOSITIONAL ENVIRONMENT

The modern *Trochammina* is an opportunistic micro-organism that can occur in almost any marine environment (Nagy 1995). The specimens discovered in the Halifax Group, especially Specimen 1 (Figure 4.1, 1.), are identified here as *Trochammina*. They cannot be identified past the genus level due to the lack of undeformed apertures (if any are visible): recent *Trochammina* are sub-divided into 25 species by means of aperture

alone. Specimen 1 from the Halifax Group appears very similar to the common marsh species, *Trochammina macresens.*

The rocks of the Halifax Group are traditionally interpreted as deep sea fan deposits, heavily influenced by continental shelf slumping. If specimen 1 is indeed *T. macrescens* then the implications of the environment of deposition are quite different than the currently accepted interpretation. Monospecific assemblages with Trochammina macrescens are indicative of depth ranges of 100 cm above mean sea level (Scott and Medioli 1980b). This find implies that the environment of deposition may have been quite different than the current interpretation.

The specimens recovered from the Goldenville Group were found in an organic lens, at the same stratigraphic setting as the trilobite find on Tancook Island (Pratt and Waldron 1991). Considering that the environment of deposition for this bed has been based up to this point on sedimentological features such as the cross bedding channels and graded bedding. This seems to suggest that the mode of deposition would be a turbidite flow. However, this lens of material was also stratified at the same strike and dip as the surrounding quartzite (Scott and Medioli, in prep). This suggests that the lens was deposited at the same time as the surrounding bedrock.

The foraminifera from this outcrop are similar to modern salt-marsh taxa (Scott and Medioli 1980). These and the host strata have been interpreted as ancient salt-marsh deposits. A marsh is defined as an intratidal to supratidal area colonized by halophytic land plants (Murray 1991). The problem lies in the absence of any plant materials; the only evidence that it may be a "salt marsh"-like deposit is the similarity of the foraminiferal morphologies. There is a lot of organic material, but no actual plant

fragments, in the sample to support the salt marsh theory or sedimentary facies. Most of what would be considered marsh plants had not yet come into existence in the Cambrian (Scott and Medioli, submittted).

Diversity decreases from upper estuarine to upper marsh environments with marsh assemblages characterized by one or two abundant species (*Trochammina* – oligotypic assemblages) (Scott and Medioli 1980). Therefore the abundance of a single recognizable species within this deposit is on par with that of modern marsh environments. Scott (1996) and Scott and Medioli (in prep.) observed two other genera (*Ammotium* and *Haplophragmoides*) as well; both common to modern marshes.

Oxidation of organic material is thought to be an important process in the early metamorphism and diagenesis of organic carbon-bearing rocks (Zentilli and Graves 1988). Carbonate formation resulting from the oxidation of organic material results in the strong depletion of $\delta^{13}C$ (Hoef 1982). This is not the norm in the precipitation of sea water (Zentilli and Graves 1988). In their study, Zentilli and Graves (1988) found that the Eastville carbonates resulted from the oxidation of organic material while they were within their original sediments with the suitable oxidants still available.

The interpretation of the high levels of carbon and oxygen suggests a shallow marine environment. Zentilli and Graves (1988) found high values of carbon, up to 5%, in the transition zone between the Halifax and the Goldenville Groups. High carbon values are indicative of shallow marine environments not deep sea environments.

The emplacement of the South Mountain Batholith at ~ 372Ma (Clarke 1997), may have played a role in the production of the chert nodules surrounding the apparent

organic horizon. This chert layer appears to have protected the lens from further metamorphism and deformation.

5.3 CHEMICAL DATA

The results of the Energy Dispersal Spectrometry indicate high concentrations of both carbon and iron in both the amber and the light brown material. The high carbon and oxygen values indicate organic material, therefore dispelling the notion that these are zircon or quartz grains. The frequency of silica does not exceed that of carbon in any of the specimens sampled.

The iron is likely responsible for the color alteration of the specimens.

Chapter 6 CONCLUSIONS

The specimens found in this study of the Halifax Group samples are foraminifera. They are a multilocular assemblage composed of *Trochammina* specimens. This assemblage is more complex than the prior Cambrian- Early Ordovician foraminiferal assemblages found. While those displayed were simple tubular and branching forms, this assemblage is composed of foraminifera with helicoidal trochospiral chamber arrangements.

The presence of these fossils in the Cambrian has broad implications for the evolutionary history of foraminifera. If a complex test arrangement such as that found in *Trochammina* is present in the Cambrian, then primitive forms must have evolved prior to this date.

The presence of *Trochammina macrescens* within this assemblage has implications for the interpretation of the sample locations. This species is restricted at the present day to areas with tidal ranges 100 cm above mean sea level. The occurrence of this species in a formation interpreted on sedimentological grounds requires further evaluation.

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