DEVONIAN FORAMINIFERA FROM MIGUASHA PARK- UNESCO WORLD HERITAGE SITE, GASPÉ PENINSULA, QUÉBEC

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Abstract

The Upper Devonian (Frasnian) Escuminac Formation from the Miguasha National Park is world renowned for its well-preserved and diverse fossil fish assemblage. It has also been the subject of continuous debate concerning its depositional environment, variously considered lacustrine, estuarine, and coastal marine. For the first time, foraminifera and thecamoebians have been identified in this formation. The presence of both foraminifera and thecamoebians suggest a brackish-water estuary environment.

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Acknowledgements

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CHAPTER 1 INTRODUCTION

1.1 Opening Statement

Miguasha National Park is a palaeontological site of world importance, containing abundant fossils of fish, plants and some invertebrates. This area was designated a World Heritage Site in 1999 in recognition of its abundant and exceptionally well preserved fossils. Samples collected in 2005 by Dr. David Scott of Dalhousie University have yielded foraminifera, which were not previously known there. This is a remarkable discovery, with considerable significance for assessing paleoenvironment and salinity during deposition of the Escuminac Formation.

1.2 Miguasha National Park

The first discovery of macrofossils in the Chaleur Bay area of the Gaspé Peninsula (Fig. 1) occurred in 1842 by Dr. A. Gesner, a geologist with the Geological Survey of New Brunswick. He was exploring the northwestern area of New Brunswick and decided to cross the Restigouche River to examine the rocks in Québec. While exploring the shoreline and cliffs he discovered the fossil plants and fish. This discovery was essentially ignored and it was not until 1879 that R.W. Ells of the Geologic Survey of Canada re-discovered the site and proper scientific exploration began (Lemieux, 1996).

The abundant and diverse fossils of the Escuminac Formation have drawn collectors and scientists from all over North America and Europe. Local collectors used to sell fossils and as a result, hundreds of fossils from Miguasha can be found in universities and museums worldwide. In 1985, the Province of Quebec created the Miguasha National Park to protect the rich fauna and flora of the Upper Devonian

(Frasnian 385-374 Ma) Escuminac Formation (Prichonnet et al, 1996). Species of plants, micro-organisms, vertebrates, and invertebrates are found here (Desbiens et al., 2005).

Continental floras in the form of abundant and well-preserved spores have been identified in the Escuminac Formation. Large isolated leaves referred to as *Flabellifolium* sp. and branch systems of two species of the progymnosperm *Archaeopteris* (*A. halliana and A. obtusa*) are present throughout the formation. The terrestrial macroflora also includes the barinophyte *Protobarynophyton*, and a *Barinophyton*-like *strobilus* in the lower part of the formation (Desbiens et al., 2005).

The terrestrial invertebrate assemblage includes the scorpion *Petaloscorpio bureau*, the archilopodan millipede *Zanclodesmus willetti*, and cuticle fragments of other undetermined arthropods. The aquatic invertebrate assemblage present in the Escuminac Formation is poorly diversified and there is a total absence of typical marine groups including corals, bryozoans, brachiopods, cephalopods, trilobites, graptolites and echinoderms (Prichonnet et al., 1996). It includes the conchostracan *Asmusia membranacea*, rare remains of a stylonurid eurypterid and a polychaete (Desbiens et al., 2005).

The most significant fossils found in the Escuminac Formation are the abundant and diverse vertebrate fauna. The vertebrate assemblage is composed of 21 species of fish. The preservation of these fossils ranges from flattened, compressed, to three-dimensional; and specimens may be found articulated or disarticulated, with various degrees of disarticulation being observed (Parent and Cloutier, 1996).

Extremely well preserved fossil fish from the Devonian provide an important record of evolution and diversification of fish species. At this time life on Earth was almost entirely aquatic; there were no reptiles, birds or mammals (Cloutier, 2001). The Devonian, also known as the "Age of Fishes", was when several new groups appeared as fish dominated aquatic environments. Fish evolved to give the first terrestrial vertebrates: tetrapods. Reports of tetrapod trackways and body fossils from the early Middle Devonian (Eifelian stage) of Poland are now known (Niedźwiedzki et al., 2010). They are from the Wojciechowice Formation which was deposited in a tidal flat or lagoon environment.

In December 1999, Miguasha National Park was added to UNESCO's list of World Heritage Sites because of the scientific significance of the Escuminac Formation. These rocks contain the most representative fauna and flora of the Devonian. The fossils found here are abundant, extremely well preserved and represent evolutionary lineages not present elsewhere in the world (Cloutier, 2001).

1.3 Early Foraminifera

Foraminifera are single-celled protists which belong to the Phylum Sarcodina, Superclass Rhizopoda, Class Granuloreticulosa (Loeblich, and Tappan, 1964). These organisms produce a shell, called a test, which can be structurally complex and is highly variable between species. Foraminifera occupy all marine habitats, from the deep ocean floor to coastal marine areas and salt marshes. They can live on the seafloor (benthic) or float in the water column (planktonic), although planktonic forms did not evolve until the Mesozoic. These organisms are important because their tests or shells can be found in sediments as fossils after the animal dies (Scott et al., 2003). This makes them an important biostratigraphic tool, but also useful for paleoclimatology and paleoceanography.

Foraminifera have been found in rocks as old as Cambrian (545-488 m.y.a.) by Culver (1991), Culver et al. (1996), and Scott et al. (2003). At this time some foraminifera evolved the ability to encase themselves in a protective covering of sedimentary particles; they did this by cementing mud and/or sand particles onto a layer of tectin, an organic compound composed of protein and polysaccharides. This forms an agglutinated wall structure, still common today, although the grains used may now include the tests of other microorganisms, oolites, or microgranules of calcite (Boersma, 1978).

The foraminifera reported by Culver (1991) and Culver et al. (1996) were unilocular (single-chamber) agglutinated specimens of the genera *Ammodiscus, Glomospira*, and *Turritellella* from the Lower or possibly middle Cambrian siltstones of the Fougon Member of the Nandoumari Formation in southeastern Senegal. Scott et al. (2003) reported on an assemblage of multi-chambered trochospiral, planispiral and planispiral/uniserial foraminifera from the Lower to Middle Cambrian sandstone and slate of the Tancook Member of the Goldenville Formation in southern Nova Scotia. This assemblage includes specimens similar to modern marsh and marine forms, and includes genera such as *Trochammina, Haplophragmoides*, and *Ammobaculites* (Scott et al. 2003; Scott and Medioli, 1980).

Prior to these findings, the oldest known foraminifera were very simple, tubular and spherical forms of the genera *Platysolenites, Spirosolenites*, and *?Psammosphera.*

These specimens are reported by McIlroy et al. (1994) as being found worldwide near the Precambrian-Cambrian boundary (~545 m.y.a.).

1.4 Objectives

The purposes of this study are to:

1) Review previous interpretations of the depositional environment of the Escuminac Formation.

2) Validate the paleoenvironmental interpretations of the Escuminac Formation using foraminifera found in the rocks.

3) Compare these fauna to other Devonian and Paleozoic fauna of similar affinity.

CHAPTER 2 METHODOLOGY

2.1 Introduction

A brief description of the processing and observational techniques used to recover microfossils from the rocks of the Escuminac Formation is included in this section. A significant amount of time was required in this study for the application of standard micropaleontological techniques. Typical lithologies of the Escuminac Formation are calcareous sandstone (mostly fine and very fine-grained with some beds of medium grain size), calcareous siltstone and shale, and laminites. The laminites are composed of alternating dark (clay and organic matter) and light (silt-sized calcite and quartz) laminae less than 1 mm thick (Desbiens et al, 2005). Samples collected for this study were taken from the siltstone and shale lithofacies.

2.2 Processing Foraminifera from Rock Samples

Samples of approximately 50 grams were selected, and mechanically broken into 5-10 cm sized pieces to expose a larger surface area to the water and chemicals during processing. Crushed samples were then washed using a sieve to remove as much rock flour as possible before processing. Including the rock flour in the sample may give the impression of disaggregation when none has actually taken place.

After washing, hot (almost boiling) water was poured over the sample and stirred. The sample was placed on a hotplate (no boiling) for 3-5 days, stirred several times daily, and distilled water was added as necessary to prevent drying out. The time required to process the samples depends on their composition, and may range from a few days for soft claystones to several weeks for harder siltstones. Not all samples will disaggregate completely, and in some cases only a few grams of residue will be obtained after repeated processing.

To aid in disaggregation of samples, household fabric softener is used. This works as a surfactant (i.e. surface acting) which causes breakdown of the ionic bonds between minerals (Wightman, 1993). After several days on the hotplate, Snuggle® fabric softener was added to samples (5ml for samples that have started to disaggregate, up to 15 ml for harder samples). Samples were stirred several times daily and distilled water added to prevent drying out.

Each week samples were washed to remove fabric softener and check the amount of disaggregation. Any large rock fragments were reprocessed using these same steps. Samples that were not disaggregating were also treated to an ultrasonic bath in 10 second bursts for up to 50 seconds.

After processing, samples contain fine residues of mud, silt, and clay minerals that must be removed to concentrate the larger sized particles which may contain microfossils. During washing, the sample residue was placed in the sieve and rinsed under a flow of running water until all particles smaller than the sieve mesh size were washed away. A strong flow of water should be avoided as this may damage fragile microfossils. After wet sieving, the residue was gently flushed into a petri dish with a fine jet of distilled water. After settling, the supernatant water was poured off and the sample was left to dry. A surface crust on the dry sample indicates insufficient washing, and any such sample should be reprocessed.

2.3 Sample picking

Each dry sample was fractionated with a series of sieves: 63μm, 125 μm, 250 μm and 500 μm. The residue fractions were then examined for foraminifera using a binocular microscope under reflected light. Residues were shaken thinly onto a shallow tray and examined for foraminifera on the basis of shape and colour. It is necessary to examine specimens carefully for features such as apertures or sutures or traces of organic linings at the edges of chambers. To aid in this, the light source was at a low angle of incidence to cast shadows over depressions and highlight relief on the surface of the specimens. Foraminifera are picked with a fine (000 gauge) artists paint brush, moistened at the tip, and placed in a 60-cell slide which has water soluble gum Tragacanth glue in it for further observation. The glue, being water soluble, will then dry and secure the foram to the slide. At any time, wetting the specimen will release the glue so that the specimen may be turned and viewed from different angles.

2.4 Photomicroscopy

The main drawback with the binocular microscope is the loss of depth of field at higher magnifications, which makes the photography of small (<400μm) specimens difficult. Low-angle incident light is quite useful for observing low relief on compressed and deformed specimens, however, it is difficult to photograph such material under low light conditions (Wightman, 1993).

2.4.1 Scanning Electron Microscope

The scanning electron microscope (SEM) was used as an observational tool in the search for apertural and other details on foraminiferal tests, as well as for specimen photography. The main drawback of the SEM is that it only gives an image of the surface of the specimen, and no indication of internal features, even in the case of translucent specimens. Features of low relief which may be seen under the binocular microscope with low incident angle reflected light are difficult to see using the SEM (Wightman, 1993). Many SEM photographs were taken but many did not show the features visible with the light microscope and low-incident angle light.

CHAPTER 3 THE GASPE PENINSULA

3.1 Introduction

The Gaspé Peninsula represents the northern segment of the Appalachian Mountains (Fig.3.1). This area has been shaped by major tectonic events such as the opening of the Iapetus Ocean in the Late Precambrian to its closure in the Middle Devonian. These rocks have also been shaped by two major orogenies: the Taconian during the Late Ordovician and the Acadian during Late Silurian to Middle Devonian (Bourque, 2005).

Figure3.1: Map showing the location of the Appalachian Mountains and their northern extent into the Gaspe Peninsula (circled). (Modified from: *http://geography.howstuffworks.com/united-states/the-appalachians.htm)*

3.2 Regional Geology and Stratigraphy

The rocks of the Gaspé Peninsula can be divided into three broad assemblages (Fig 3.2): Latest Precambrian to Late Ordovician rocks which occupy the northern part of the Peninsula, which were strongly deformed by the Taconian orogeny; 2) Late Ordovician to Late Devonian rocks located in the center and southern part of the Peninsula deformed by the Acadian orogeny; 3) Late Devonian and Carboniferous flat-lying rocks, deformed by faulting during the Alleghanian orogeny (Bourque, 2005).

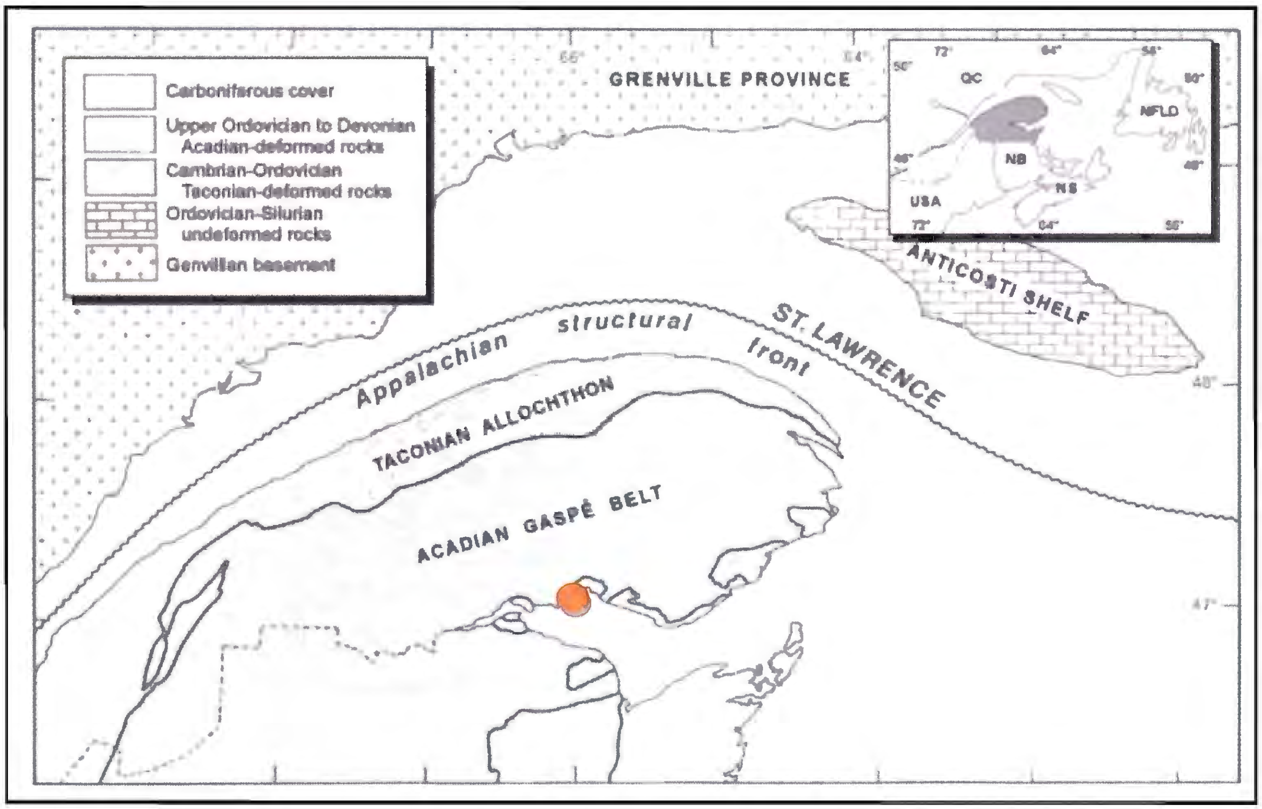

Figure 3.2 Tectonic setting of Gaspé Peninsula, location of Miguasha National Park marked in red (Modified from Bourque, 2005).

The Late Ordovician to Late Devonian rocks deformed during the Acadian orogeny can be divided into three structural units, from north to south (Fig. 3.3): the Connecticut Valley-Gaspé Synclinorium, the Aroostook-Percé Anticlinorium and the Chaleurs Bay Synclinorium, which is the focus of this study (Bourque, 2005).

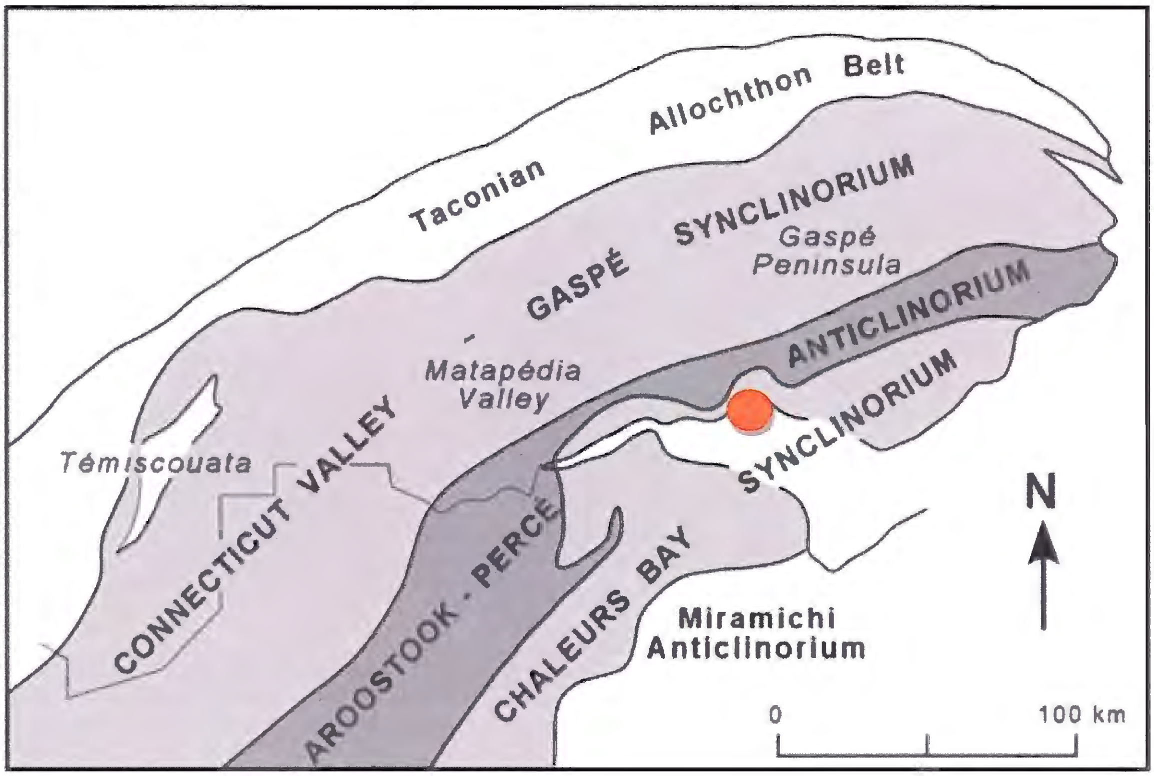

Figure 3.3 Divisions of the Gaspé Belt in Québec and New Brunswick showing the distribution of Late Ordovician to Late Devonian rocks. Location of Miguasha National Park marked in red. From Bourque, 2005.

The core of the Chaleurs Bay syncline is occupied by mafic to intermediate volcanic and sedimentary rocks (Fig 3.4) of the Early Devonian Indian Point and Val d'Amour Formations (Dalhousie Group); these are in turn overlain by a sequence of clastic rocks which includes the Lower Devonian Lagarde Formation, the early Middle Devonian Pirate Cove Formation, and the early Upper Devonian Fleurant and Escuminac Formations (Miguasha Group). The remaining rocks in the syncline include the Carboniferous Bonaventure Formation and Quaternary deposits (Rust et al., 1989; Bourque, 2005).

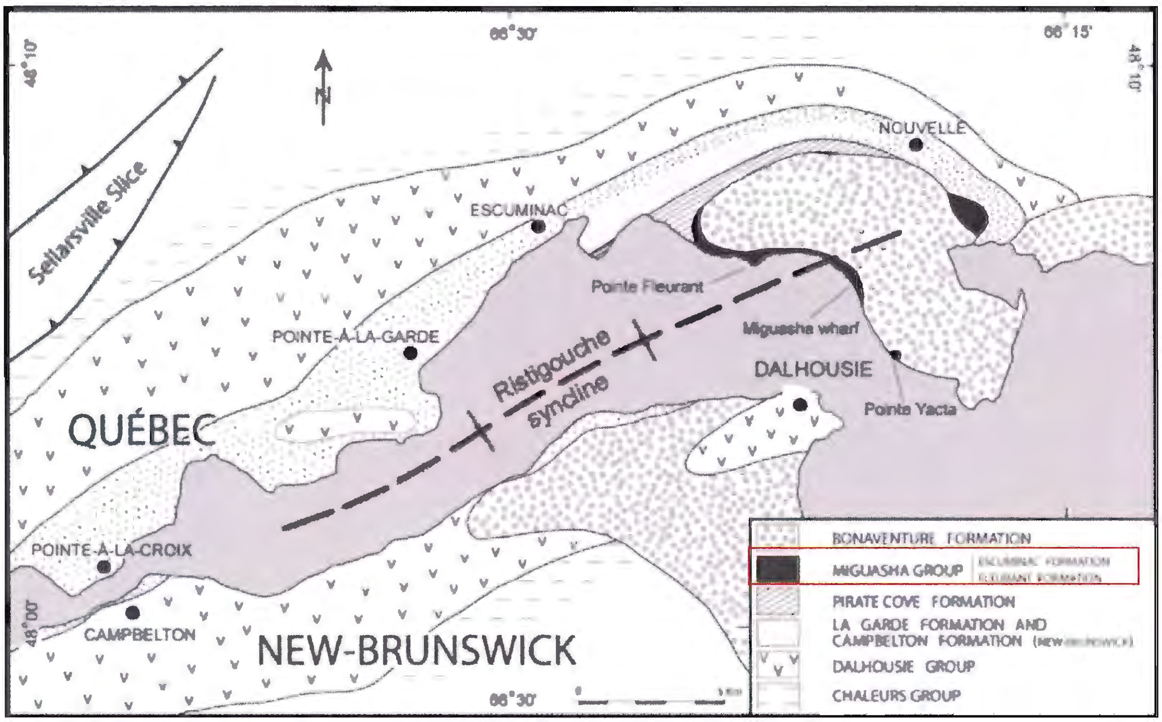

Fig 3.4: Geologic map of the Chaleur Bay syncline, also referred to as the Ristigouche syncline, showing the distribution of the Miguasha Group in the northeastern section. Modified from Desbiens et al, (2005).

The oldest Devonian strata in southern Gaspé is the Lagarde Formation; a gray to green boulder to pebble conglomerate, with minor sandstone and mudrocks. Clasts in the conglomerate are primarily lavas, with minor intrusives, quartz and quartzite, and locally some limestone clasts. This formation is interpreted as a proximal alluvial deposit based on sedimentology (Rust et al. 1989).

The Pirate Cove Formation includes alternating units of red limestone conglomerate and red and grey sandy siltstone to mudstones with lenses of sandstone (Bourque, 2005). The conglomerate units are mainly horizontally stratified pebble to cobble conglomerate, with some tabular units of planar cross-stratified pebble conglomerate. The siltstone/mudstone units contain rippled siltstones with abundant *in situ* roots. The sandstone lenses form channels up to 1.8 m thick which frequently fine upward. The depositional model for this formation includes two separate alluvial systems: a lateral alluvial fan-braidplain system and an axial muddy alluvial plain (Rust et al., 1989).

The Fleurant Formation overlies the Pirate Cove Formation with an angular unconformity. It is composed of well-rounded, horizontally layered pebble to cobble conglomerate, with mainly limestone clasts. Lenses of finer-grained cross-stratified conglomerate transition into planar or trough cross-stratified sandstones. Thinly laminated shale or siltstone is also present. Rust et al. (1989) interpreted this formation as a fluvial braidplain deposit.

The Escuminac Formation conformably overlies the conglomerates of the Fleurant Formation. Together these two formations comprise the Miguasha Group. The Escuminac Formation is composed of gray-green rhythmically laminated mudrocks, and graded siltstones to sandstones. The Carboniferous Bonaventure Formation, also a conglomerate, lies discordantly on top of the Escuminac Formation (El Albani et al, 2002).

3.3 The Escuminac Formation

3.3.1 Introduction

The Escuminac Formation is located on the south coast of the Gaspé Peninsula in the Chaleur Bay region. Outcrops of the Escuminac Formation are found east and west of Miguasha Wharf, at Pointe Yacta, and inland at Nouvelle (Fig. 3.4). The Escuminac Formation is 119 m thick and is best exposed along the coast forming steep cliffs varying from 3 to 30 m high. The formation is preserved in a synclinal fold whose axis is oriented in a NE-SW direction. (El Albani et al, 2001).

3.3.2 Lithology

Four different lithofacies are found in the Escuminac Formation: 1) sandstone, 2) siltstone 3) shale and 4) laminites (Fig. 3.5). These lithofacies contain diagenetic pyrite, fibrous calcite, and carbonate concretions, locally occurring together (El Albani et al. 2002).

The Escuminac Formation is composed of poorly sorted calcareous sandstones, mostly fine- and very fine-grained with some beds of medium grain-size, with detrital quartz, plagioclase feldspar, and muscovite. Sandstone beds vary in thickness from 1 cm to 2.25 m and average 32 cm in thickness (El Albani et al. 2002). Most of the sandstone beds are of turbidite origin (Desbiens et al. 2005).

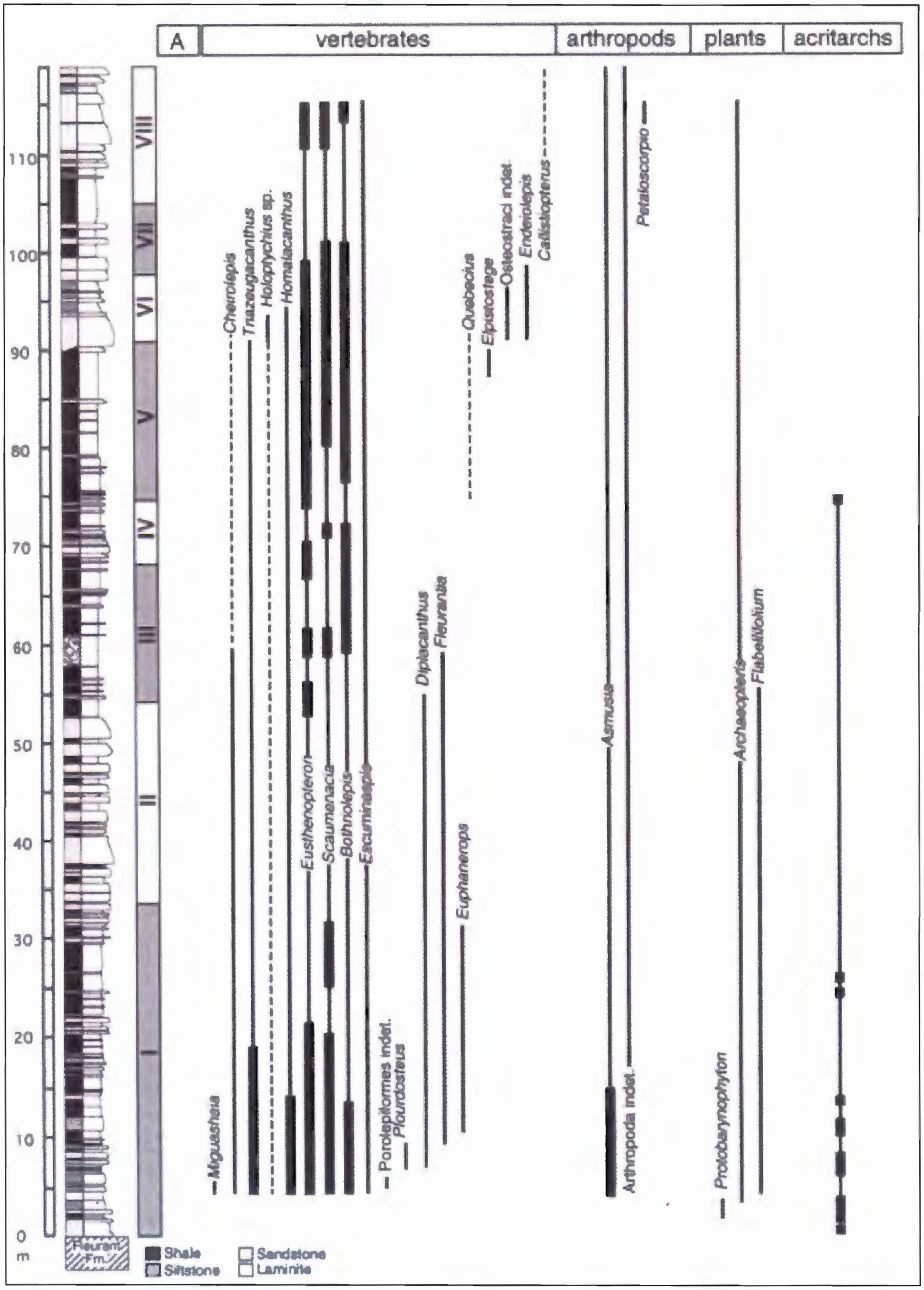

Figure 3.5 Stratigraphic column of the Escuminac Formation. Roman numbers correspond to the eight units of Hesse and Sawh (1992) which are described in Table 3.1. Faunal and floral distributions of species according to Cloutier et al, 1996. Modified from Desbiens et al, 2005.

Light grey calcareous siltstones occur throughout the formation. They display bed thicknesses from 1 cm to 1.70 m, averaging 23 cm. The laminate lithofacies, termed "rhythmites" by Dineley and Williams (1968), are composed of alternating dark (clay and organic matter) and light (silt-sized calcite and quartz) laminae of less than 1 mm thick. Muscovite mica is abundant and plagioclase feldspar is present. This lithofacies occurs in beds varying in thickness from 1 to 89 cm, averaging 9 cm and are more common in the lower part of the formation. This lithofacies has been interpreted as tidal laminites. Diagenetic fibrous calcite thin beds are common in the laminate lithofacies (El Albani et al. 2002).

Dark grey, light grey and greenish shales are the most abundant lithofacies. Two types of lithofacies occur in the shaly layers: homogeneous shale and shale with fine parallel layers of dark amorphous organic matter. The thickness of the shale beds ranges from 2 cm to 4.11 m, averaging 35 cm. Most fish found in this lithofacies are poorly preserved and are represented as isolated bony elements such as scales (El Albani et al., 2002).

Fossililerous carbonate concretions are common at many levels of the formation. These may be flattened, circular and laminated concretions found in laminites and laminated shales or dense siltstone-sandstone concretions that occur in shales as well as in the siltstone or sandstone. The diameter of the concretions ranges from 2 cm to 1.2 m (El Albani et al. 2002, Desbiens et al. 2005).

Sedimentary structures are present throughout the Escuminac Formation. Small and large flute casts, ripple marks, groove, prod, and bounce marks are common; Ball-and-pillow structures, deformed sand balls in shale, as well as also occur. There are a wide variety of linear markings, the origin of some remains unknown (Dineley and Williams, 1968). The five divisions of the Bouma sequence have been recognized in the Escuminac Formation; however there is no bed that contains an entire sequence and graded bedding is rare (Prichonnet et al. 1996).

The Escuminac Formation has been the subject of numerous studies to determine its sedimentology and fossil distribution. Russell (1939) proposed 5 zones of discontinuous distribution based on fossils as known at that time. Dineley and Williams (1968) divided the formation into 4 successive units based on the distribution of sandstone beds. Hesse and Sawh (1992) subdivided the formation into 8 units based on the sandstone to shale ratio. This information is summarized in the following table.

Unit	Bed #	Meters above base	Sandstone/shale ratio	Notes
I	1-111	0-32	Ss/sh: 0.65	Shale dominated; upward shale alternates with fine to very fine-grained sandstone and laminite beds. Mud cracks and desiccation mud chips occur in lower 3 m. Bed 8 is most diversified including 8 species and the branchiopod *Asmusia.*
II	112-217	32-53	Ss/sh: 3	Fine-grained sandstone rich, laminite beds are rare and thin. Flute, groove and load casts are common. Rare fossils.
III	218-276	53-68	Ss/sh: 0.3	Shale-dominated with thin turbidite sandstone beds, some well-developed sole marks. Fish abundant in laminated concretions.
IV	277-324	68-74	Ss/sh: 0.9	Mainly sandstone-siltstone turbidites alternating with shale and laminite beds. Some concretions with rare fish.
V	325-355	74-88	Ss/sh: 0.06	Shale dominated with laminites and sandstone turbidites. Very rich in fossiliferous concretions.
VI	356-368	88-106	Ss/sh: 3.6	Sandstone-dominated, large channel at the base which incises the underlying beds. Above this alternating turbidite sandstone beds and shale. Large calcite cemented concretions and diverse fish assemblage.
VII	369-374	101-106	Ss/sh: 0.65	Shale-dominated, lower few beds sandstone. Fossils rare and fragmented except for bed 370, a 60 cm-thick bone unit which is approx. 40% disarticulated plates of *Bothriolepis*.
VIII	375-394	106-118	Ss/sh: 6.3	Sandstone unit, upper beds have alternating reddish and greenish layers. Large concretions, plant and scorpion fragments, 3-dimensional fish.

Table 3.1: Summary of the Escuminac Formation based on the lithostratigraphic subdivision of Hesse and Sawh (1992).

3.3.3 Paleoenvironment

The depositional environment of the Escuminac Formation has variously been considered as lacustrine, marine, coastal marine, transitional, brackish or estuarine (El Albani et al. 2002).

Dineley and Williams (1968) suggested a fresh- to brackish-water lacustrine environment based on lithology, sedimentary structures, and fossils. Geochemical parameters have been used to interpret the paleoenvironmental conditions. Results of C, O and B isotopes and B concentrations (Chidiac, 1996), $^{87}Sr/^{86}Sr$, Na, F, Sr, and La analyses (Schmitz et al., 1991) suggest a marine or transitional environment. A diverse assemblage of acritarchs and a scolecodont show a marine influence during the deposition of the Escuminac Formation (Cloutier et al., 1996). Hesse and Sawh (1992) proposed an estuarine environment to accommodate the fauna, geochemistry and stratigraphic associations.

The laminites in the Escuminac Formation are important for determining the depositional environment. The millimeter-thick alternating light and dark laminae indicate the absence of benthonic organisms, probably due to periodically stagnant, anoxic bottom water (Hesse and Sawh 1992).

CHAPTER 4 RESULTS

4.1 Escuminac Microfauna

The type section of the Escuminac Formation near Miguasha wharf has been numbered from bed 1 to 394. Eleven samples have been analyzed for this study; they range from bed 6 to bed 357 (Fig. 4.1). An assemblage of agglutinated foraminifera (Plate 1) is present in the Escuminac Formation although they are not overly abundant.

The foraminifera found in the Escuminac Formation have been informally grouped under generic names of similar and commonly known, modern agglutinated foraminifera genera. These include: *Trochammina, Thurammina*, *Webbinelloidea* and *Cribrostomoides*. Comparing these Devonian specimens with modern genera serves to place them in a broad, easily identifiable category. Specimens from the Escuminac Formation are relatively poorly preserved and therefore it is not possible to identify them to the species level or erect new taxa based on them as physical traits needed to describe new genera are not clearly distinguishable.

Modern day representatives of *Trochammina,* and *Thurammina* are found in marsh and estuarine environments as shown by Scott and Medioli (1980). Similar agglutinated foraminifera have been found in black shales from numerous locations in the Illinois and Appalachian Basins covering the entire Late Devonian (Frasnian and Famennian) (Schieber, 2009). Malec (1992) reports an assemblage of foraminifera from a borehole in the western part of the Góry Świętokrzyskie Mts, central Poland. This assemblage contains *Webbinelloidea* sp. which are similar to foraminifera found in the Escuminac Formation.

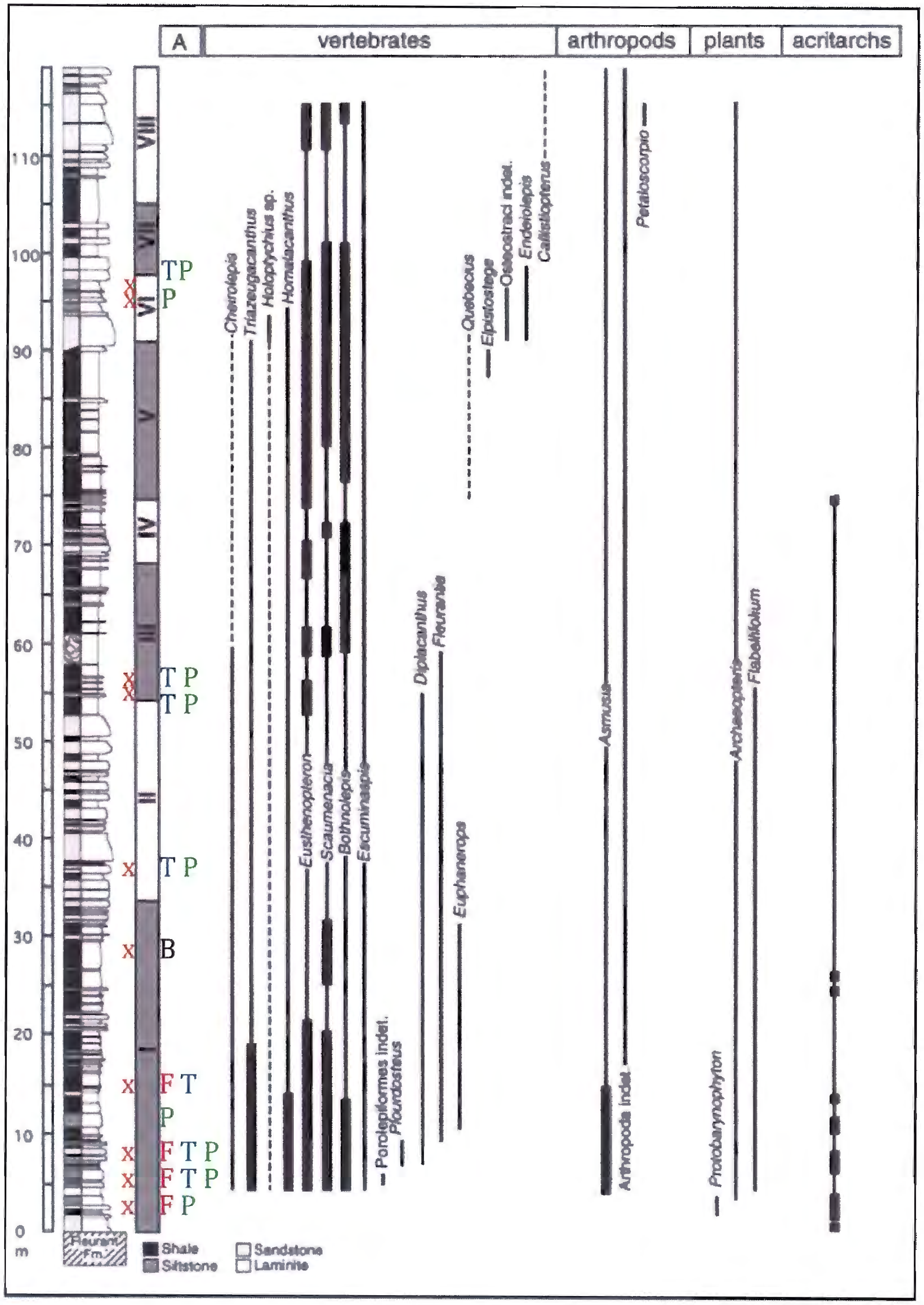

Figure 4.1: Stratigraphic column of the Escuminac Formation with sample locations indicated by X, and groups of microfossils present, F- foraminifera, T-thecamoebians, and P-palynmorphs, or B-barren.

In addition to foraminifera, thecamoebians have also been found in the Escuminac Formation (Plate 2). Thecamoebians is an informal term used to describe a polyphyletic group of Sarcodina, from the Class Rhizopodea, as well as Class Reticularea (Medioli et al, 1990). This is a separate group which is usually found in fresh water environments, but some brackish-water and possibly marine forms are known. Medioli et al (1990) questions whether or not there are any marine thecamoebians, due to how marine conditions are defined and how some marginal forms are classified. Thecamoebians from the Escuminac Formation have been grouped under similar modern thecamoebian genera. These include: *Centropyxis*, *Citron*, and *Difflugia*. These forms are all present in freshwater Cretaceous deposits of Alberta (Medioli et al, 1990). *Centropyxis* and *Difflugia* are known today from numerous lakes along the eastern North American coast from the Arctic to Florida (Collins et al, 1990).

Relatively well preserved palynomorphs have also been found in the Escuminac Formation (Plate 3). These forms are morphologically diverse, but a much smaller assemblage is reported here as compared to Brideaux and Radforth, (1969): 34 spore types, Cloutier et al, (1996): 31 spore types, or McGregor, (1996): 36 spore types. The Escuminac Formation appears to contain a number of new species. The variety of spores suggests progymnosperms as well as several plant groups in the regional vegetation; no palynomorphs of marine origin were found. The Escuminac miospores are part of a Frasnian mega-assemblage that extends across southern Euramerica from eastern North America to Western Europe (McGregor, 1996). This is similar to findings by Brideaux and Radforth, (1969), who suggested that Escuminac palynomorphs are comparable to Devonian assemblages in Scotland, Western Europe and western Russia instead of assemblages from North America. Identification of palynomorph species found in the Escuminac Formation are based on studies by Brideaux and Radforth (1969), Cloutier et al, (1996) and McGregor, (1996).

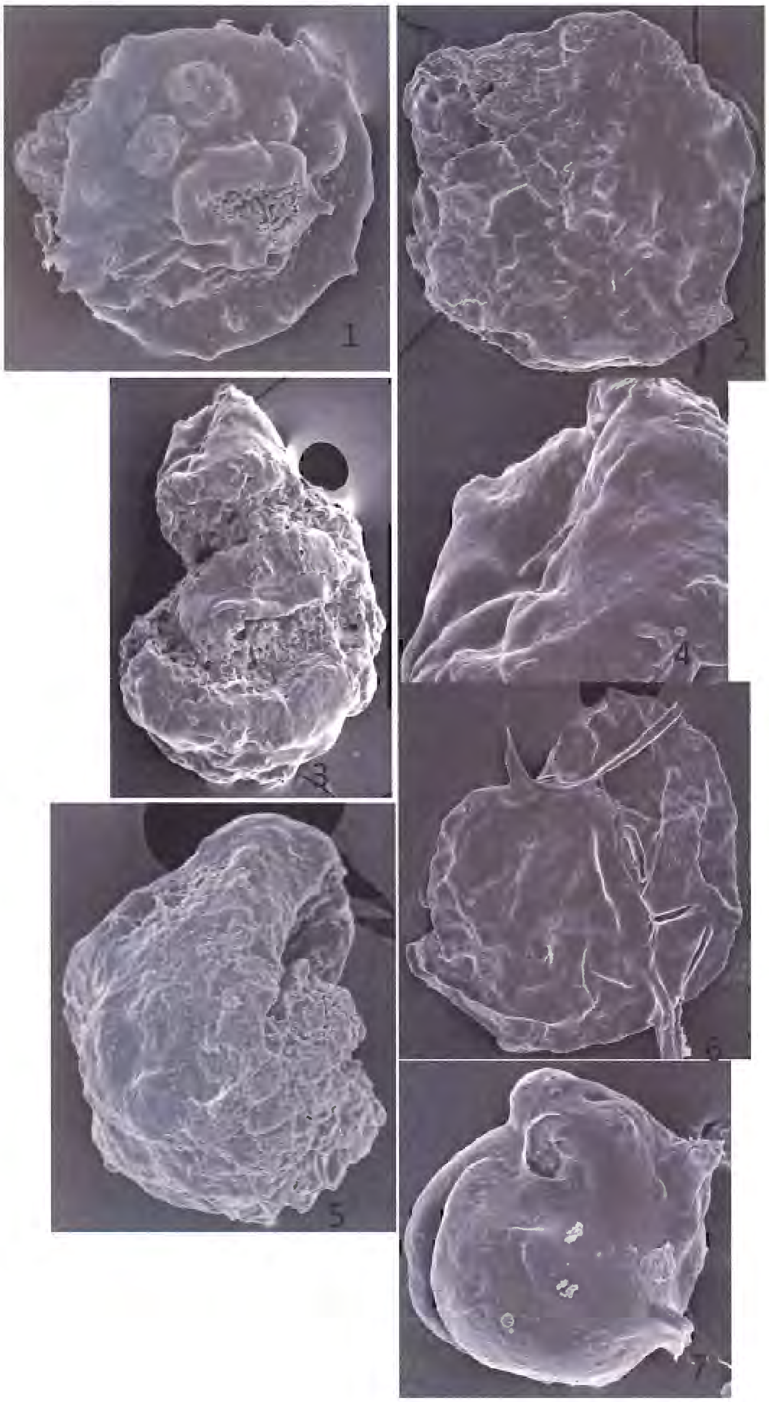

Plate 4.1

Scanning electron micrographs of foraminifera from the Escuminac Formation.
1 *Trochammina* sp,x500 **2** *Thurammina* sp, x300 **3** Ammobaculites? or*Trochammina* sp, x200 **4** Enlargement of aperture of specimen in Figure 3, x1000 **5** *Cribrostomoides* sp. x700 **6** *Trochammina* sp, showing collapsed chambers, x300 **7** *Webbinelloidea* sp, x700

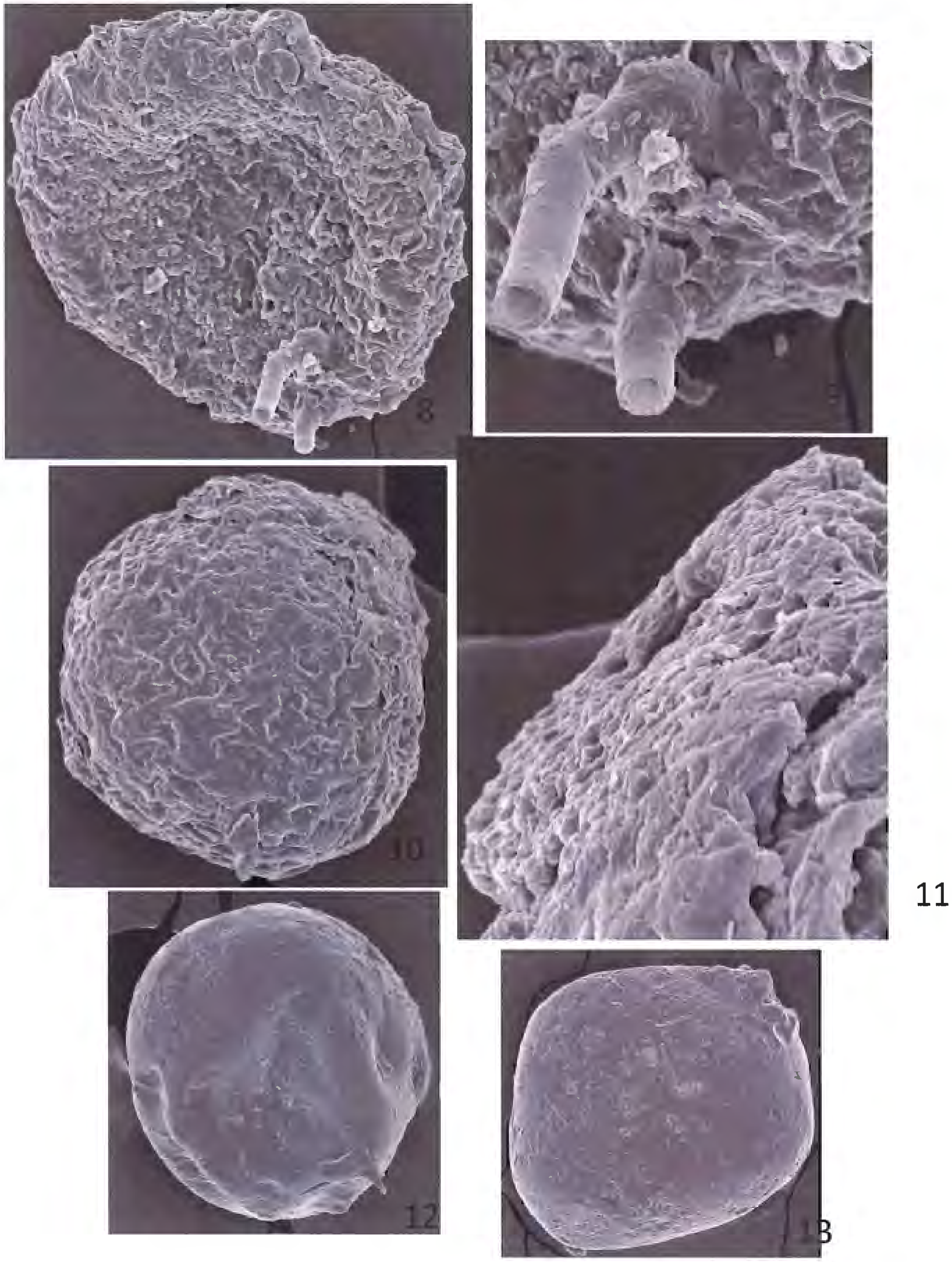

Plate 4.2

Scanning electron micrographs of thecamoebians from the Escuminac Formation.
8 *Centropyxis* sp. x700. **9** Enlargement of specimen in Figure 8, x2000 **10** *Difflugia* sp, x500 **11** Enlargement of aperature of specimen in Figure 10, x3000 **12** *Centropyxis* sp, x700 **13** *Citron* sp, x350

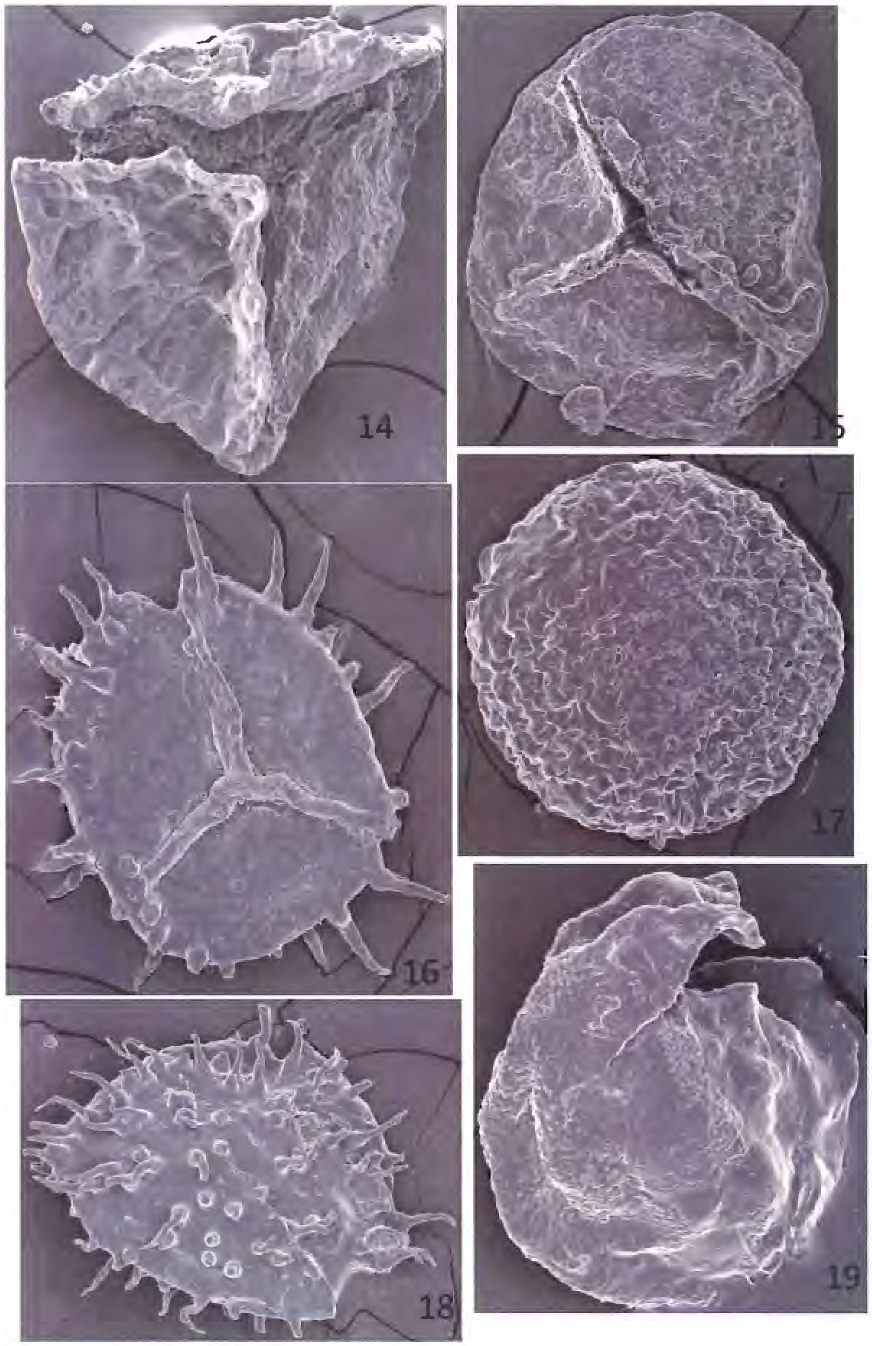

Plate 4.3

Scanning electron micrographs of miospores found in the Escuminac Formation. **14** *Grandispora* sp, x150 **15** *Punctatisporites* sp. cf. *P. pseudobesus* Playford 1962, x250 **16** *Ancyrospora carnarvonensis* (Balme) x300 **17** *Verrucosisporites bulliferus* Richardson and McGregor 1986, x350 **18** *Acanthotriletes* sp. A, x250 **19** *Rhabdosporites* sp. x500

CHAPTER 5 CONCLUSIONS

5.1 Depositional Environment of the Escuminac Formation

The Escuminac Formation contains 5 categories of fossils: 1) plants (macroscopic and microscopic), 2) invertebrates, 3) fish, 4) ichnofossils, and 5) coprolites.

Coprolites and ichnofossils are not useful for delineating paleoenvironment; coprolites provide information on the behavior of the organism that made them, but often that organism cannot be identified. Nearly identical ichnofossils can be produced by various animals that have comparable behaviors but are found in different environments (Prichonnet et al, 1996).

The most abundant plant macrofossils are fronds and stems of *Archaeopteris*. A diverse assemblage of miospores is present throughout the Escuminac Formation (Brideaux and Radforth 1969, Cloutier et al, 1996). However this material has all been transported in and indicates there were forests of progymnosperms and other vegetation nearby.

The branchiopod genus *Asmusia* is the most common invertebrate found in the Escuminac Formation. It is more abundant near the base of the formation. *Asmusia* belongs to the Conchostraca, which arose in the Early Devonian and still have 15 living genera. The forms living today are found in freshwater environments, although a few can tolerate somewhat brackish waters (Prichonnet et al, 1996).

Eurypterids are found in the upper part of the Escuminac Formation. *Pterygotus* which belongs to the family Pterygotidae is one of the largest eurypterids known. According to Copeland and Bolton (1985), eurypterids show a paleoecological adaptative sequence with only marine representatives in the Ordovician, euryhaline and lagoonal species in the Silurian, to brackish and freshwater forms in the Devonian. Mainly freshwater forms are known from the Carboniferous and Permian, however Maples and Schultze (1989) report marine species from this time (Prichonnet et al, 1996).

The scorpion *Petaloscorpio bureaui* is found in the upper part of the Escuminac Formation as rare partial specimens. This species belongs to the euscorpions, which are terrestrial. This suggests they were transported in like the plant material and not useful for determining paleoenvironment (Prichonnet et al, 1996).

The invertebrate assemblage is also notable because of the absence of typical marine groups such as corals, bryozoans, brachiopods, cephalopods, trilobites, graptolites, and echinoderms.

The Escuminac Formation is known for its diverse and abundant assemblage of vertebrates. They have attracted attention since their discovery and made this formation famous around the world. A complete description of the distribution and preservation of vertebrates in the Escuminac Formation can be found in Parent and Cloutier (1996).

The Agnatha are represented by 2 major groups: the Osteostraci and the Anaspida. The Osteostraci have only a 1 genus (*Escuminaspis*), and this is the youngest representative of this group. The Osteostraci originated in the Early Silurian and are known from lagoonal to marine environments. Devonian forms are usually attributed to lacustrine or fluvial environments, but possibly also deltaic. The Anaspida found in the Escuminac Formation are the first examples of this group and are unique to this formation. They are represented by the genera *Endeiolepis*, *Euphanerops*, and *Legendrelepis* (Prichonnet et al, 1996).

The placoderms are represented by 2 genera: *Plourdosteus* (Arthrodira) a rare form and *Bothriolepis* (Antiarchi) which is the most abundant species found in the Escuminac Formation. Early placoderms were marine forms except for 1 genus. *Plourdosteus* and *Bothriolepis* are later forms of the group and are known from both fresh and marine waters (Prichonnet et al, 1996).

The acanthodians have 3 genera in the Escuminac Formation: *Diplacanthus* (Diplacanthidae), *Triazeugacanthus* (Mesacanthidae), and *Homalacanthus* (Cheiracanthidae). The acanthodians occur in both marine and non-marine environments (Prichonnet et al, 1996).

The other ichthyofauna found in the Escuminac Formation belong to the clade Osteichthyes. These are bony fish which originated in the Silurian and have dominated fresh and marine waters since the Devonian (Prichonnet et al, 1996).

Now for the first time agglutinated foraminifera and thecamoebians are reported from the Escuminac Formation. The foraminiferal assemblage reported here contains specimens which are similar to modern day marsh genera (Scott and Medioli, 1980). Thecamoebians are found mainly in freshwater and have been found living at all latitudes (Medioli et al, 1990).

The sedimentology of the Escuminac Formation indicates deposition by turbidity currents. The succession of light and dark beds occurs throughout the formation, with some zones of increased occurrence such as Units V and VIII (Hesse and Sawh, 1992). Sedimentary structures including parallel lamination, ripple-cross lamination, convolute lamination and ball-and-pillow structures are present (Hesse and Sawh, 1992).

The above summary of sedimentology and fossil content, when combined with the presence of both foraminifera (marine) and thecamoebians (freshwater) suggests the Escuminac Formation was formed in a brackish-water estuary near the coastline allowing marine and non-marine forms to be found together (Fig. 5.1). This would accommodate the various lines of evidence previously described including 1) a microfaunal and fish assemblage with both marine and non-marine species, 2) the lack of typical marine groups, 3) presence of turbidites, 4) boron concentrations and isotopic compositions of oxygen and carbon (Chidiac, 1996), and 5) stratigraphic position with fluvial sequences above and below.

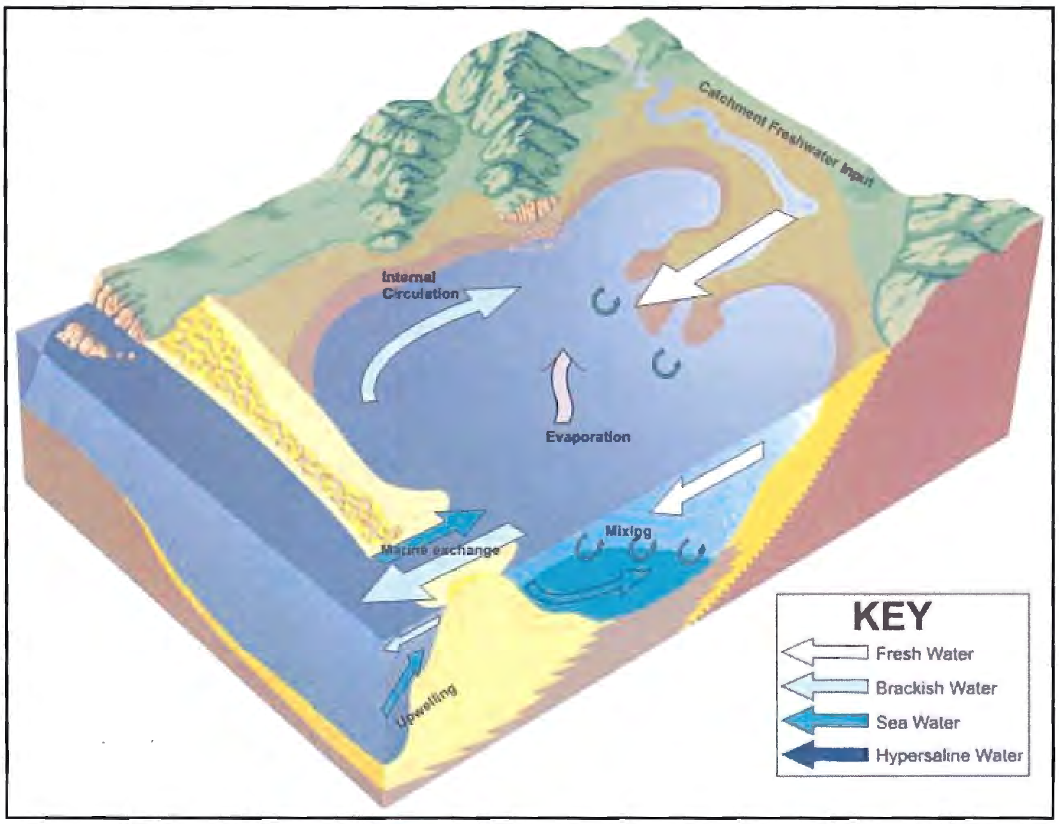

Figure 5.1: Hypothetical depositional model for the Escuminac Formation. From: http://www.ozcoasts.gov.au/conceptual_mods/geomorphic/wde/wde_pos_hydro.jsp

Since Goujet and Emig (1985) demonstrated that at least part of the old Red Sandstone is of marine origin, this brackish water environment may fit into the broader paleogeographic model of the Upper Devonian Old Red Continent. Further work is needed on the Escuminac Formation in the form of a detailed study of the siltstone and shale layers to determine their microfossil content.

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