Palynology of the Lower Cretaceous Chaswood Formation, Elmsvale Basin and Shubenacadie Outlier, Nova Scotia

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May 10, 2002

Submitted in partial fulfillment of the Bachelors of Science in Earth Sciences, Dalhousie University.

Abstract

The unconsolidated sand and clay deposits of the Shubenacadie and Musquodoboit basins have been documented in detailed studies since the 1950's. General mapping projects from as early as the 1900's have postulated that the deposits are of Cretaceous age. More recently they have been found to be of late Early Cretaceous (Aptian-Albian) age. Previous workers have hypothesized a non-marine depositional environment, but marine foraminifera have also been reported, suggesting the possibility of marine pulses. The present study has found freshwater protists such as the dinoflagellates *Nyktericysta* sp. and *Peridinium* sp., zygnematacean (algal) cysts *Lecaniella foveata, Lecaniella irregularis, Tetraporina* sp.*, Ovoidites grandis, Ovoidites parvus* and *Ovoidites spriggii* and other protists such as *Schizocystia rugosa, Schizospora reticulatus* and rare *Botryococcus* sp. A variety of trilete spores, gymnosperm pollen grains and angiosperm pollen grains have also been found giving an age of Barremian to Lower Albian. The palynomorphs tend to occur in assemblages dominated by one or more fossil types. For example, assemblages dominated by freshwater protists represent an environment of shallow, slow moving fresh water, while the assemblages dominated by trilete spores and pollen represent terrestrial deposits where little or no standing water was present. All of the assemblages found in the present study support a non-marine depositional environment.

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Acknowledgements

I would like to thank the following people for their help and guidance throughout this project. R. A. Fensome (GSC-Atlantic), who was my primary advisor for this thesis. Your help, patience, and enthusiasm was greatly appreciated. R. A MacRae (GSC-Atlantic) for all of our talks on “protists” and all of your help with all aspects of this project. D. B. Scott (Dalhousie), your input was appreciated.

R. R. Stea (NSDNR) for your guidance with the stratigraphy of the area and for providing figures. W. C. McMillian (GSC-Atlantic) for all of your help with diagrams and figures. F. Thomas (GSC-Atlantic) and B. Crilley (GSC-Atlantic) for your expertise with the SEM and with palynological preparation techniques respectively. Without you, this project could not have been completed. J. McMullin (NSDNR) for your assistance with sampling at the core library in Stellerton. M. Zentilli (Dalhousie) for your help in guiding all of the honours students through their projects.

Other people I would like to thank are J. H. Calder, T. Finlayson, J-P Gobiel, A. Hawkes, G.Pe-Piper, D. Piper, K. Vaughn, and G. L. Williams for all of your various helpful tips, enthusiasm and conversations throughout the course of this project. I would like to acknowledge the Geological Survey of Canada (Atlantic) and the Nova Scotia Department of Natural Resources for providing materials, lab time and office space.

I would especially like to thank my parents and brothers, your love and understanding means so much. Thank you and I love you all.

I would like to dedicate this thesis to my good friend Fred.
His help for the last four years has been greatly
appreciated and will not be forgotten.
Also to my parents, thanks so much!

Chapter 1–Introduction

1.1 Introduction

This study uses palynology (the study of organic-walled microfossils) to clarify the paleoecology and stratigraphy of the unconsolidated sediments of the onshore Cretaceous in Nova Scotia, specifically in the Musquodoboit Valley (“Elmsvale Basin”) and the Shubenacadie area (“Shubenacadie Outlier”) (Fig 1.1). A Cretaceous age for these sediments have been suggested since the late 19th century, but a more accurate age was not determined (Fowler and Stea 1978).

Figure1.1-Map of Cretaceous deposits in the Maritimes Provinces. (modified after various sources).

The age of the deposits had been assessed mainly through palynology. R. A. Scott (in Stevenson 1959) examined samples of a lignite taken from Shubenacadie kaolin clay deposits, from which he recorded palynomorphs of a "definite Cretaceous age"; the presence of schizaeaceous fern spores suggesting a Lower Cretaceous age. Stevenson and McGregor (1963), while carrying out a mapping project for the GSC, analyzed several samples from lignite deposits. No angiosperm pollen grains were found, so the deposits were determined to be pre-Albian. During a groundwater study, Lin (1971) found an early Cretaceous "microspore" (i. e. miospore) assemblage in lignite samples from the Elmsvale Basin. Davies et al. (1984) reported deposits from Gays River, near Shubenacadie, to be of Aptian and possibly Early Albian age (124.5 Ma-100 Ma, Gradstein et al. 1995).

What is the paleoecology of the deposits? Due to the amount and types of palynomorphs present, the general stratigraphic setting, the general lithostratigraphic sequence and the sub-rounded to rounded sand grains and clasts, these deposits are generally thought to be non-marine in origin, probably fluvial or fluvial-deltaic (Stea and Fowler 1981, Lin 1971, Stevenson and McGregor 1963). This conclusion is supported by unpublished palynological observations (R. A. Fensome and R. A. MacRae, personal communication, 2001).

In contrast Warringer (1996), reported brackish and marine foraminifera, as well as freshwater thecamoebians, in two cores through the Shubenacadie deposits: SHU94-4,5 and SHU95-2,3. The assemblages were found towards the bottom of these two cores, below 140 m and 90 m, respectively.

An extensive project to map and analyze these deposits was begun in 1993 by the Nova Scotia Department of Natural Resources (NSDNR), and the Geological Survey of Canada (GSC). The study has resulted in the expansion of the known area of Cretaceous onshore deposits from the Shubenacadie Outlier 0.5 km^2 to over 15 km^2, as well as an expansion of the Elmsvale Basin. It has also established a thickness of these deposits from 50 to 200 m (Stea et al. 1996, Stea and Pullen 2001).

Palynology and stratigraphy of three sets of cores have been studied for the present project: MUS95-2, SHU94-3 and SHU94-4,5. Core MUS95-2 is located in the northeastern portion the Elmsvale Basin, approximately one kilometre from the town of Elmsvale. The Shubenacadie cores (SHU94-3 and SHU94-4,5) are located in the northern part of the Shubenacadie outcrop, approximately 3.5 km southeast of the town of Shubenacadie (Stea, et al. 1996) (Fig 1.2). Warringer (1996) found foraminifera assemblages in SHU94-4,5. Palynological samples were taken from approximately the same interval as the foraminifera were found, as well as through the rest of the core.

1.2 Objectives

The main objectives of this study are to use palynology to :

1. Determine the paleoenvironment and the paleoecology of the deposits.
2. Determine a more precise age of the sediments.

3. Test the paleoecological interpretations derived from prior studies of foraminifera.
4. Compare the Cretaceous deposits found in Nova Scotia with those found in other parts of North America, and thus place them in regional and continental perspective.

The main focus of this project is a detailed study of the palynology of sediments found in the Elmsvale Basin and Shubenacadie Outlier and to incorporate results from previous studies. This will provide additional insight into the stratigraphy of the onshore Cretaceous strata and their economic potential.

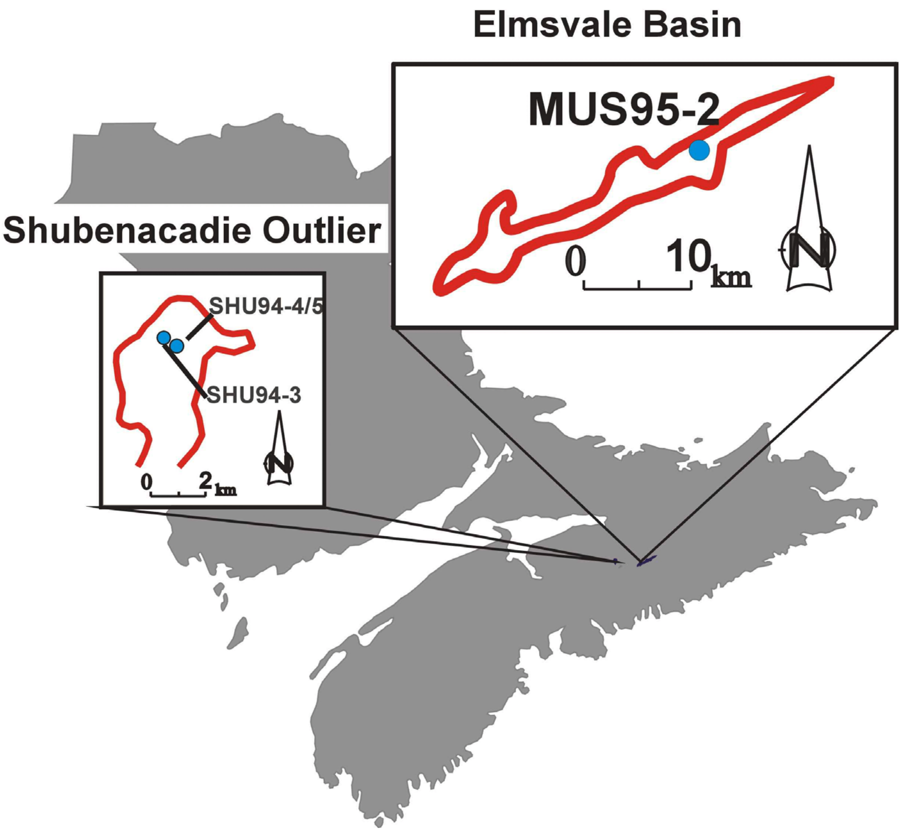


Figure1.2-Location of core within the deposits. (modified after Stea and Pullen 2001, and various sources)

Chapter 2: Geological Background

2.1 Study Area

The study area is located in the Musquodoboit Valley and Shubenacadie areas of Hants and Colchester counties, Nova Scotia. The Elmsvale Basin underlies the towns of Middle Musquodoboit, Elmsvale, and Centre Musquodoboit. The long axis of the basin runs parallel to the Musquodoboit River and Highway 224. The known outcrop is approximately 20 km long and up to 5 km wide, but the full areal extent of the deposit is still not known. The Shubenacadie Outlier is located near the town of Shubenacadie, its outcrop striking parallel to Highway 224. The mapped outcrop is approximately 6 km long and 4 km wide but again the full extent is still unknown. The Elmsvale Basin and Shubenacadie Outlier are approximately 12 km apart.

Before describing the rocks of the study area in detail, they need to be placed in a global perspective – what was happening in the world at the time they were deposited?

2.2 Global Cretaceous

The Cretaceous Period (Table 2.1) was a time of generally warm climates, high sea levels and large reptiles. During the early Mesozoic, the supercontinent of Pangea began to break up. By the Cretaceous, the breakup was almost complete, although the continents were closer together than they are today (Fig. 2.1). Newfoundland and southern Labrador were starting to split from Europe and the Atlantic Ocean was expanding northward (Atlantic Geoscience Society, 2001, Monroe and Wicander 2001). Throughout earlier Mesozoic history the dominant land plants were ferns and gymnosperms. During the Early Cretaceous the angiosperms first appeared, though they didn't become common until later on in the Cretaceous (Monroe and Wicander 2001).

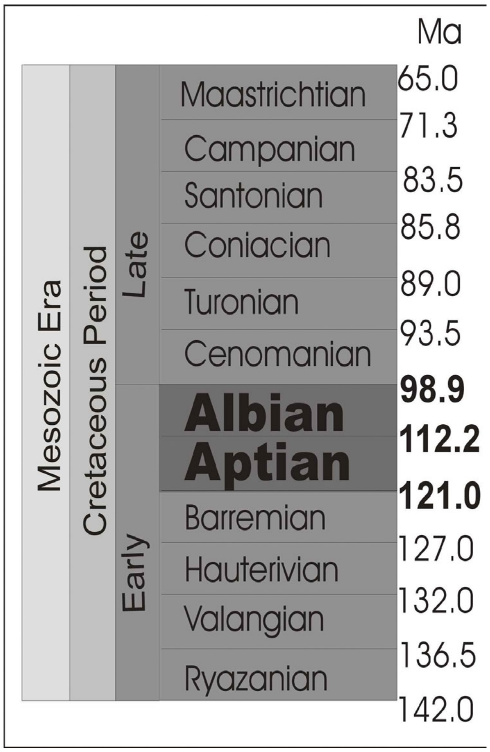


Table 2.1-Cretaceous time scale (Gradstein et al 1995)

The stages most important in this study are the Aptian and Albian, the last two Early Cretaceous stages (Table 2.1). These stages were proposed by d'Orbigny in 1840 and 1844 respectively. The Aptian was named after Apt, a village in southeastern France, the type locality of "Upper Neocomian" strata. The name "Albian" came from *Alba,* the Roman name for the village of Aube, France where the type section is found (Harland et al. 1990). The current absolute age for these stages are 121.0 to 112.2 Ma for the Aptian and 112.2 to 98.9 Ma for the Albian (Gradstein et al. 1995). The Aptian and Albian were times of relatively high sea level in North America. The seas covered much of what we now know as mainland North America, especially between the Canadian Shield and the Western Cordillera in Canada.

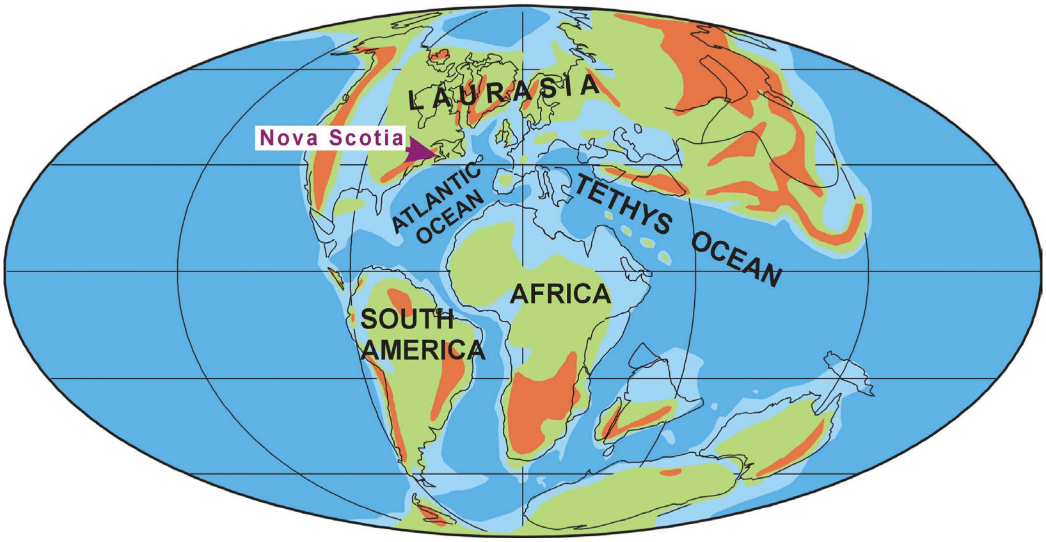


Figure 2.1-Albian paleogeography. (modified from Atlantic Geoscience Society 2001) Dark blue=deep ocean, Light blue=shallow ocean, Green=land, Orange=mountainous regions

2.3 Cretaceous Deposits of onshore North America

Extensive Cretaceous deposits occur onshore in North America. These are mostly confined to the western part of both Canada and the U.S.A., and include extensive marine sediments deposited in a seaway that intermittently extended from the Arctic to the Gulf of Mexico, known as the Western Interior Seaway. This seaway was located between the Canadian Shield and Cordillera (Fig. 2.2). There are, however, extensive marine and non-marine Cretaceous deposits in the Canadian Arctic.

Although it is small in comparison to western Canadian and Arctic outcrops, there is a small Cretaceous outlier in the Moose River Basin of northern Ontario. Studies by Fensome and Norris (1982) Zippi and Bajc (1990) and, Zippi (1998) have demonstrated the presence of late Early Cretaceous non-marine assemblages from deposits of the Moose River Basin, based on studies of modern environments. These assemblages turn out to have similar characteristics to those of the Nova Scotian basins. Therefore, it is worth discussing the Moose River Basin in more detail.

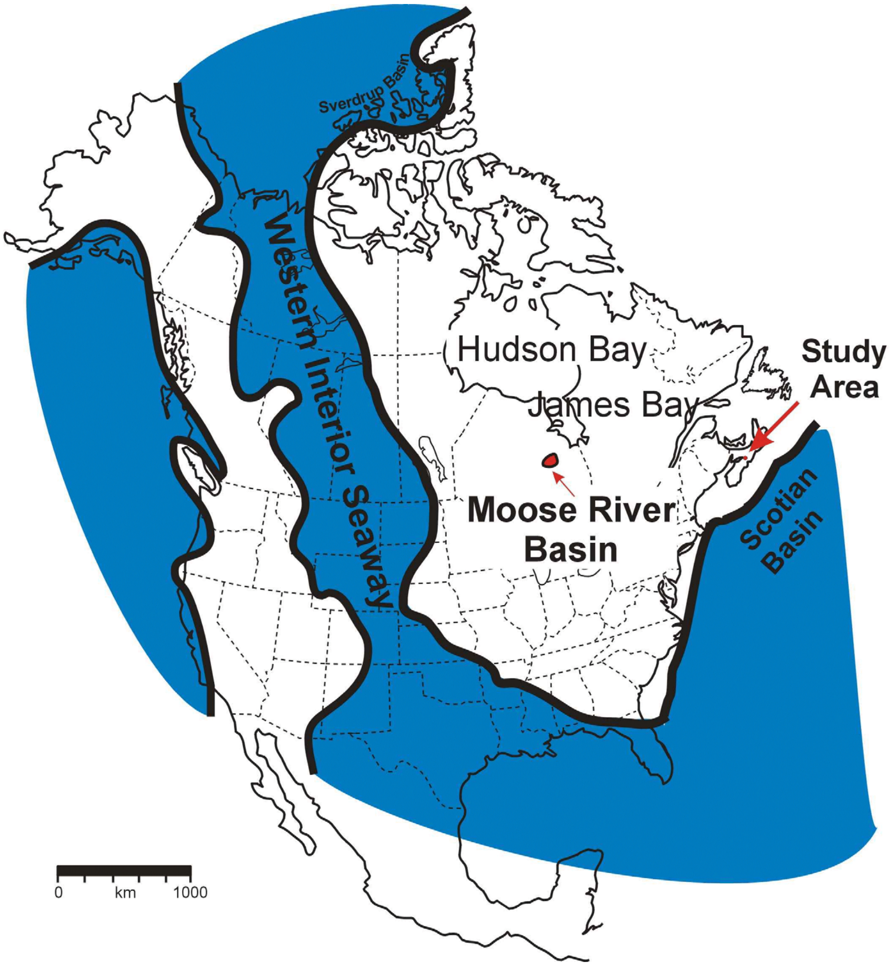


Figure 2.2-Extant of Cretaceous shallow seaways and other deposits from the Lower Cretaceous in North America. (Modified from Stelck and Koke 1987)

The Moose River Basin is located in the James Bay Lowlands of Ontario approximately 100 km from the coast of James Bay and 110 km from the Ontario-Quebec border (Fig 2.3). The Moose River Basin is fault bounded, with Precambrian rocks to the south. Upper Lower Cretaceous (Albian) strata of the

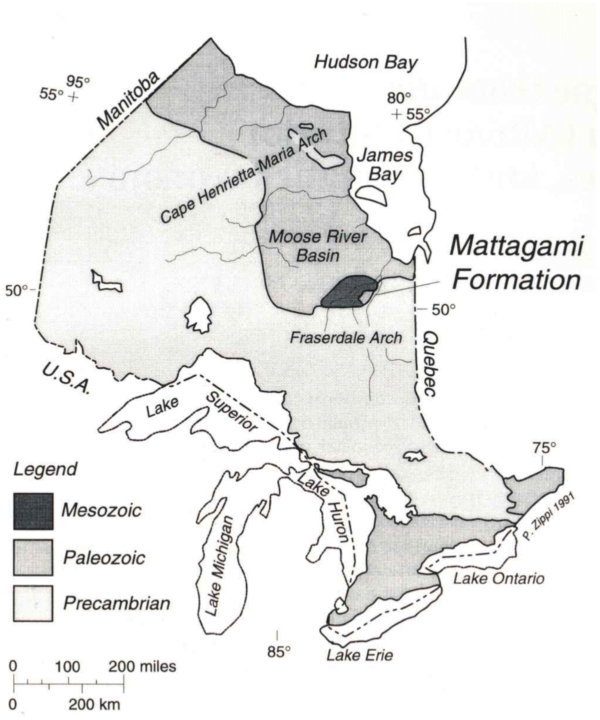


Figure 2.3-Location of the Moose River Basin and Mattagami Formation. (after Zippi 1998)

Mattagami Formation outcrop in the basin. The formation consists of non-marine, uncemented mudstones, carbonaceous shales, siltstones, lignites and quartz sands, thinning to the north and west (Fensome and Norris 1982, Zippi and Bajc 1990 and, Zippi 1998). The Cretaceous deposits are underlain by Paleozoic marine sediments and overlain by Quaternary till. The Cretaceous strata are thickest near the southern margin of the basin, suggesting that deposition was tectonically controlled. Zippi (1998) provided a detailed analysis of the protist palynology of the Moose River Basin. The deposits contain many of the palynomorph taxa found in the present study; Zippi compared the assemblages with modern analogues, concluding that they variously represented floodplain, small pond, and swamp deposits, all non-marine.

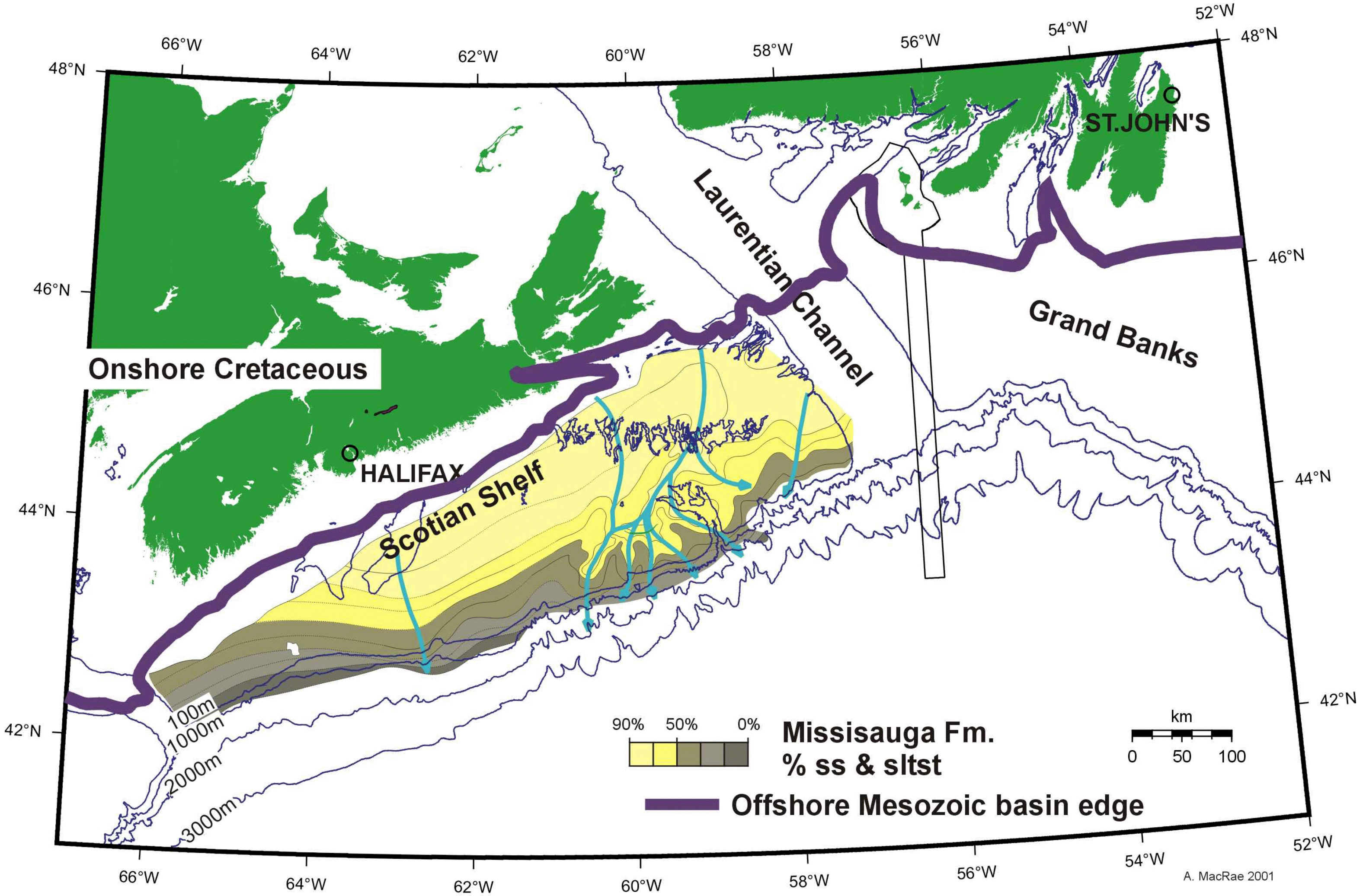
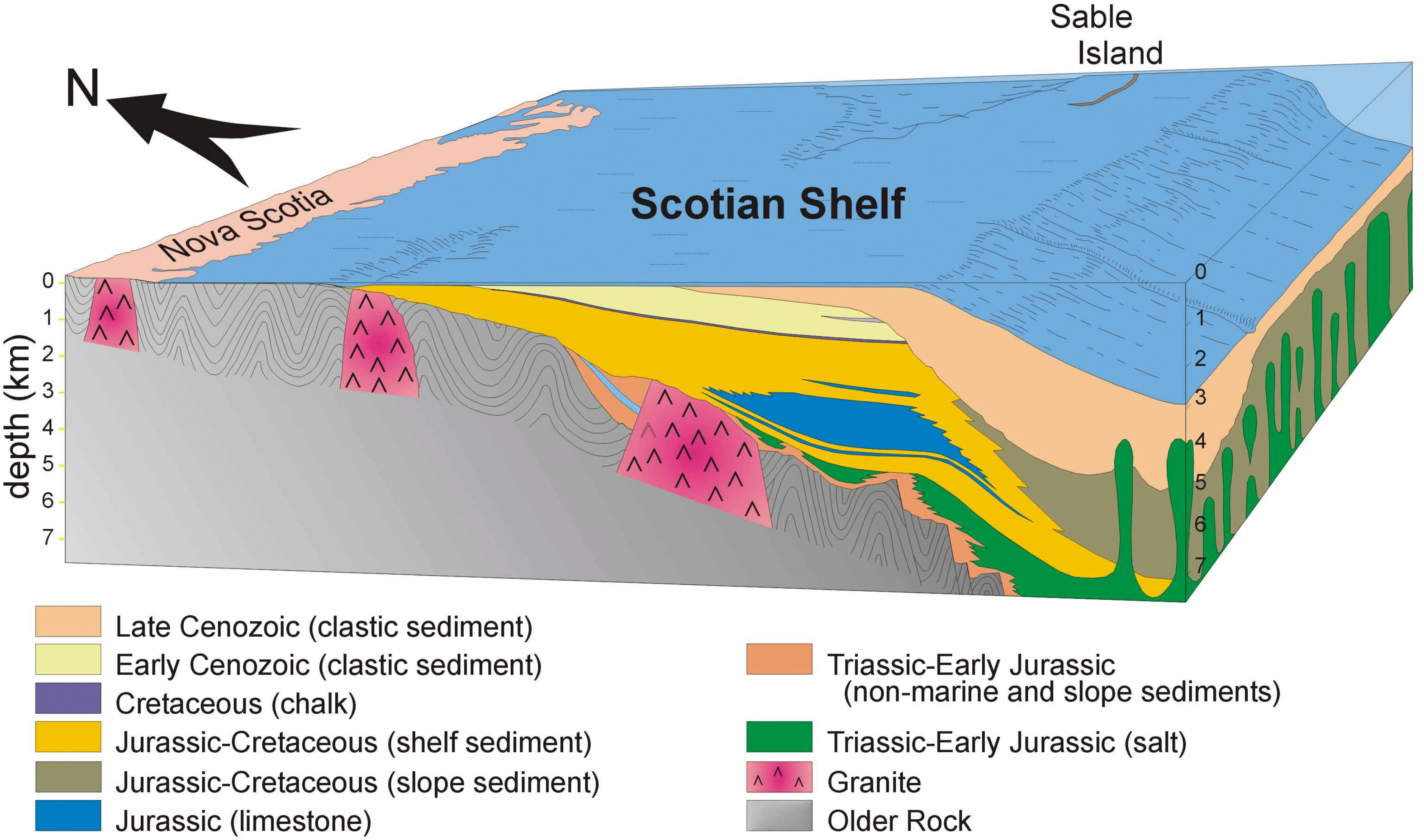


Figure 2.4-Map of the onshore deposits and the offshore Missisauga Fm. Which is approximately the same age as the onshore deposits. (after Wade and MacLean 1990)



Courtesy of John Wade, GSC (Atlantic)

Figure 2.5a-Geological cross section of offshore Nova Scotia, Scotian Shelf. (after Atlantic Geoscience Society 2001)

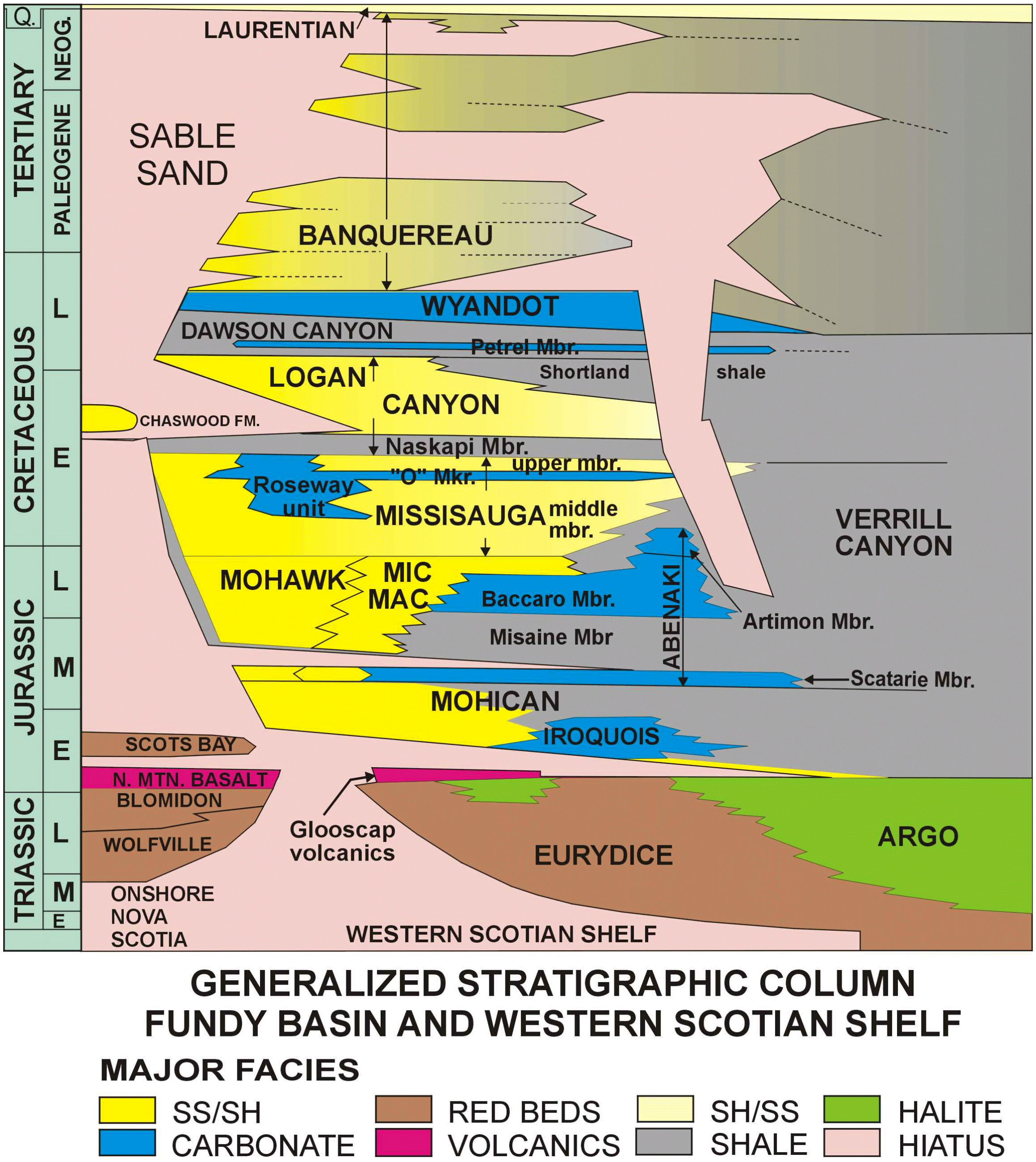


Figure 2.5b-Stratigraphy of the Western Scotian Basin and onshore Cretaceous strata with the Chaswood Fm. added. (Modified from Wade and MacLean 1990)

2.4 Cretaceous deposits in offshore eastern Canada

The main Mesozoic-Cenozoic basin off Nova Scotia is the Scotian Basin, lying about 400 km offshore (Fig 2.4). The Scotian Basin is divided into several smaller sub-basins, including the Shelburne and Sable Subbasins. The Scotian

Basin is separated from mainland Nova Scotia by the La Have Platform, which is underlain mostly by harder basement rocks. Cretaceous strata are also found in the Orpheus Graben, approximately 200 km from the study area. The Early Cretaceous deposits in the Sable Basin and Orpheus Graben comprise of the Missisauga and Logan Canyon formations (fig 2.5a, b). The Missisauga Formation contains alluvial plain to inner neritic deposits. Rocks in the area are sandstones and shales. Strata have a variable thickness due to the fluvial-deltaic nature of the deposit. The Missisauga Formation is Berriasian-Valanginian to Barremian in age. The overlying Logan Canyon Formation contains two very prominent shale members: the Naskapi Shale and the Sable Shale. The formation consists of alternating shale-sandstone units deposited in a broad coastal plain and shallow shelf environment. The age of this formation is Aptian to late Cenomanian. Both formations have marine and non-marine strata indicated by the palynomorph assemblages (Wade and MacLean 1990). The Missisauga Formation extends over approximately 14 000 square kilometers whereas the onshore deposits together are only approximately 60 square kilometres. This is a huge difference in size with only a 400 km distance between them. A key to improving the biostratigraphy of the onshore deposits will be in better understanding the non-marine component of the offshore assemblages (R. A. Fensome, personal communication 2002)

2.5 Onshore Cretaceous Deposits in the Maritimes

Onshore in the Maritime Provinces, Cretaceous deposits are known to occur in several areas: the study areas– Elmsvale Basin and Shubenacadie

Outlier (Hants and Colchester counties); West India Road/Brazil Lake (Hants County); Brierly Brook in the Antigonish Highlands (Antigonish County); Belmount in the Cobequid Highlands (Colchester County); Diogenes Brook in the Creignish Hills (Inverness County); Stewiacke Cross Roads (Colchester County); and most recently a confirmed deposit at Cassidy Lake, near Sussex, New Brunswick (Fensome 2002 personal communication). These are generally unconsolidated and consist of silica sands, kaolin clays, and minor lignites. The deposits are not laterally extensive, though the full extent of many of the areas is as yet uncertain (Stea and Pullen 2001, Stea et al. 1996, Dickie 1986).

2.6 Structure of the Shubenacadie Outlier and Elmsvale Basin

The Cretaceous deposits, which can be up to 200 m thick, are found in steep-sided, down-faulted blocks within Carboniferous rocks (Dickie 1986, Stea and Pullen 1997, 2001, Stea et al. 1996, Finck et al. 1994). As well as from basin-bounding faults, both basins have internal faulting.

Stea and Pullen (1997) published seismic data along three transects in the Elmsvale Basin and found faults or fault systems that were cutting Cretaceous and older sediments, but not the overlying Quaternary sediments. Thus, faulting occurred sometime during or after the deposition of the Cretaceous strata but before that of the Quaternary till. Stea and Pullen (1997) have interpreted this faulting as post-Lower Cretaceous in age.During the Aptian-Albian, the offshore was experiencing a period of ocean spreading that initiated renewed tectonic uplift and ramping (Dickie 1986). These events are hypothesized to have occurred onshore as well (Grist and Zentilli 2000, Stea and Pullen 1997).

To a lesser extent the Shubenacadie Outlier has had seismic studies completed on it and some faulting has been found but more detailed work is necessary to determine a more detailed structure.

Early Carboniferous Windsor Group evaporites and carbonate rocks, interbedded with grey and red clastic sedimentary sequences, underlie both basins. The two basins are separated by Wittenburg Mountian, a horst of Cambro-Ordovician Meguma Supergroup metasedimentary rocks (Stea et al 1996).

2.7 Lithostratigraphy of the Chaswood Formation

The Cretaceous strata in the Elmsvale Basin and Shubenacadie Outlier have been previously studied by Fowler (1972) and Hill (1976). Most recently they have been formally defined the as the Chaswood Formation, which were described as consisting of interbedded silica sands, clays, lignitic clays, andminorlignites (Stea and Pullen 2001).The Chaswood Formation is subdivided into three informal members(Fig. 2.6a, b, c): the lower, middle and upper members (Stea and Pullen 2001). The lower member is approximately 60 m thick consisting of 5-15 m of, sand-dominated packages and 3-10 m thick, mud-dominated packages. The sand packages in the lower member are thicker than any sands in the younger members. Gravel is present in small percentages within the sand packages, mostly as basal lags. The mud units in the lower member are variously colored (red, mottled purple, yellow, grey, light grey) and are massive laminated silty clays. There are a few organic-rich, mud-dominated

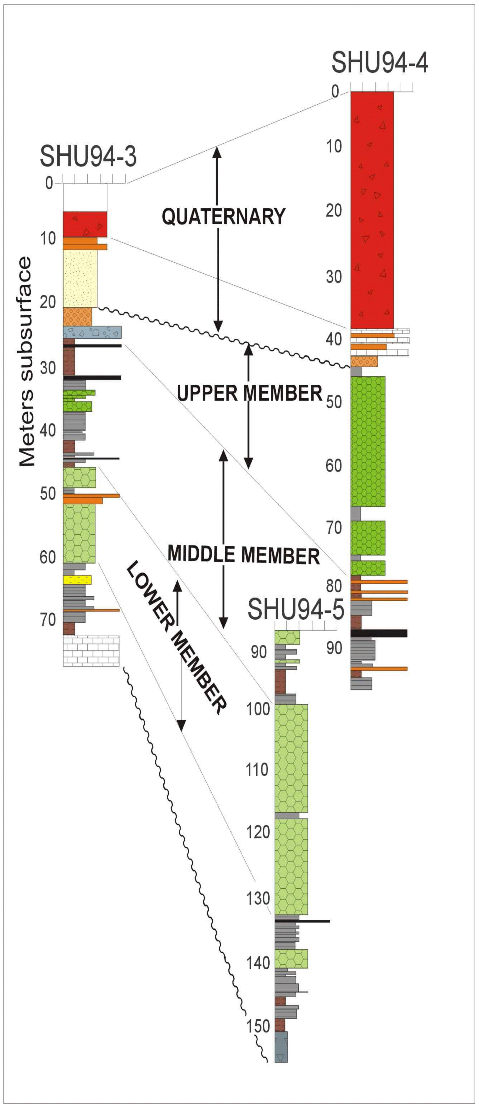


Figure 2.6a-Lithostratigraphy of the Shubenacadie Outlier cores SHU94-3 and SHU94-4,5. Refer to 2.6c for a symbol key. (modified from Stea and Pullen 2001)

units near the base, with rhythmites reported at the base of one core, MUS96-2 (refer to Stea and Pullen 2001).

The middle member is characterized by a dark-grey to black lignitic clay, lignite, and laminated silty-clays. Pyrite is common in the lignitic clay and lignite layers as both rounded grains and as dendritic growths along fracture planes.

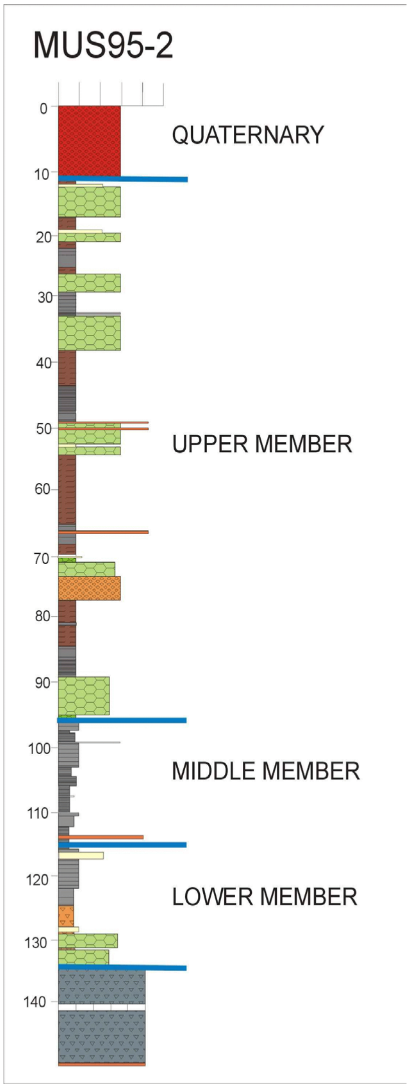


Figure 2.6b- Lithostraticraphy of the Elmsvale Basin core MUS95-2. Refer to 2.6c for a symbol key. (modified from Stea and Pullen 2001)

There is a light grey, calcium carbonate-cemented silica sand in the middle member associated with organic-rich clay. The lower and upper boundaries within the member are sharp to gradational.

Figure 2.6c- Stratigraphic key.
(modified from Stea and Pullen 2001)

The upper member is in sharp or gradational contact with the middle member. It is up to 40 m thick, and consists of mostly inorganic mud- and sand-dominated facies, consisting of 0.5-10 m thick, fining upward cycles of white to light grey, coarse to fine transitions of gravel to sand. The silica units can be overlain by 0.5-2 m of light-grey, red, yellow and purplish mottled silty clay, probably representative of paleosol development. The sand units in the upper member are more enriched with clay than the lower member sands. There are also light-grey kaolin bands within the sand units (Stea and Pullen 2001).

All three members of the Chaswood Formation show a cyclicity as noted by the natural gamma and conductivity logs (Stea and Pullen 2001). The lower member can be differentiated from the upper member by lower frequency gamma log and thicker sand-clay oscillations with more abrupt contacts between the facies. Lignites are more common in the lower and middle members. The upper member has higher background gamma counts with distinct fining upward successions (Stea and Pullen 2001).

Chapter 3-Palynology

3.1 What is Palynology?

The term palynology was coined in 1944 by Hyde and Williams to replace the more restricted term “pollen analysis”. In its strictest sense, palynology is the study of the pollen and spores of bryophytes and vascular plants, modern or fossil. As currently applied, it includes the study of all modern pollen and spores plus all fossil organic-walled, acid-resistant microfossils, thus including cysts of such protist groups as dinoflagellates and zygnemataceans. The objects of palynology (spores, pollen, cysts, etc.) are called “palynomorphs”(a term coined by R. A. Scott and introduced by Tschudy in 1961), and the study of fossil palynomorphs can be referred to as paleopalynology.

Palynomorphs are thus essentially organic-walled microfossils that are resistant to corrosive chemicals such as hydrochloric acid (HCl), hydrofluoric acid (HF), nitric acid (H_2NO_3), and nitrogen hydroxide ($NHOH_3$) (Jansonius and McGregor 1996). They are mainly composed of complex organic substances such as sporopollenin, chitin or pseudochitin (Traverse 1988) and represent a variety of biological entities, from protists like dinoflagellates to spores and pollen of vascular plants, as well as foraminiferal linings, chitinozoans, and polychaete jaws (Jansonius and McGregor 1996).

3.1.1 History of Palynology

In 1640 the Englishman, N. Grew, became the first person to observe pollen grains under a microscope. These “microscopes” were a series of convex lenses with small working distances. By 1730, a true compound lens microscope was used by E. Culpeper, and for the first time the microscopic world “came to life”. By the 1880's the microscope became a basic research tool for many aspects of science, including the study of pollen and spores (Jansonius and McGregor 1996). Göppert in 1938 was first to describe fossil spores and pollen and to produce line drawings of what he saw (Traverse 1988). In 1884, P. Reinsch published the first photomicrographs of fossil spores, which he had extracted from Russian coal samples using techniques formulated by Schulze in 1855. In the early 1930's, R. Potonié and his students laid out the study of fossil pollen and spores, developing a morphological system for classifying dispersed spores (Jansonius and McGregor 1996). G. Erdtman was responsible for the great expansion of analytical and statistical pollen studies during the 1920-1940's. The 1950's saw another great expansion of palynology as oil companies, such as Shell and Esso, began to use palynology as a biostratigraphic research tool (Traverse 1988 and Jansonius and McGregor 1996). During this period W. R. Evitt recognized the dinoflagellate affinity of many spiny Mesozoic-Cenozoic palynomorphs, or hystrichospheres, and these fossils became generally more important than pollen and spores for Mesozoic-Cenozoic biostratigraphy. Palynology is still used in the oil industry, to determine paleoenvironment, paleogeography, biostratigraphy, and maturation. It also has many other uses in scientific research, such as in evolutionary studies of plants.

3.2 Pollen and Spores

Lower plants (ferns and "pre-ferns") can produce two different types of small spores (generally less than 200 µm): (a) isospores, which represent both male and female gametophytes, these being the same size and morphology regardless of gender; and (b) microspores, which represent male gametophytes, larger megaspores (generally larger that 200 µm) representing the female gametophyte. In more "advanced" plants, the megaspore is enclosed and retained by the parent in the megasporangium, or ovule, and then develops into the seed (Traverse 1988).

Paralleling the evolution of megaspores into seeds was the evolution of microspores into pollen grains. The earliest pollen grains looked morphologically similar to microspores and isospores, the only difference being biological function. However in dispersed fossil assemblages, it is difficult to determine in many cases whether a palynomorph is a microspore, isospore or pollen grain. Therefore, an all-encompassing term, "miospore" was derived by G. K. Guennel in 1952 to include all fossil spores of 200 µm or less. In Mesozoic and Cenozoic assemblages it is usually much easier to determine whether a palynomorph is a pollen grain or a micro/isospore, in large part because of extant representatives. However, the term "miospore" is still very useful to encompass pollen grains and small spores. The literature can sometimes be confusing as some authors still incorrectly use the term "microspore" when they are referring to miospores (Traverse 1988).

Most fossil miospores and “palynomorph” protists contain a resistant wall of organic material called sporopollenin or a similar substance. Sporopollenin is an almost inert organic compound with an approximate empirical formula of $C_{90}H_{142}O_{27}$. The exact empirical formula is difficult to determine because the procedures which break down the substance produce simple sugars and other compounds that do not prove the structural formula. Each palynomorph has a varying amount of sporopollenin in its wall. In paleopalynology sporopollenin is a very important substance because once spores are in the sediment they tend to stay there and not break down (Traverse 1988). However, there are a few conditions under which sporopollenin does break down (Traverse 1988): (a) in oxidizing environments; (b) in highly alkaline environments; (c) during carbonization; (d) when exposed to high temperatures over a relatively short period of time; (e) as a result of mineral recrystallization in the sediment– for example during the conversion of limestone to dolomite.

3.2.1 Spores

Many organisms produce resistant cells during their life cycles, usually at least in part for reproductive purposes. These resistant cells are referred to as cysts in zoology and spores in botany. In palynology, the term “spore” generally refers to a durable reproductive cell of bryophytes and “lower” vascular plants such as lycopods and ferns. They come primarily from land-based vegetation and are found in greatest numbers in non-marine strata. However, spores are found in both marine and non-marine sediments because they are easily transported by animals, wind and, especially, water. The usefulness of dispersed spores as biostratigraphic and paleoecologic tools is well established, even though natural affinities are sometimes obscure (Playford and Dettmann 1996).

There are two main types of organisms that produce spores as part of their reproductive process: bryophytes and pteridophytes. Bryophytes (mosses, liverworts, and hornworts) are non-vascular green plants that have been thought of as modern relicts of the transition from green algae to vascular land plants (Fig 3.1). They require substantial amounts of water to reproduce (like amphibians among animals) and first appeared in Ordovician-Silurian times.

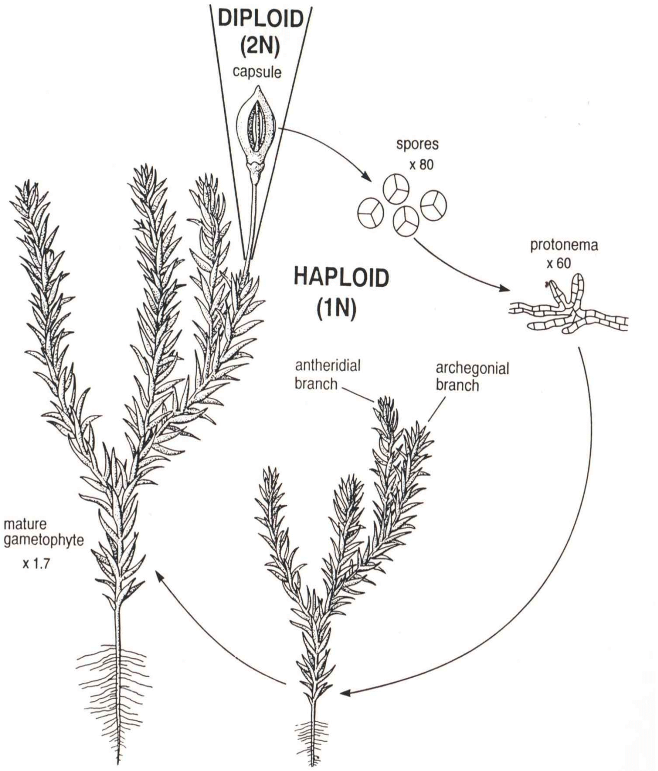


Figure 3.1-Life cycle of a typical bryophyte.
(after Playford and Dettmann 1996)

The Pteridophyta, although not a natural grouping in plant classification, is a very useful one in paleopalynology (Fig 3.2). This group includes all vascular embryophytes that do not produce true seeds (Traverse, 1988). As noted in Playford and Dettmann (1996), the pteridophytes are ferns (Pterophyta) and, so-called fern allies(or "pre-ferns") – Psilophyta, Lycopodophyta, Pro-gymnosperms and Sphenophyta. Isosporous pteridophytes produce only one type of spore of similar size, whereas heterosporous pteridophytes produce both microspores and megaspores in their life cycle.

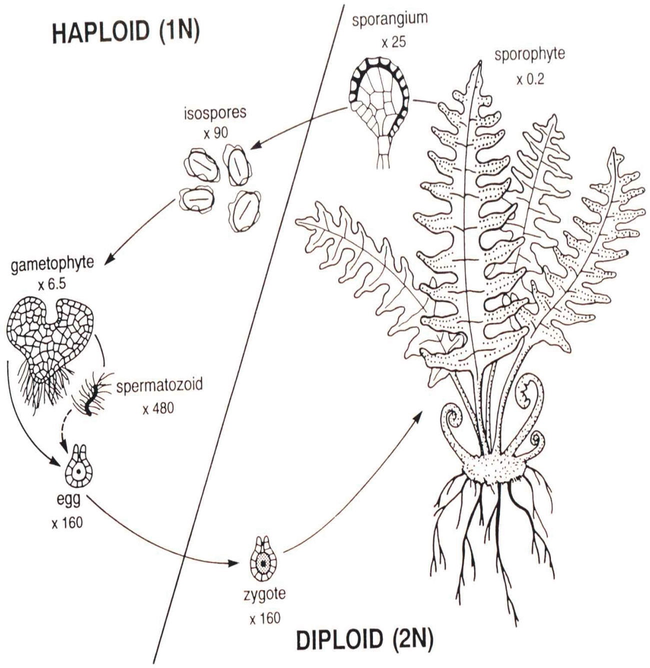


Figure3.2-Life cycle of a typical pterophyte.
(after Playford and Dettmann 1996)

3.2.2 Pollen

The word "pollen" is derived from the Latin word, spelled identically to the modern English, meaning fine flour or dust. The correct singular is "pollen grain", and "pollen" or "pollen grains" is the correct plural, not "pollens". Pollen grains are the male gametophytes of advanced vascular plants and evolved from the microspore of pteridophytes. There are two common types of pollen in palynological assemblages: gymnosperm and angiosperm both of which are seed-bearing.

Gymnosperm pollen (Fig. 3.3) first appeared during the late Devonian. The pollen of gymnosperms varies from small, simple, inaperturate grains to large saccate (monosaccate, bisaccate, trisaccate) forms, and includes distinctive ornamented polyplicate forms. Gymnosperm pollen range in size from 10 µm to over 200 µm (Jarzen and Nichols 1996).

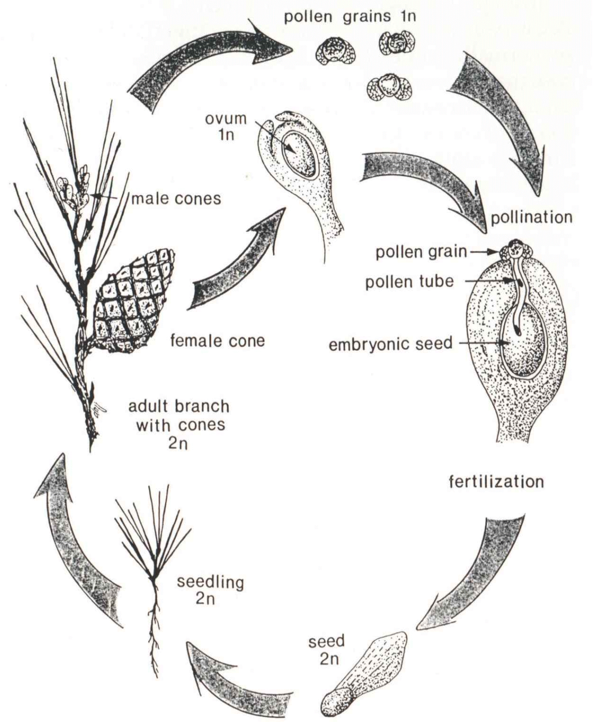


Figure 3.3-Life cycle of a typical gymnosperm. (after Jarzen and Nichols 1996)

Angiosperms (flowering plants) first appeared in the Early Cretaceous, in the equatorial regions of Morocco in the late Valanginian (Schrank and Mahmood

2002), but it was not until the Cenomanian that they had a world-wide distribution (Traverse 1988, Brenner 1976, Crane *et al.* 1995). Angiosperm pollen are the male gametophytes of flowering plants (Fig 3.4)and have many morphological features that distinguish them from gymnosperm pollen. Angiosperm pollen comes in many sizes and morphologies. In non-marine Late Cretaceous and younger strata, angiosperms sometimes dominate miospore assemblages. They evolved very quickly, especially in equatorial latitudes (or tropical climates) in the Late Cretaceous (Brenner 1976, Crane *et al.* 1995, Jarzen and Nichols 1996). Traverse (1988) and Jarzen and Nichols (1996) give a detailed account of pollen morphology.

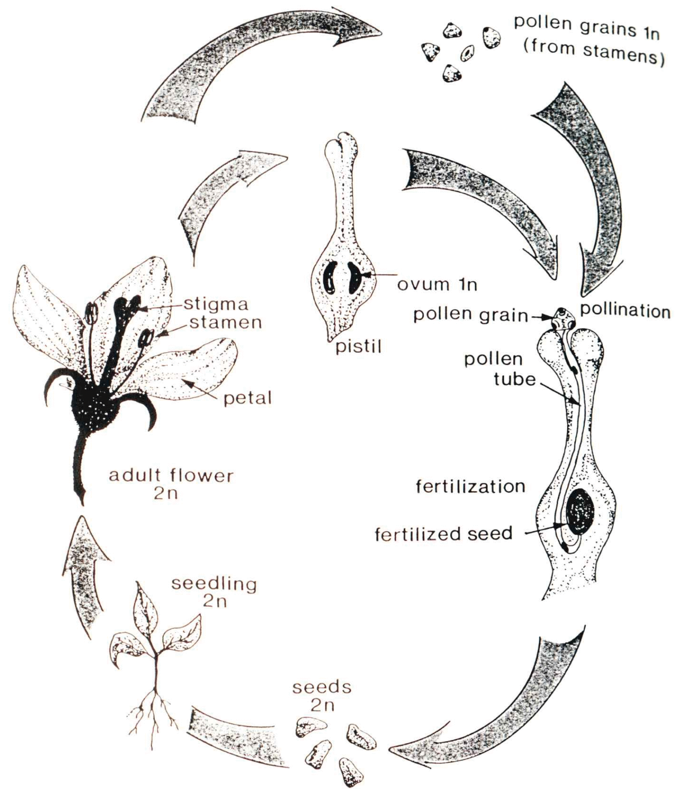


Figure 3.4-Life cycle of a typical angiosperm.
(after Jarzen and Nichols 1996)

3.3 Protists

“Protist” is the modern, preferred term for primarily single-celled organisms. Traditionally, plant-like protists were termed “algae”and animal-like protists were “protozoa”, but it is now known that the terms algae and protozoa make little phylogenetic sense. A monophyletic group like the dinoflagellates, for example, can include plant-like and animal-like forms.

Protists can be not only unicellular but occasionally multicellular – for example there are multicellular dinoflagellates, but more familiar examples include some sea weeds. Protists can live in fresh water, salt water, glaciers, deserts, basically anywhere on Earth. They are generally aquatic organisms. They can be photosynthetic or require a food source for nutrients. They can be a variety of colors and have a variety of morphologies. Some plant-like protists, like the marine “kelps” or “sea grass”, look very similar to vascular plants, while others like “pond scum” look like conventional algal protists.

The two groups of protists most important to this study are the Chlorophyta and the Dinoflagellata. These two groups together make up a large portion of the protists studied in paleopalynology.

3.3.1 Phylum Chlorophyta

The Chlorophyta, or ”green algae”, are very diverse and inhabit a wide range of habitats, including fresh and salt water and damp soils. Chlorophytes are characterized by the presence of chlorophyll a and b as well as cellulose in their cell walls (Bold and Wynne 1985, Van Geel and Grenfell 1996). Within the division Chlorophyta, there are several families, not all of which are represented by fossils. In this study, fossils representing the families Zygnemataceae and Botryococcaceae were found.

3.3.1a Family Zygnemataceae

Zygnemataceans (Fig 3.5) are filamentous chlorophytes that have short or long cylindrical cells. The filaments are unbranched, except in some species for an occasional rhizoidal branch that attaches cells to a substrate, like the roots of plants. Modern zygnemataceans have colorless cytoplasm and are commonly observed in a state of rotating motion or cyclosis. The cell walls are composed of three different layers: a mucous, amorphous outer layer and two fibrillar inner layers (Bold and Wynne 1985). Within the Zygnemataceae there are several genera, separated on the basis of morphology and number of chloroplasts. Some of these genera produce fossilizable cysts (or “spores”), although the affinity of fossil zygnematacean spores was not recognized until recently. Zygnematacean spores first appeared as fossils during the Early Carboniferous or perhaps even earlier. Some genera have not changed greatly in morphology since that time, while others have become extinct (Van Geel and Grenfell 1996).

The Zygnemataceae are one of the most common protistan groups inhabiting freshwater environments. They also occur in brackish water (Van Geel and Grenfell 1996). Most are found as green slimy masses in shallow, oxygen-rich, stagnant water. Some forms are more likely to be found along lake margins, in flowing waters of rivers and streams, in damp soils, and in swamps or bogs. There are no known marine zygnemataceans, but their spores are sometimes found in marine strata, as they are easily transported (Grenfell 1995, Van Geel and Grenfell 1996).

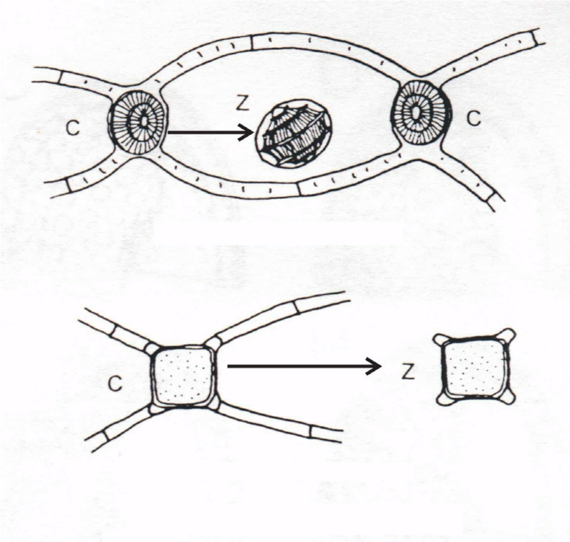


Figure 3.5-Conjugation and zygospore formation in extnat zygnemataceans. C=conjugating filaments and Z=zygospore. Zygospores are found in the fossil record. (after Grenfell 1995)

3.3.1b Family Botryococcaceae

The genus *Botryococcus* has a long geological history extending as far back as the Precambrian (Guy-Ohlson 1992). It is a freshwater protist found in lakes, ponds, ditches, bogs, wet mud, and any other body of fresh water (Fig. 3.6). *Botryococcus* was originally thought to belong to the division Xanthophyta (“yellow-green algae”), but it is now known to be a member of the division Chlorophyta (Batten and Grenfell 1996). These algae are of economic significance since they are a major source of hydrocarbons. They have even been studied as a possible renewable source of hydrocarbons (Batten and Grenfell 1996, Guy-Ohlson 1992).

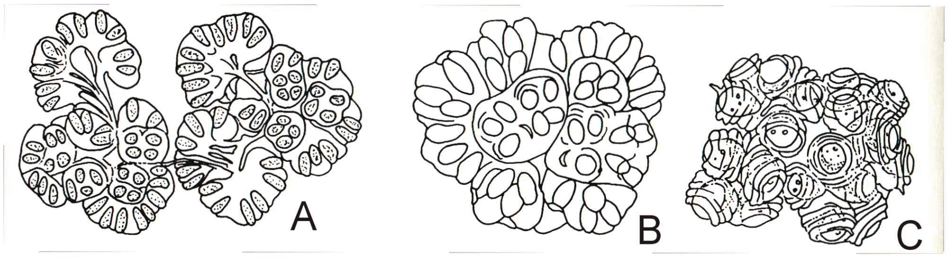


Figure 3.6-Different structures of Botrycoccus. A=compound colony, B=surface view of an orange colony, C=surface view of a green colony (after Batten and Grenfell 1996)

Botryococcus occurs in colonies of different colors and are composed of more of less pear-shaped, thin-walled cells that are arranged radially, with the broad edge pointing outward. Each cell rests in a cup with a thick "cap" covering the cell. Typically, the diameter of the colony is approximately four times larger than the length of the cells, and if the colony becomes larger than that it typically divides in two (Guy-Ohlson 1992, Batten and Grenfell 1996). *Botryococcus* has changed little with time, so modern representives of the genus are almost identical to the organisms from the Precambrian (Guy-Ohlson 1992). There can however be significant variation in specimens of a single species (Batten and Grenfell 1996). The appearance of fossil *Botryococcus* can be very different from modern counterparts, but this is thought to be a product of diagenesis and not a taxonomic trait. (Batten and Grenfell 1996).

3.3.2 Phylum Dinoflagellata

The word dinoflagellate comes from the Greek *dino* meaning "whirling" and the Latin *flagellum* meaning "small whip". Dinoflagellates are usually single-celled organisms that have two characteristic flagella. Many have a complicated cellulosic armor that consists of plates, forming a "tabulation" (Fig 3.7).

Dinoflagellates can be found in both marine and fresh water and some species produce fossilizable organic-walled, calcareous, or in rare cases even siliceous cysts – although only organic walled forms are found as palynomorphs. Dinoflagellates first appeared as fossils in the mid Triassic and are still a major component of the modern plankton. Most fossil dinoflagellates appear to represent a resting cyst, and are referred to as dinocysts. These cysts are formed in the dinoflagellate theca and may or may not reflect the basic shape of the motile cell. The dinoflagellate affinity of dinocysts that do not resemble the motile cell is shown by the distribution of processes and/or by the shape and position of the excystment aperture (archeopyle), both features reflecting the tabulation. For a more complete look at dinoflagellates see Fensome et al. (1996).

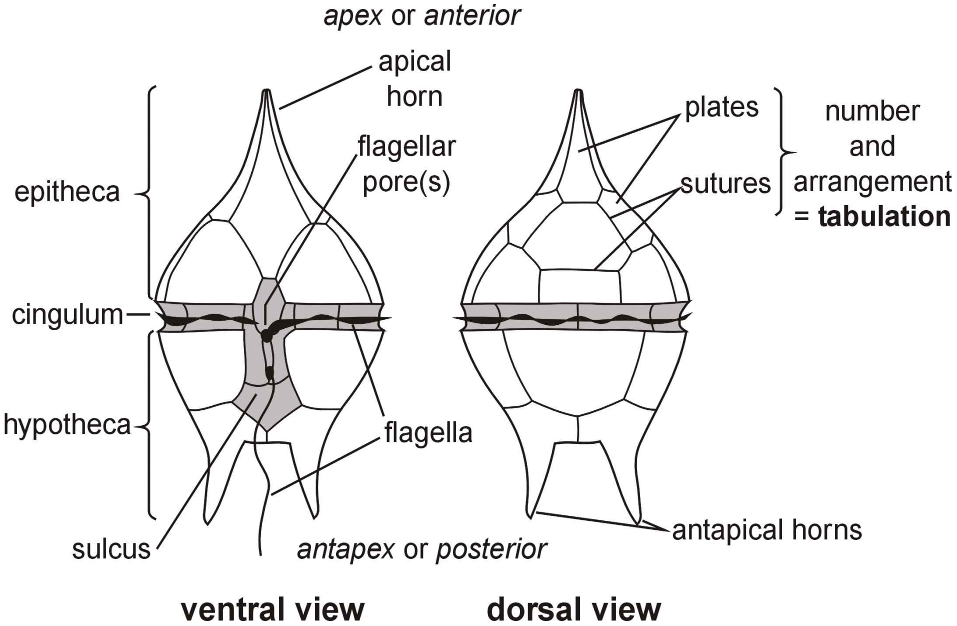


Figure 3.7-Basin morphology of a motile dinoflagellate. Fossil dinoflagellates are cysts, but cyst morphology can be related to motile stage morphology. (after Evitt 1985)

3.3.3 Group Acritarcha

When Evitt (1961) recognized the dinoflagellate affinity of many Mesozoic and Cenozoic “hystrichospheres”, there remained a group of fossil protist-like forms whose affinity was still unknown. To encompass these, Evitt (1963) coined the term “acritarch”. Since Evitt’s paper, the affinity of some acritarchs has been discovered (e.g., some have been identified as zygnemataceans) but the affinity of others, especially in Paleozoic rocks, remains unresolved. So little is known about these fossils that they are not usually useful in paleoenvironmental studies, but they can be very useful in biostratigraphic studies, especially in Paleozoic rocks. Acritarchs are not often used in Mesozoic-Cenozoic biostratigraphy, as there are usually other, more useful, fossils that have established biostratigraphic ranges. Acritarchs are morphologically variable, have a wide size range, and may resemble other palynomorphs. However, by definition, they lack diagnostic features that would allow their assignment to a known group with confidence (Strother 1996).

Chapter 4: Methods

4.1 Drilling

All cores used in this study were provided by the Nova Scotia Department of Natural Resources. The drilling was completed by Logan Geotechnical Incorporated and the Nova Scotia Department of Natural Resources during 1994 and 1995. Both efforts used standard rotary diamond drilling and wireline coring methods with water as a lubricant and ALCOMER 12 LOS as a drilling fluid. The holes were started with HQ diameter rods and reduced, when required, to NQ rods (when the drill bit cut through the glacial till layers). The HQ rods were left “free hanging” in the holes and tended to travel down the hole as the drilling progressed. Some holes were successful in reaching bedrock (Windsor Group limestones) while others were not. Of the cores employed in this study, recovery of core MUS95-2 was good and bedrock was reached. SHU94-3 had very good recovery of clays, silts and lignites but poor recovery of silica sands; bedrock was reached. While drilling hole SHU94-4 the drillers experienced some difficulty – during a bit change the HQ rod fell sideways in the hole and could not be recovered. Several attempts were made to re-open the hole but eventually the hole was abandoned and SHU94-5 was drilled 5 m from SHU94-4. Recovery of this well (SHU94-5) was started where SHU94-4 left off and this hole made it all the way to bedrock (Finck et al. 1994, Stea et al. 1996).

4.2 Sample Collection and Preparation

SHU94-4,5 was sampled by K. D. Eisnor, R. A. Fensome, and R. A. MacRae with the assistance of J. McMullin of the Nova Scotia Department of Natural Resources on October 25 and November 19, 2001 at the Nova Scotia Department of Natural Resources Core Library in Stellerton, Nova Scotia. Samples locations were governed primarily by lithology and secondly by the placement of previous foraminifera samples taken by C. Younger (Dalhousie University) for a project completed by J. Warringer (Warringer 1996). Detailed aspects of sample location will be discussed below. Were possible samples taken were, small fragments (about thumb nail sized) that were loose, so as to keep the continuity of the core intact. In areas where this was not possible, the core was split and only a quarter of the core piece was extracted. The total amount of sample needed for processing is approximately 10 gm. These samples were then sent to the lab at GSC Atlantic for processing.

Cores MUS 95-2 and SHU94-3 were primarily sampled by other workers. The gaps in these two cores were not recorded at the time of sampling so the location of the samples have been determined assuming no significant gaps are present. The cores sampled in detail for this study, SHU94-4,5, was sampled and a basic stratigraphic column was drafted. This draft showed that in core SHU94-5 there was approximately 26 m recovered of the approximately 70 m of core that was measured by the drillers. This means that approximately two thirds of the core was missing from the core boxes. Further investigations of stratigraphic columns from previous workers found that the missing parts were coarse to fine sands that, as mentioned previously, were difficult to recover. The sampling of the core originally did not take these “gaps” into account. As a result, the sample distribution is uneven, however, all significant recovered stratigraphic intervals were sampled (Fig 4.1-4.4). Core SHU94-4 also has many gaps, but they are not as extensive as the gaps in SHU94-5, except toward the top of the Cretaceous interval.

The palynological processing for samples used in this study was completed by B. C. Crilley using the procedure outlined in Fig 4.5. The samples are first submersed in a solution of 10% HCl. They are then decanted and washed in water. The next step is to put the sample in concentrated HF. The sample is again decanted and washed and again put into HCl. After a final washing, the sample can take three different paths, as seen in Fig 4.5 The final step is for the sample residue to be put on a strew mount slide or to be stored for further analysis. The technique was recorded in detail by Barss and Williams (1973).

4.3 Microscopy methods

The resulting strew mount slides were examined systematically using Zeiss Opto-photo Photo Microscope serial number 031873 at the Geological Survey of Canada (Atlantic). Both standard size fractions (between 180 µm and 30 µm, and less than 30 µm) were analyzed, because some pollen grains are very small. Slides were examined initially to determine the species present, then re-examined to make counts of palynomorph types. Counts were carried out by starting on the lower left corner of the slide and going systematically toward the

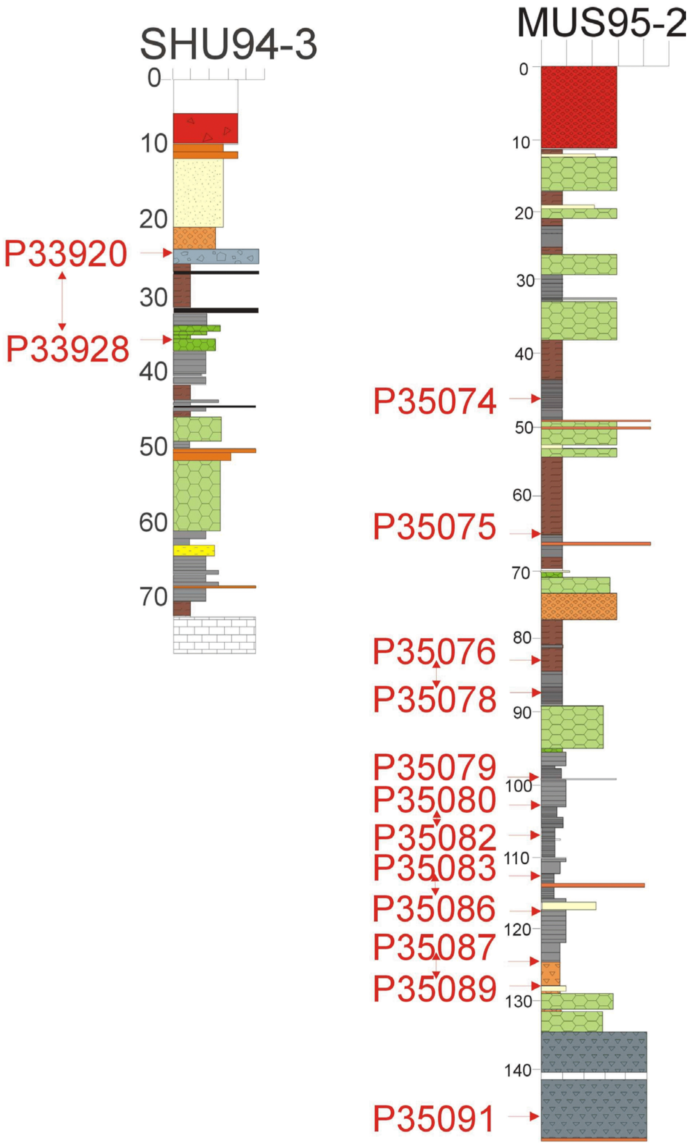


Figure 4.1-Cores used in this study that were sampled by previous workers. Sample locations are approximated as more detailed information was not available. See Fig 2.6c for a symbol key. (modified from Stea and Pullen 2001)

top. Approximately 100 specimens were counted in the large size fraction and approximately 50 specimens were counted in the small size fraction, where available. The counts were necessary for the paleoenvironmental aspect of this project, and graphs of these counts are presented and discussed in appendix 2.

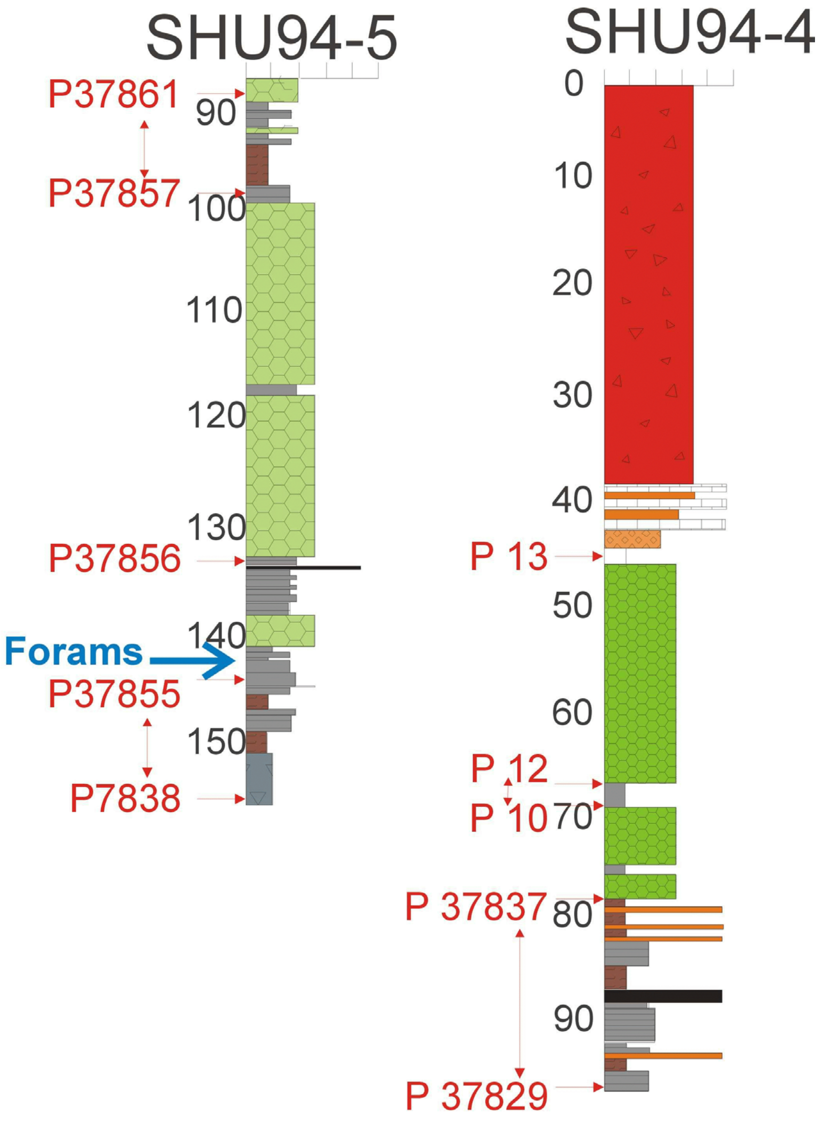


Figure 4.2-Location of samples within the stratigraphic columns of the cores sampled for this study. SHU94-4 P10-P13 were barren samples. See Fig 2.6c for a symbol key. (modified from Stea and Pullen 2001)

4.4 Scanning Electron Microscope Techniques

Scanning electron microscope stubs were prepared in the GSC (Atlantic) palynology lab at the by B. C. Crilley. These stubs used residue from the preparation of the strew mounts. A portion of this material is diluted with alcohol so that there is a substantially greater amount of alcohol than sample. A drop is

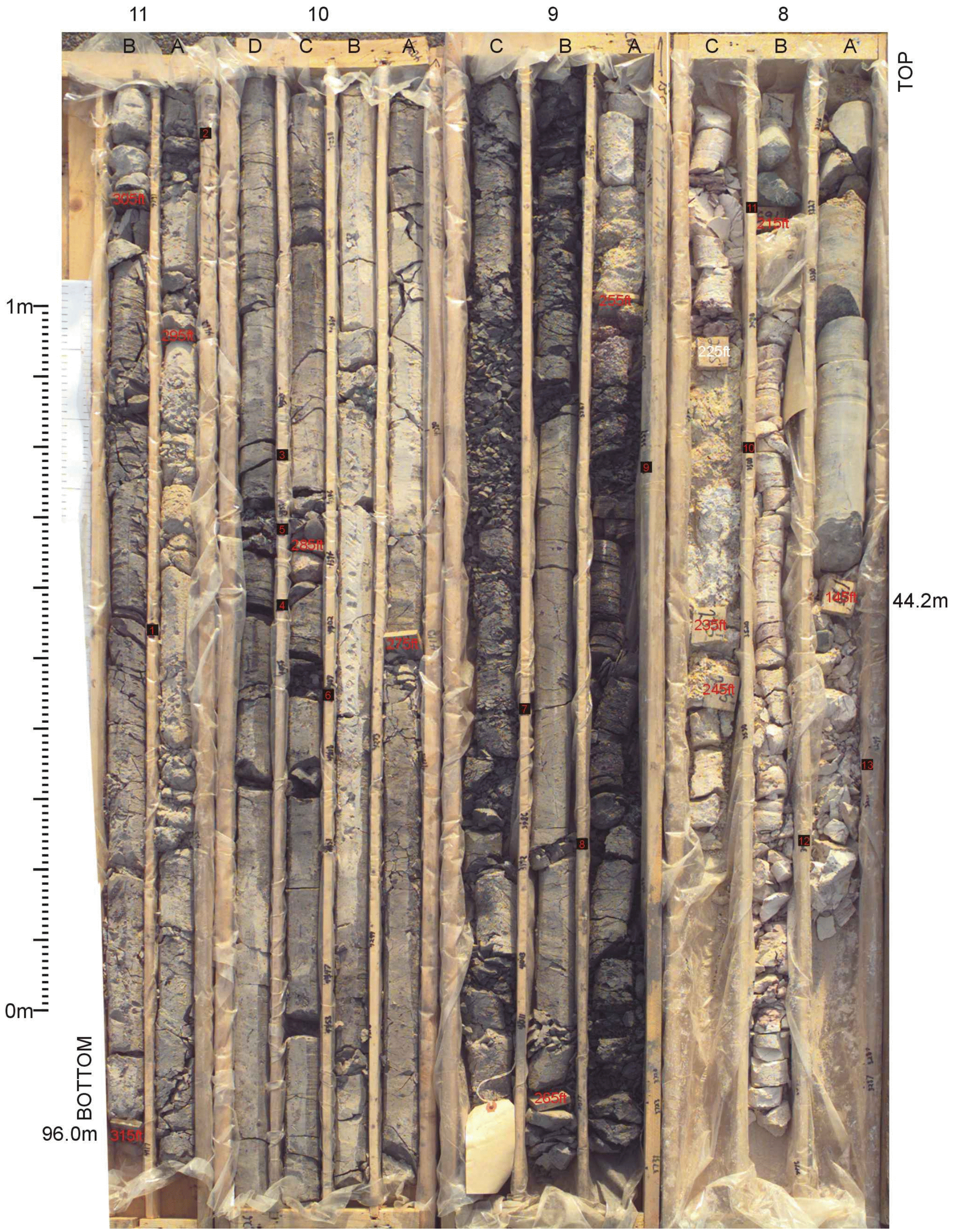


Figure 4.3-Photo of SHU94-4. Red numbers in black boxes represent palynological samples taken.

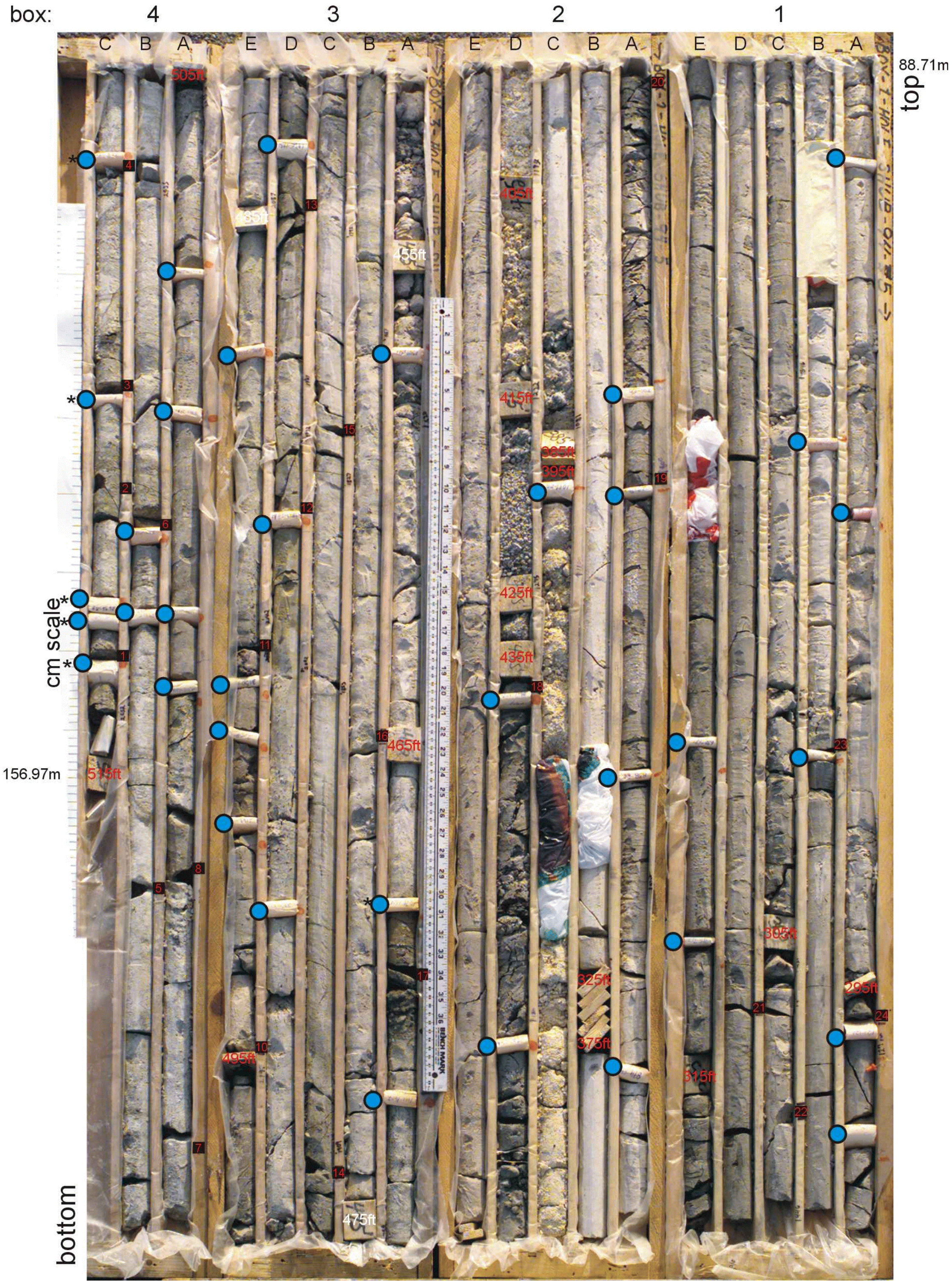


Figure 4.4-Photo of SHU94-5. Red number in black boxes represent palynological samples. Blue dots represent foraminifera samples of J. Warringer (1996). Stars indicate productive foraminifera samples.

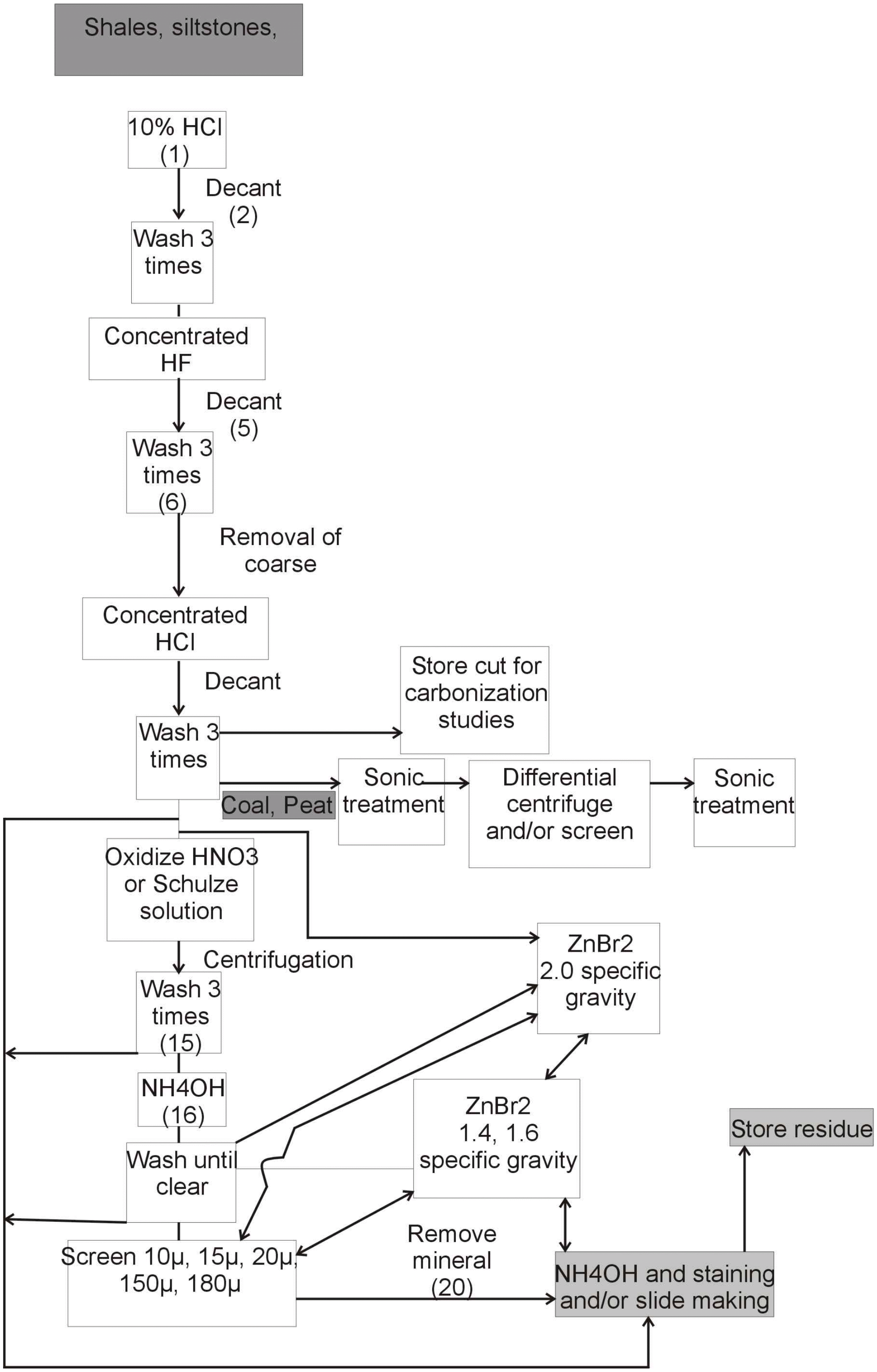


Figure 4.5-Palynological processing flow chart. (modified from Barss and Williams 1973)

then placed on a glass coverslip allowing the alcohol to evaporate between each application. This allows the residue portion of each drop to adhere to the slide before a new drop is added. When this step is finished (this could take many hours to complete) the glass slide is attached to a ready made aluminum stub which is approximately 2.5 cm in diameter. The stub is then coated with gold-palladium and is dried in an evaporator.

The scanning electron microscope used in this study is an ElectroScan E3 environmental scanning electron microscope located at GSC (Atlantic) and operated by F. Thomas.

Chapter 5–Systematics

5.1 Species List

Remarks

Below is a complete list of species observed in the samples studied. Not all of these species are important in age and paleoecological determinations. Thus, only the species that are important in these determinations have been treated in this systematic section. Some problematic or interesting taxa are also discussed in detail. Dimensions are expressed as minimum (average) maximum.

References for suprageneric dinoflagellate names can be found in Fensome et al (1993) and for spores, pollen and some of the other non-dinoflagellate protists can be found in Jansonius and Hills (1976-1990). Other references for species in the species list can be found in the reference list in the back of this report.

Paleoecological interpretations of protists mostly follow Zippi (1998), who compared the species in his study of the Moose River Basin to nearest modern representative. If paleoecology was not taken from Zippi (1998), it is noted in the description.

Miospores

Aequitriradites verrucosus (Cookson and Dettmann 1958) Cookson and Dettmann 1961 Plate 3, Figure 6
Appendicisporites sp. Plate 1, Figure 4, 7
Biretisporites potoniae Delcourt and Sprumont 1955 Plate 3, Figure 2
Bisaccate sp. Plate 13, Figure -1, 5, 6
Cerebropollenites mesozoicus (Couper 1958) Nilsson 1958 Plate 13, Figure 7-8
Cibotiumspora sinuata Couper 1953 Plate 2, Figure 8, 9
Cibotiumspora tricuspidata Bolkhovitina 1953 Plate 2, Figure 10
Cicatricosisporites abacus Burger 1966 Plate 1, Figure 3

Cicatricosisporites australiensis (Cookson 1953) Potonié 1956 Plate 1, Figure 1
Cicatricosisporites minutaestriatus (Bolkhovitina 1961) Pocock 1965 Plate 1, Figure 2, 9
Cicatricosisporites sp. Plate 1, Figure 5, 10-11
Circulina parva Brenner 1963
Concavisporties toralis (Leschik 1955) Nilsson 1958 Plate 3, Figure 4
Concavissimisporites asper (Bolkhovitina 1953) Singh 1964 Plate 3, Figure 7
Concavissimisporites crassatus (Delcourt and Sprumont 1955) Delcourt et al 1963 Plate 2, Figure 3
Concavissimisporites montuosus Döring 1964 Plate 2, Figure 1-2, 4
Cyadopites folicularis Wilson and Webster 1946 Plate 13, Figure 3
Deltoidospora australis (Couper 1953) Pocock 1970 Plate 3, Figure 3
Deltoidospora minor (Couper 1953) Pocock 1970 Plate 3, Figure 1
Dictyophyllidites harrisii Couper 1958 Plate 3, Figure 5
Eucommiidites troedssonii Erdtman 1948 Plate 13, Figure 4
Gleicheniidites circinidites (Cookson 1953) Dettmann 1963 Plate 2, Figure 5
Gleicheniidites senonicus Ross 1949 Plate 2, Figure 6
Gleicheniidites sp. Plate 2, Figure 7
Impardecispora gibberula (Kara-Murza 1951) Venkatachala et al. 1969 Plate 4, Figure 3
Impardecispora marylandensis Plate 4, Figure 2
Impardecispora purverulenta (Verbitskaya 1962) Venkatachala et al. 1969 Plate 4, Figure 1, 7, 9
Neoraistrickia sp. B of Fensome 1983 Plate 4, Figure 5
Pilosisporites trichopapillosus (Thiergart 1949) Delcourt and Sprumont 1955 Plate 4, Figure 4, 8
Plicatella sp. Plate 1, Figure 6, 8
Podocarpidites sp. Plate 13, Figure 2
Polycingulatisporites sp. Plate 4, Figure 6
Retimonocolpites cf. *pennyi* Schrank and Mahmoud 2002 Plate 6, Figure 7-8; Plate 7, Figure 1-3
Retimonocolpites peroreticulatus Doyle 1975 Plate 6, Figure 1-6, Plate 7, Figure 4-12
Retitriletes aklavikensis Fensome 1983 (unpublished) Plate 12, Figure 5
Retitriletes singhii Srivastava 1972 Plate 12, Figure 1
Spore A Plate 5, Figure 1-8
Stereisporties antiquasporites (Wilson and Webster 1946) Dettmann 1963
Tigrisporites reticulatus Singh 1971
Trilobosporites hannonicus (Delcourt and Sprumont 1955) Potonié 1956 Plate 12, Figure 3
Trilobosporites trioreticulatus Cookson and Dettmamm 1958 Plate 12, Figure 4, 8
Undulatisporites undulapolus Brenner 1963 Plate 12, Figure 2,7
Vitreisporites pallidus (Reissinger) Nilsson 1958

Protists
Botryococcus sp. cf *braunii* Kützing 1849 Plate 8, Figure 1-2
Lecaniella foveata Singh 1971 Plate 10, Figure 1-2
Lecaniella irregularis Zippi 1998 Plate 10, Figure 3-4
Nyktericysta sp. Plate 9, Figure 1-5
Ovoidites parvus (Cookson and Dettmann 1959) Nakoman 1966 Plate 10, Figure 6-7, 9
Ovoidites spriggii (Cookson and Dettmann 1959) Zippi 1998 Plate 10, Figure 5, 8
Peridinium sp. Plate 9, Figure 6-8
Schizocystia rugosa Cookson and Eisenack 1962 Plate 8, Figure 3-4
Schizosporis reticulatus Cookson and Dettmann 1959 Plate 8, Figure 5-6
Spicadinium sp Plate 11, Figure 1-2
Tetraporina sp. of Zippi (1998) Plate 12, Figure 6

5.2 Protists

5.2.1 Dinoflagellates

Phylum Dinoflagellata (Bütschli 1885) Fensome et al. 1993

Class Dinophyceae Pascher 1914

Order Gonyaulacales Taylor 1980

Family Ceratiaceaceae Willey and Hickson 1909

Genus *Nyktericysta* Bint 1986

Type Species: *Nyktericysta davisii* Bint 1986

Nyktericysta sp.

Plate 8 Figure 1-5

Description: *Nyktericysta* sp. generally has 5 horns: one apical, 2 lateral, and 2 antapical. The two wall layers, the endophram and the periphragm are clearly separated by a cavity. The endophram shows through the periphragm. This creates an endophragmal reticulum on some specimens. Neither wall layer shows any visible pores (unlike other species of *Nyktericysta*). None of the specimens found showed any paratabulation. The archeopyle is visible on some specimens in the form of a missing or torn apical horn, thus conforming with the apical archeopyle know from other species of the genus.

Size(5 specimens measured):
Length (from apex to antapex): 50 (59) 75 µm
Width: 25(44) 52 µm
Apical horn: 15 (23) 30 µm
Antapical horn: 7(12) 20 µm

Occurrence: ?Aptian, Albian-Cenomanian

Paleoecology: *Nyktericysta lacustra* the species most similar to Nyktercysta sp., poliferates in freshwater but can be found (possibly transported in) in brackish to marine conditions. Horn development is environmentally controlled (Zippi 1998).

Order Peridiniales Haeckel 1894

Family Peridiniaceae Ehrenberg 1831

Genus Peridinium

Type Species: Peridinium cinctum

Peridinium sp.

Plate 9, Figure 6-8

Description: *Peridinium* sp. has 3 horns: one apical and 2 antapical with rounded tips. Two wall layers separated by a cavity. No visible ornamentation on either the endophram or the periphragm. There may be paratabulation visible but it is not clear. Due to the poor preservation of the single specimen found, the type of archeopyle is difficult to determine. The two possible archeopyles are: (1) 2a plate is intact and precingular plates (3'', 4'', and 5'') are missing; (2) 3' is intact and all of the intercalary and precingular plates are missing. The second archeopyle type is more typical for this genus however freshwater species generally do not have typical archeopyles. This is not a form recognized in marine settings on the Scotian Basin of the same age(R. A. Fensome personal communication 2002), but similar modern species are found in Lake Ontario (Burden et al 1986).

Size(1 specimen measured):
Length: 53 µm
Width: 50 µm
Apical horn: 20 µm
Antapical horns: 7 µm

Paleoecology: In the present study, this form is associated with *Nyktericysta* sp, and zygnematacean cysts that have been proposed to represent freshwater environments. Possible modern analogs are found in fresh water lakes (Lake Ontario).

5.2.2 Other

Phylum Chlorophyta

Class Chlorophyceae

Order Zygnematales Borge and Pascher 1931

Family Zygnemataceae (Meneghini) Kützing 1898

Genus *Lecaniella* Cookson and Eisenack 1962

Type Species: *Lecaniella margostriata* Cookson and Eisenack 1962

Lecaniella irregularis Zippi 1998

Plate 10 Figure 3-4

Description: *Lecaniella irregularus* is an elliptical to subspheroidal zygospore commonly splitting into two equal halves along equatorial suture. The separate halves may curl inward to form a canoe shape. Some halves may be flattened to form a circular saucer shaped body. The outer surface is ornamented with irregular rugulae. The rugulae do not form complete enclosures around the lumina. The inner surface of the zygospore is smooth.

Paleoecology: *Lecaniella irregularis* is found in non-marine (freshwater) deposits. It is common in flood plain deposits and swamp facies (Zippi 1998).

Lecaniella foveata Singh 1971

Plate 10 Figure 1-2

Description: *Lecaniella foveata* comprises a saucer shaped, oval to circular zygospore, with a relatively thick irregularly ornamented outer wall. The ornamentation is foveolate to imperfect foveo-reticulate to rugulate. The inner wall is composed of numerous fine laminations. The species is confined to forms with a completely closed lumina.

Paleoecology: Modern analogs common in fresh water lakes, ponds and slow moving streams. It is also common in flood plain and swamp facies.

Genus *Ovoidites* Potonié 1951 ex Thomson and Pflug 1953

Ovoidites Potonié 1951 (invalid name)
Ovoidites Potonié ex Thomson and Pflug 1953
Ovoidites Potonié ex Thomson and Pflug, emend Krutzsch 1959
Ovoidites Potonié ex Pontonie 1966
Brazilea Tiwari and Navale 1967
Psiloschizosporis Jain 1968
Pilospora Venkatachala and Kar 1968
Schizophacus Pierce 1976

Type Species: *Ovoidites ligneolus* Potonié ex Krutzsc 1959

Ovoidites parvus (Cookson and Dettmann1959) Nakoman 1966

Plate 10 Figure 6-7, 9

Schizosporis parvus Cookson and Dettmann 1959
Schizosporis laevigatus Stanley 1965
Ovoidites parvus (Cookson and Dettmann) Nakoman 1966
Schizophacus parvus (Cookson and Dettmann) Pierce 1976

Description: *Ovoidites parvus* is a smooth cyst with no ornamention and sometimes very fine pores. It is ellipsoidal in shape and generally spits apart into two halves of semi-ellipsoides. Sometimes the two halves stay partly attached making the shape of a Pac-man mouth. Average size for *Ovoidites parvus* is 76 µm in length and 35 µm in width (Zippi 1998).

Paleoecology: Common in fine grained carbonaceous sediments of floodplain and swamp facies of freshwater origin (Zippi 1998).

Ovoidites spriggii (Cookson and Dettmann 1959) Zippi 1998

Plate 10 Figure 5,8

Schizosporis spriggii Cookson and Dettmann 1959
Schizophacus spriggii (Cookson and Dettmann) Pierce 1976

Description: *Ovoidites spriggii* is characterized by circular to sub-circular outline and almost no surface ornamentation, with no visible pores. Other *Ovoidites* species are elongate ellipsoides, and are sometimes found in partially separated halves. Size is on average is 64 µm in length and 55 µm in width (Zippi 1998).

Paleoecology: Generally same as *Ovoidites parvus.*

Genus *Schizosporis* Cookson and Dettmann 1959

Schizosporis Cookson and Dettmann 1959

Type Species: *Schizosporis reticulatus* Cookson and Dettmann 1959

Schizosporis reticulatus Cookson and Dettmann 1959

Plate 8 Figure 5-8

Description: *Schizosporis reticulatus* is generally inflated, spherical to slightly ellipsoidal with the shortest dimension being perpendicular to equatorial plane. The suture circumscribes the equator. Species are often split into two hemispherical to saucer shaped halves that may remain attached or typically separate into two parts. The halves generally retain the original shape. The inner wall is thin, smooth and continuous with the only disruption being the suture. The outer wall is cellular, with the cells creating a honeycomb like structure. The outer wall has a average thickness of about 3 μm (Zippi 1998).

Occurrence: Berriasian to Cenomanian in North America. Distribution may range into the Late Jurassic in Australia. They have a very wide spread occurrence in North America, Australia and Europe (Zippi 1998).

Paleoecology: Common in freshwater environments. Modern equivalent to *Schizospora reticulatus* have been found by Pierce (1977) in freshwater ponds. Pierce demonstrates that *Schizosporis reticulatus* had similar environments to modern Zygnemataceae.

Genus *Schizocystia* Cookson and Eisenack 1962

Type Species: *Schizocystia rugosa* Cookson and Eisenack 1962

Schizocystia rugosa Cookson and Eisenack 1962

Plate 8 Figure 3-4

Schizocystia laevigata Cookson and Eisenack 1962
Tetraporina rugosa (Cookson and Eisenack 1962) Elsik 1968

Description: *Schizocystia rugosa* complete specimens have four sides with straight to deeply concave walls. The sides perpendicular to the suture are straight, while the other sides resemble a capital letter B. Specimens are usually separated into two halves. The walls are generally laevigate (smooth) but they may have some ornamentation (e.g. vermiculate).

Occurrence: Albian to Maastrichtian in North America. In Australia *S. rugosa* ranges from Valanginian to Cenomanian and in Belgium in Santonian (Zippi 1998).

Paleoecology: *Schizocystia* are believed to be reproductive spores of freshwater algae and have similar tolerances as modern Zygnemataceae. Where specimens of *Schizocystia* are very abundant, marine palynomorphs are generally absent. However this species does occur infrequently in marine assemblages (Zippi 1998).

Genus *Tetraporina* Naumova 1939

Tetraporina Noumova 1939
Tetrapidites Klaus ex Meyer 1956
Tetraporopollenites Frantz 1960
Balmella Pant and Mehra 1963

Type Species: *Tetraporina antiqua* Naumova 1950

Tetraporina sp. of Zippi 1998

Plate 12, Figure 6

Description: *Tetraporina* is a single walled cyst. The wall is very thin (less than 1 µm). Generally a smooth wall with no ornamentation. Shape is a rectangle with the corners folded in and rounded. Some specimens have folds in the wall layer.

Occurrence: Carboniferous to Recent

Paleoecology: *Tetraporina* is found in depositional systems with other zygnemataceans (Zippi 1998).

Class Chlorophyceae Kützing 1843

Order Chlorococcales Marchand 1895

Family Botryococcaceae Willey 1909

Genus *Botryococcus* Kützing 1849

Type Species: *Botryococcus braunii* Kützing 1849

Botryococcus sp. cf *B. braunii* Kützing 1849

Description: Only a few specimens of *Botryococcus* were found in this study. They were all small specimens primarily found in the SEM. Their structure was hard to determine because of the small amount of specimens however they appear to be similar to species found in Zippi (1998). The specimens are a muticellular colony with densely clustered irregular cups. Each lobe of the *Botryococcus* can have numerous cups usually three to six. For a general description of *Botryococcus* see section 3.3.1b of this thesis.

Occurrence: Ordovician to Recent.

Paleoecology: The paleoecology of the fossil species can be inferred by looking at the modern species. Modern *Botryococcus* is a freshwater dispersed algae which can be planktonic, attached benthic or epiphytic on submerged plants. It is common found in hard water lakes and ponds with a medium alkalinity.

Group Acritarcha

Genus *Spicadinium* Batten 1988

Spicadinium sp.

Plate 11 Figure 1,2

Description: Similar to *Spicadinium akidoton* Batten 1988 (see Batten and Lister 1988b). Ovoid body with hair like processes 5 μm to 25 μm with an average length of 15 μm. Processes are very thin 1 μm or less and taper as they get further from the body to a sharp point. The processes are generally longer than the average diameter of the body which is 7.5 μm. Processes appear to sit in cup like structures or thickenings on the body. Body is totally covered by processes and walls are not easily distinguished. No opening is visible on the body.

5.3 Pollen

Genus *Retimonocolpites* Pierce 1961

Type Species: *Retimonocolpites dividuus* Pierce 1961

Retimonocolpites cf. *pennyi* Schrank and Mahmoud 2002

Plate 6, Figure 1-6, 9-11, Plate 7, Figure 4-12

Description: Monosulcate with a narrow sulcus. Sulcus not visible on all specimens. Unknown, on these specimens, whether the sulcus extends from one end to the other. The reticulum is loosely attached to a smooth nexine and is a thick, reticulate, columellate sexine consisting of muri that surround irregular polygonal, rounded to elongate lumina. Reticulum is generally the same size as the nexine. The polygons of the reticulum are very small, less than 3 µm in diameter. Polygons are irregularly shaped but the same general size over the entire specimen.

Occurrence: ? Barremian- ? Late Barremian

Retimoncolpites peroreticulatus Doyle 1975

Plate 6, Figure 7-8, Plate 7, Figure 1-3

Peromonolites peroreticulatus Brenner 1963
Peromonolites reticulatus Brenner 1963
Liliacidites peroretiulatus (Brenner) Singh 1971
Liliacidites reticulatus (Brenner) Singh 1971
Retimonocolpites reticulatus (Brenner) Doyle 1971

Description: *Retimonocolpites peroreticulatus* is a monsulcate pollen species with a sulcus that extends from end to end of the grain. The reticulum is unusually coarse (polygons over 3 µm in diameter) and tends to detach from the nexine. Individual polygons of the reticulum can be twice the size of the body formed by the nexine. The reticulum is thick with a bumpy ornamentation on the surface. Polygons are irregularly shaped but the same general size over the entire specimen.

Occurrence: ?Aptian -Lower Albian?

5.4 Spores

Genus *Cicatricosisporites* Potonié and Gelletich 1933

Type Species: *Cicatricosisporites dorogensis* Potoniè and Gelletich 1933

Description: See Potonié and Gelletich 1933 page 522.
Diagnosis: Specimens of *Cicatricosisporites* have a subtriangular to subcircular shape. The exine has a two layered, uniform thickness exine with ornamentated ribs that sometimes appear to have a crossed structure. The ribs are called costae. The size, thickness, and spacing of the costae as well as the size of the spore determine what species it belongs to. This group is very complex and species are inconsistenly defined and applied.

Genus *Appendicisporites* Weyland and Krieger 1953

Type Species: *Appendicisporites tricuspidatus* Weyland and Greifeld 1953

Description: See Burden and Hills 1989

Diagnosis: These are triangular spores that have costae similar to *Cicatricosisporites*. They have one or more extensions, or appendices at the corners of the outline. These appendices are extra and not simple extensions of individual costae.

Genus *Plicatella* Maljavkina 1949

Type species: *Plicatella trichacantha f.tricantha, Plicatella trichacantha f typica* Maljavkina designated by Potonié 1960

Description: see Burden and Hills 1989 page 58

Diagnosis: This is a triangular species with costae similar to *Cicatricosisporites.* The appendages on the corners of the outline, are described more as lobes, thickenings or caps rather than extensions. The costae are usually connected to the lobes.

Spore A

Plate 5, Figure 1-8

Description: Triangular spore with thickened exine surrounding a hole the penetrates through the entire spore. The spore has small lobes that are often tilted towards either the proximal or distal side or sometimes they are straight off the apices. The lobes are sometimes pointed or rounded. The spore has a smooth wall and the hole in the center can have a smooth wall or it can have a punctate or foveolate wall.

Diagnosis: It is unsure whether this is a new species or whether this is a preservational artifact of another species. It has thickenings similar to *Gleicheniidites*, lobe thickenings similar to *Cibotiumspora*, appendices similar to *Plicatella* or *Appendicisporites*. This species has a wide variation within the type both in light microscope and in SEM.

Chapter 6-Paleoecology and Biostratigraphy

6.1 Paleoecology

The paleoenvironment of the Cretaceous deposits of the Elmsvale Basin and Shubenacadie Outlier has been previously thought to be non-marine fluvial or fluvial-deltaic (Dickie 1987, Stea et al 1996) with primary deltaic features (Dickie 1987). These conclusions were mainly through lithostratigraphic and sedimentological considerations. This study involved a palynological analysis of the cores to determine, in part, a paleoevironment for the strata. The general nature of the palynomorph assemblages support a non-marine interpretation.

Spores and pollen are in most cases the most abundant palynomorphs in the samples. These represent trees, bushes, and herbs that were growing in the area during the Cretaceous. The dominant presence of spores and pollen gives evidence for a terrestrial environment. The relative abundance of the types of spores and pollen from sample to sample can be indicative of certain terrestrial environments, but this detail was beyond the scope of this work. Evidence for a non-marine environment is also provided by the abundance in some samples of freshwater zygnematacean cysts and rare dinocysts that are generally considered to be of non-marine origin.

All of these elements, especially the pollen and spores can be transported into the marine environment, so their presence alone is not conclusive. However, the absence of a diversity of dinocysts is very strong evidence, albeit negative, of a non-marine affinity for the Chaswood Formation (see futher discussion below).

Zippi (1998) found a similar distribution of zygnemataceans and dinoflagellates in the Moose River Basin (Table 6.1). He determined through detailed work on the modern analogs of the fossil cysts that they occur primarily freshwater stream, lake, swamp and flood plain deposits. Due to the work of Zippi, who remarks that *Schizosporis reticulatus* is a definitive indicator of freshwater environments, the work by Pierce (1977) on possible modern analogs of *Schizosporis reticulatus*, and especially the lack of a diverse dinoflagellate assemblage, I am concluding that the environment for the Elmsvale Basin and Shubenacadie Outlier is similar to the Moose River Basin–and thus non-marine. Zippi specifies for each species in his study a possible environment. The general environment for the study is, paludal lacustrine environments such as lakes, ponds, and swamps, as well as, slow moving streams.

The Nova Scotia Cretaceous has a lower species diversity, compared with the Moose River Basin. This could be for one of several reasons: (1) the age of the sediments – Mattagami Formation in the Moose River Basin is slightly younger (Albian) than the Chaswood Formation (Aptian – see below); (2) the species were not preserved; (3) the issue of a major river system in the area may not have allowed for the proliferation of as many different types of organisms in Nova Scotia; or (4) as in modern settings, not all species occur in the same environment everywhere; but most likely, (5) the fact the fewer samples were looked at in the present study than by Zippi in the Moose River basin.

Table 6.1- Comparison of the Moose River Basin palynomorphs with the Nova Scotia palynomorphs from the present study

Moose River Basin	**Nova Scotia**
Botryococcus sp. cf. *B. braunii*	*Botryococcus* sp. cf. *B. braunii*
Lecaniella irregularis	*Lecaniella irregularis*
Lecaniella foveata	*Lecaniella foveata*
Ovoidites parvus	*Ovoidites parvus*
Ovoidites spriggi	*Ovoidites spriggii*
Ovoidites grandis	*Schizocystia rugosa*
Ovoidites spriggi	*Tetaporina* sp. 1 of Zippi 1998
Schizosporis reticulatus	*Nyktericysta* sp.
Schizocystia rugosa	*Peridinium* sp.
Tetaporina sp. 1	*Spicadinium* sp.
Sphaeroplea fenestrata n. sp.	*Schizosporis reticulatus*
Nyktericysta lacustra n.sp.	
Balmula sp. 1	
Chomotriletes minor	
Cymatiosphaera sp. cf. *C. pachytheca*	
Cymatiosphaera sp. 1	
Retirotundia pseudoreticulata	
Pediastrum sp. cf. *P. boryanum*	
Pediastrum sp. cf. *P. boryanum* var. longicorne	
Scenedesmus sp. A	
Coelastrum sp. cf. *reticulatum* var. cubanum	
Oedogonium cretaceum	
Mougeotia sp. cf. *M. laetevirens*	

The two species of dinoflagellates present, *Nyktericysta* sp. and *Peridinium* sp., are forms generally considered to have a non-marine affinity (Zippi 1998, Mao et al 1999). *Nyktericysta* can be found in both marine and non-marine sediments, however the general consensus is that they are non-marine indicators when dinoflagellate diversity is low. Their occurrence in marine sediments may be due to transportation from non-marine to marine environments. Species of *Nyktericysta* and its relatives have been found in basins in China. China was cut off from the sea in the early to mid Mesozoic, and all basins except those near Tibet are considered to be non-marine. This is similar to the situation for the Moose River Basin, where there was no evidence for marine strata within hundreds of kilometres of the basin. The basins of China are both sedimentologically and palynologically considered to be non-marine (Mao et al 1999).

Modern species of *Peridinium* have been found in two lakes in Awenda Provincial Park, near Georgian Bay, Ontario (Burden et al 1986). Hense, although the single specimen from the Chaswood Formation is not from a known species, it is of the type that would be expected from non-marine deposits.

Other evidence for a non-marine depositional environment in the Nova Scotia deposits is that there is a small diversity of dinoflagellates–indeed none other that *Peridinium* and *Nyktericysta*. In marginal marine environments up to the average spring tide, marine dinoflagellates are found in modern environments (Farr 1989). On the assumption that modern environments were similar to past environments, the lack of marine dinoflagellates in the Chaswood Formation suggests non-marine environments, thus supporting lithostratigraphic and sedimentological evidence.

A contrasting interpretation is that of a marginal marine environment on the basis of foraminifera found by Warringer (1996). D. B Scott (personal communication 2002) suggests that this may be evidence enough to interpret a marginal marine environment for the strata of the Shubenacadie Outlier. Although palynomorphs do not support this interpretation, however his suggestion can not be totally ruled out as the lack of marine palynomorphs can not be used to definitely determine a non-marine environment. The foraminifera were found in a breccia zone near the base of the cores (Fig 6.1). Palynological investigations of the breccia in the bottom of two of the cores in this study, MUS95-2 and SHU94-5, have only Carboniferous palynomorphs present in the samples. This suggests that the breccia may be of Carboniferous age.

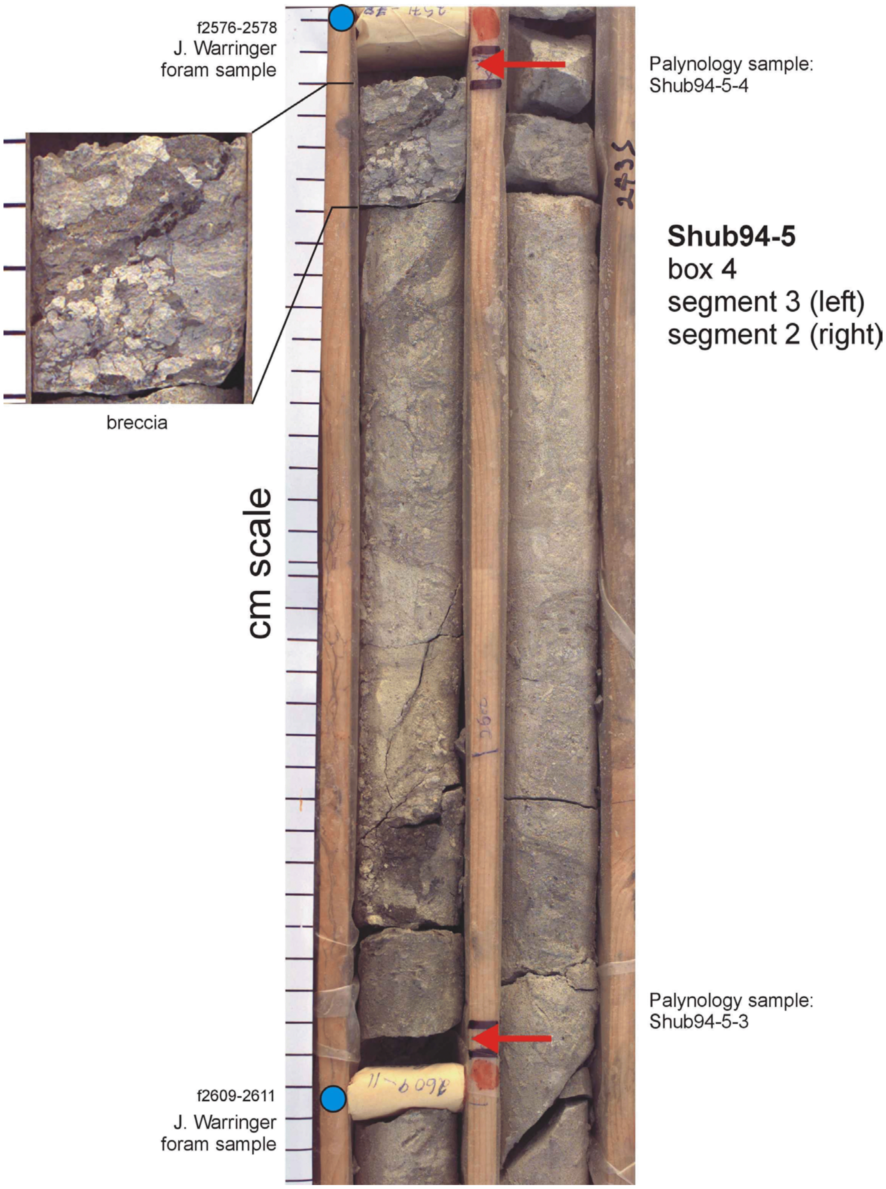


Figure 6.1-Breccia zone at the base of SHU94-5. Red arrows represent palynology samples containing Carboniferous palynomorphs. Blue dots represent productive foraminifera samples of J. Warringer (1996).

6.2 Biostratigraphy

Figure 6.2 through 6.5 are the range plots of the four cores studied in this project. Figure 6.2 is the plot of core SHU94-3. It shows an abundance of bisaccates throughout, as well as *Gleicheniidites*, *Deltodiospora*, and *Cicatricosisporites*. The fresh water protists seem to be more abundant near the top of the core rather than the bottom, *Botryococcus* appears in the middle of the core, and *Retimonocolpites peroreticulatus* begins to appear in the middle of the core and goes to the bottom of the sampled section. Figure 6.3 is the plot of Shubenacadie SHU94-4. It shows a general lack of bisaccates in the core. This core has a restricted range of *Retimonocolpites* and *Eucommiidites*. Freshwater protists tend to be present more toward the top of the samples. Spore A is quite abundant in this core. Figure 6.4 is the plot of Shubenacadie SHU94-5. It shows an abundance of fresh water protists near the top of the core. The bottom samples below 465 ft (139.5 m) contain only Carboniferous spores. Figure 6.5 is the plot of MUS95-2. This is the core that shows the most variation in species from top to bottom. In the middle of the core there is a proliferation of fresh water protists like the dinoflagellates, *Nyktericysta* sp and *Peridinium* sp. as well as *Lecaniella, Schizosporis, Schizocystia,* and *Ovoidites*. In this core, *Retimonocolpites peroreticulatus* is only present in the middle part of the core. This has one of three implications: (1) the species was not present to be preserved in the ther zones due to environmental factors, (2) the species has a limited age range and this is the range of the species, and (3) this may suggest

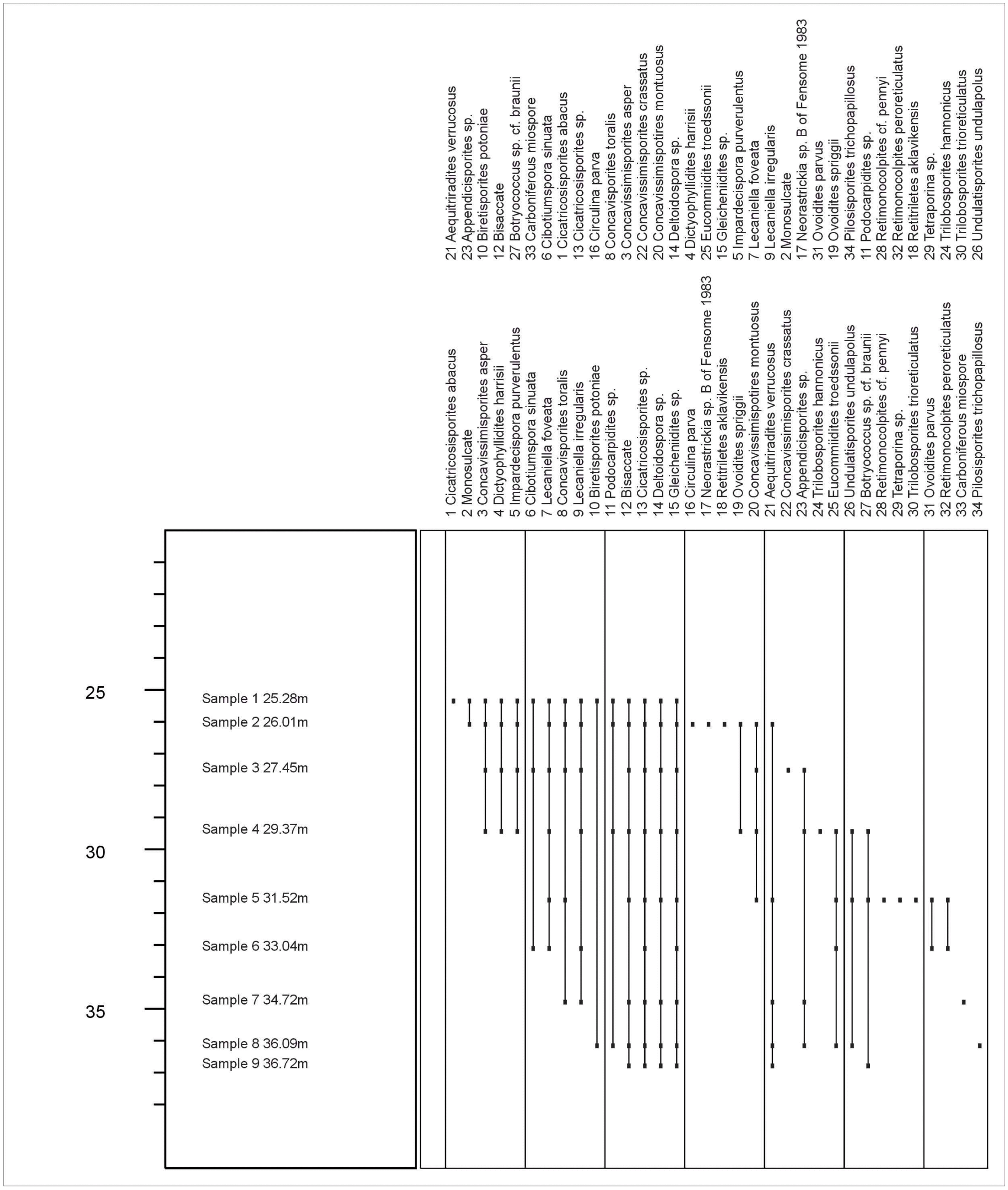


Figure 6.2-Range plot of Shubenacadie Outlier core SHU94-3.

a possible change in preservation conditions. The bottom samples in MUS95-2 again appear to be Carboniferous.

The age of the Cretaceous strata of the Elmsvale Basin and theShubenacadie Outlier is difficult to determine in detail. Generally Mesozoic

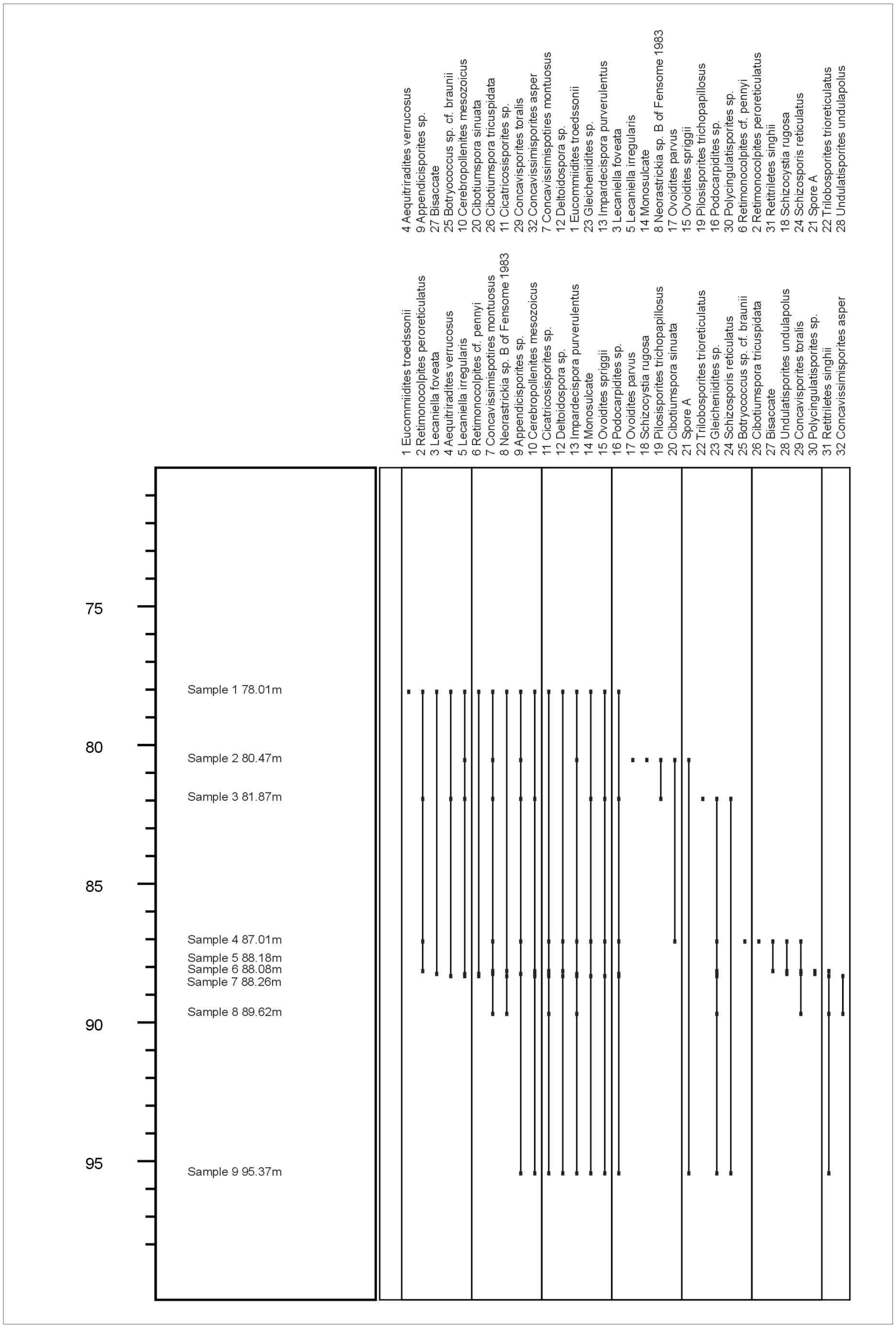


Figure 6.3-Range plot of Shubenacadie Outlier core SHU94-4.

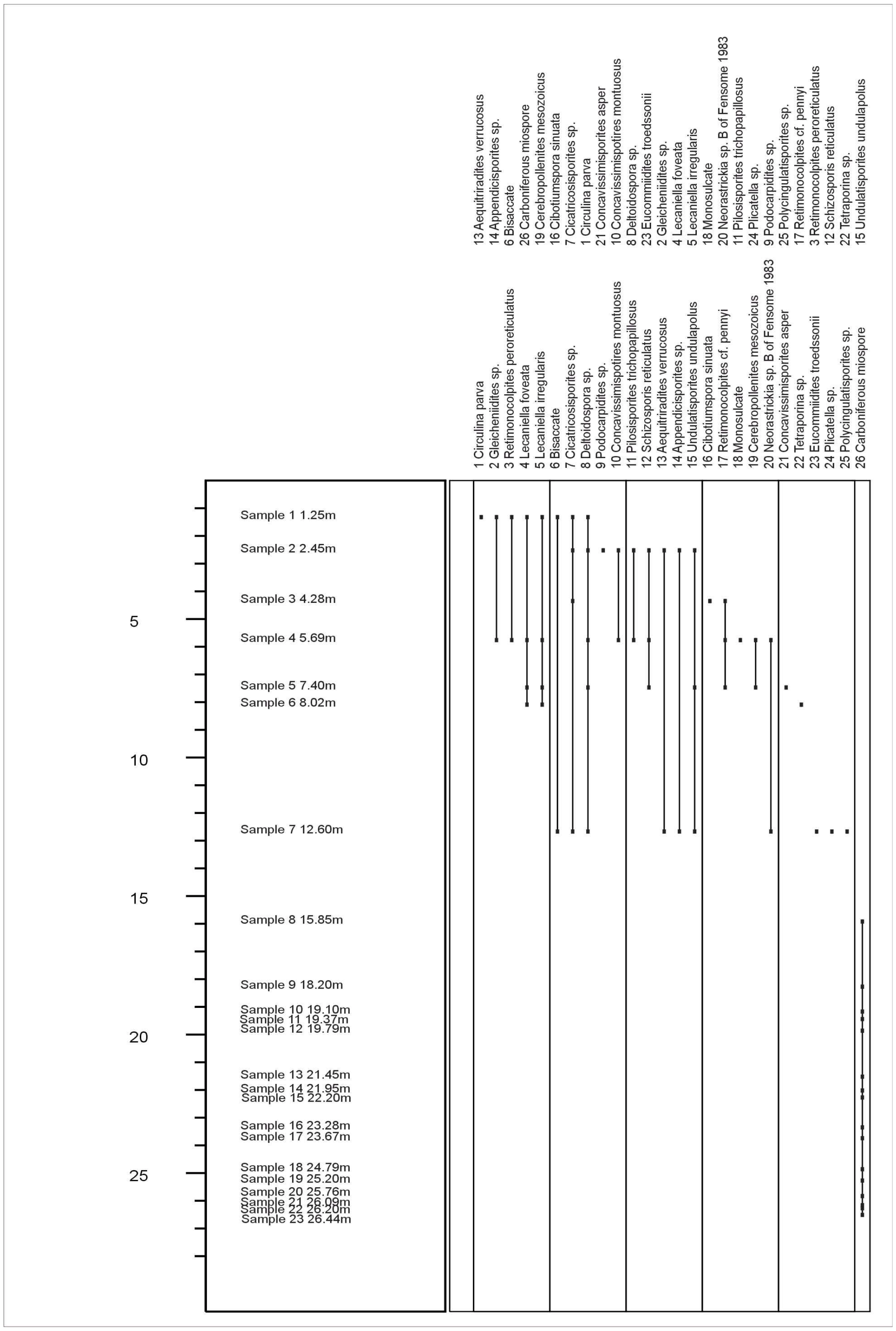


Figure 6.4-Range plot of Shubenacadie Outlier core SHU94-5.

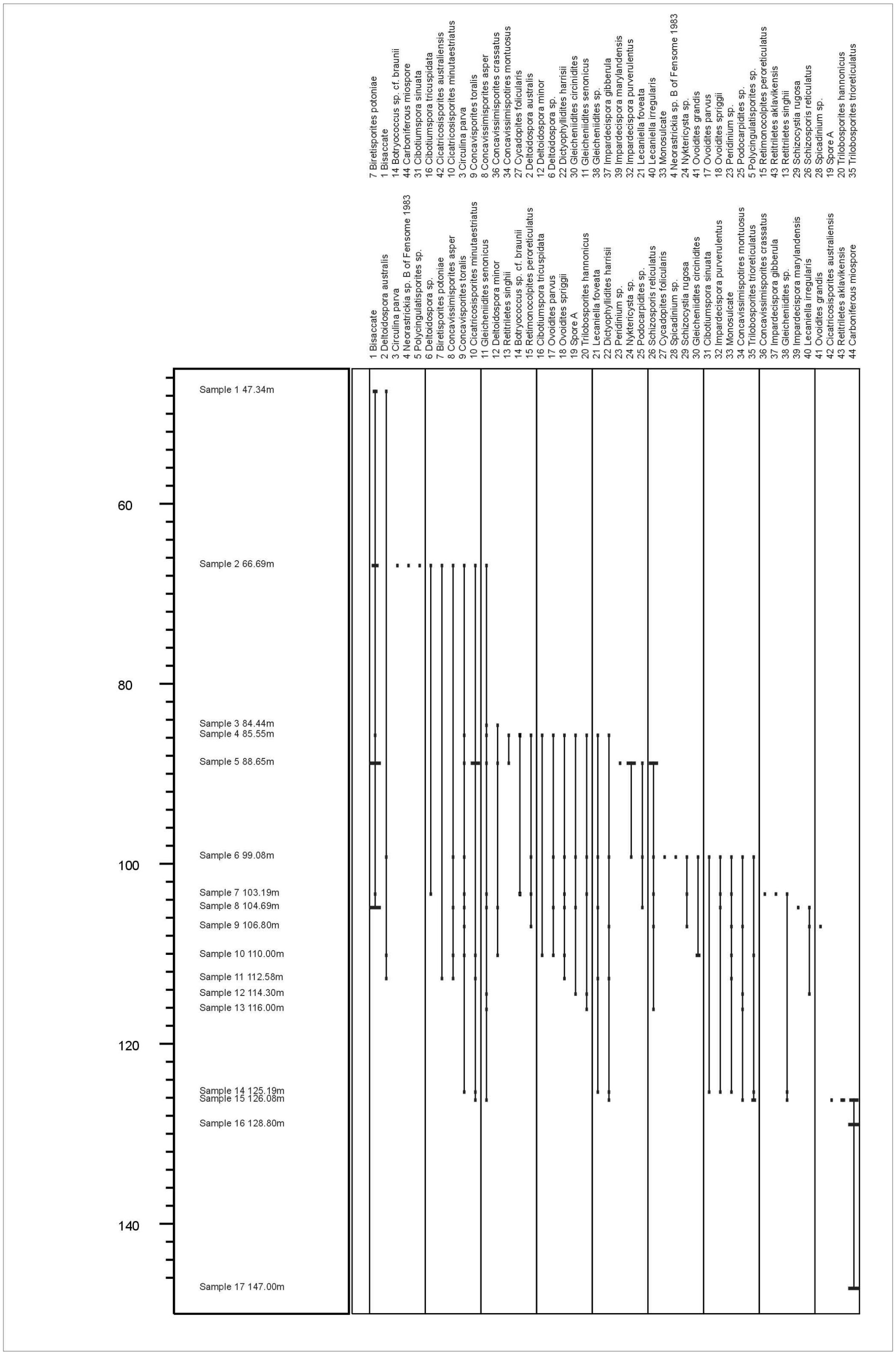


Figure 6.5-Range plot of Elmsvale Basin core MUS95-2.

Figure 6.5-Range plot of MUS95-2as spores and pollen, which dominate the Chaswood Formation, do not have well documented age ranges, so age determinations from these fossils are more difficult. The two species of angiosperm pollen in this study give some indication of the age. The main avenue for determining the age of the sediments is the presence of monsulcate pollen and the lack of tricolpate pollen and tricolporate pollen. Tricolpate angiosperm pollen grains first appeared in the fossil record later than the monosulcate forms in which the *Retimonocolpites* species belong, but paleolatitude also appears to have an influence. Hickey and Doyle (1977) devised a method for determining the age of a sample based on the paleolatitude of the area and the type of angiosperm pollen present. Using a program developed by the Ocean Drilling Stratigraphic Network, I was able to determine the paleolatitude of Nova Scotia (Appendix 1). However, due to the fact that the age it is yet unsure, I used a range of ages from the Barremian-Aptian to the Albian-Cenomanian (the ranges previously determined for the strata). The paleolatitudes for these ages in Nova Scotia are from 31^o N to 35^o N. Using the paleolatitudes above with an error bar of 5^o either way, and the lack of tricolpate pollen grains, I used Hickey and Dolye's graph to determine that the youngest age for the deposits to be Early Albian. (Fig 6.6). Due to the angiosperm pollen present, and the type of other palynomorphs, it is more likely that the age is Aptian, but an older age cannot be ruled out.

Most recently G. Dolby (J. Calder, personal communication 2002), in preliminary studies of the Elmsvale Basin core MUS95-2, reported finding tricolpate grains and *Rugubivesiculites reductus*. This suggests a late Albian. The Cretaceous deposits of onshore Nova Scotia are sufficiently thick to span a significant part of mid to late Early Cretaceous time, so the two results are not necessarily in conflict. Further integrated work will refine the age range of the

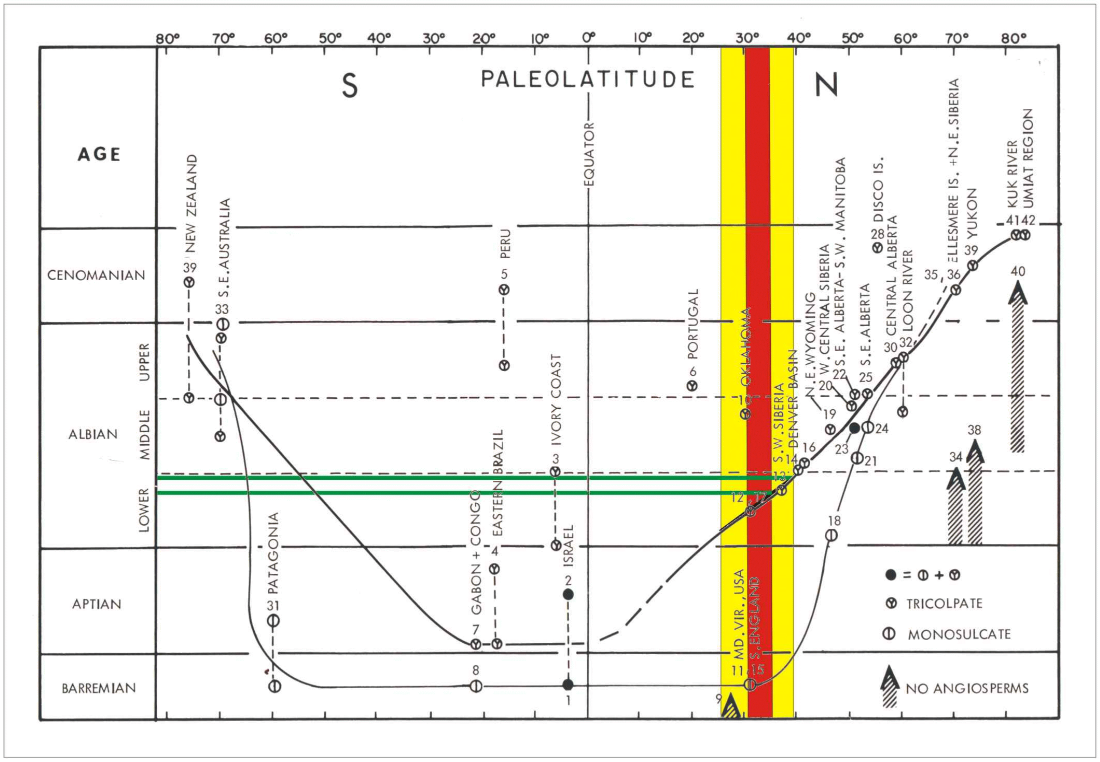


Figure 6.6-Shows the dividing line between the presence of monosulcate and tricolpate pollen grains. The paleogeographic range of Nova Scotia, as determined from the Ocean Drilling Stratigraphic Network, is shown in orange. The error of 5 ^{o} is in yellow. This shows an age of Lower Albian or older. (Hickey and Doyle 1977)

Chapter 7- Conclusions and Further Work

7.1 Conclusions

The main objectives of this project are to use palynology to :

1. **Determine the paleoenvironment and the paleoecology of the deposits.**

The palynology of the Shubenacadie and Musquodoboit deposits are interpreted to be non-marine deposits based on the presence of spores, pollen, zygnemataceans, and possible fresh water dinoflagellates and especially, the absence of a diversity of marine dinoflagellates. The strata in the Shubenacadie Outlier cores possibly represent floodplain deposits. The Musquodoboit Basin cores show no evidence of any water influence except in the middle mud units. This is interpreted to be a paludal-lacustrine deposit due to the presence of two species of possible freshwater dinoflagellates and the proliferation of zygnematacean cysts in this area.

2. **Determine a more precise age of the sediments.**

Based on the established paleolatitdinal and stratigraphic distributions of angiosperm pollen types, the material studied is Early Albian at youngest, but probably Aptian. An older age cannot be ruled out, however.

3. **To test the paleoecological interpretations derived from prior studies of foraminifera.**

Palynological study in the areas of breccia where foraminifera have previously been found, suggest that this is not of Cretaceous age. Only Carboniferous spores were present in the breccia zones possibly suggesting that this is not part of the Chaswood formation, but of a much older formation.

However, due to these finding and the uncertainty surrounding the breccia zones, a marginal marine environment cannot be ruled out for the Chaswood Formation. More detailed work is needed to determine the origin of the breccia.

4. Compare the Cretaceous deposits found in Nova Scotia with those found in other parts of North America.

The Chaswood Formation is comparable to the Moose River Basin in many ways. In the structure, distance from the sea, and playnomorphs they are comparable enough to determine that the environments are similar. The Moose River Basin contains strata of paludal-lacutrine, flood plain and swamp facies similar to those found in the Chaswood Formation.

7.2 Further Work

1. Compare more cores in the Musquodoboit Basin to determine if the presence if the distribution of freshwater protists is continuous or local.
2. Compare more cores from the Musquodoboit Basin and the Shubenacadie Outlier to see if detailed correlations can be established.
3. Assess the provenance of the sands to determine where these sediments have come from and how far they may have traveled (presently being studied by J-P. Gobeil and G. Pe-Piper) to determine if the deposits are in situ.
4. Look at more cores in both of the areas and try to compare them to the wells in the offshore to see if a link exists between the onshore sediments and the offshore oil producing sediments.
5. To attempt a magnetostratigraphy of the area to try to determine if this will help focus the age of the Chaswood Formation.

6. More in depth work on the breccia zone to determine the age and environment.
7. Study the foraminifera and palynology together to better understand the paleoenvironment of the area.
8. Compare the findings in this study to more studies of marginal marine assembles to determine, if any, the relationship between modern marginal marine and the study area.
9. To look more closely at the spores and pollen to determine if differents paleoenvironments can be recognized through relative abundances of each.
10. To look at the other Cretaceous basins throughout the Maritimes to determine correlations.
11. Integrate work being completed by Calder er al (personal communication 2002) to determine the age range of the deposits.

References

Atlantic Geoscience Society
2001 The Last Billion Years. Nimbus Publishing, Halifax NS, Canada, Atlantic Geoscience Society Special Publication No. 15, –pp.

Barss, M. S. and Williams, G. L.
1973 Palynology and nannofossil processing techniques. Geological Survey of Canada paper 73-26, 25 pp.

Batten, D. J and Grenfell, H. R.
1996 Chapter 7D *Botryococcus*. In: Jansonius, J. and McGregor, D. C. (editors), Palynology: Principles and Applications Volume 1 pp. 205-214. American Association of Stratigraphic Palynologists Foundation Dallas, U. S. A.

Batten, D. J. and Lister, J. K.
1988a Evidence of freshwater dinoflagellates and other algae in the English Wealden (Early Cretaceous). Cretaceous Research, volume 9, pp. 171-179.

Batten, D. J. and Lister, J. K.
1988b Early Cetaceous dinoflagellate cysts and chlorococcalean algae from freshwater and low salinity palynofacies in the English Wealden. Cretaceous Research, volume 9, pp. 337-367.

Berggren, W., Kent, D. , Switcher III, C., and Aubry, M.
1995 A revised Cenozoic geochronology and chronostratigraphy. In: Berggren, W. Kent, D, Aubry, M, and Hardenbol, J. (editors), Geochronology Time Scales and Global Stratigraphic Correlation. Society of Sedimentary Geology Special publication No 54, pp. 129-212.

Brenner, G.
1963 The spores and pollen of the Potomac Group of Maryland. Maryland Department of Geology, Mines and Water Resources, Bulletin 27, 215 pp.

Bint, A. N.
1986 Fossil Ceratiaceae: a restudy and new taxa from the mid-Cretaceous of the Western Interior, USA. Palynology, volume 10, pp. 135-180.

Bold, H. C. and Wynne, M. J.
1985 Introduction to the Algae. 720pp.; Prentice-Hall Inc. New Jersey, U.S.A.

Bolkhovitina, N. A.
1953 Spores and pollen characteristic of the Cretaceous deposits of central regions of the U. S. S. R. Transaction o the Academy of Sciences of the U. S. S. R., no. 145; Geological Institute Serial, no. 61 184 pp. 16 pl. (in Russian).

1961 Fossil spores of the fern family Gleicheniaceae (taxonomy and distribution. In: Neustadt, M. I. (editor) the Importance of Palynological Analysis for Stratigraphic and Palaeobotanic Investigations, pp. 65-75; Nauka, Moscow, U.S.S.R. (in Russian),

Brenner, G. J.
1976 Middle Cretaceous floral provinces and early migrations of angiosperms. In: Beck, C. B. (editor) Origin and Early Evolution of Angiosperms, 24 pp. Columbia University Press, New York. U.S.A.

Burden, E. T. and Hills, L. V.
1989 Illustrated key to genera of Lower Cretaceous terrestrial palynomorphs (excluding megaspores) of western Canada. American Association fo Stratigraphic Palynologist Foundation, Contribution Series no. 21, 147 pp.

Burden, E. T., McAndrews, J. H., and Norris, G.
1986 Palynology of Indian and European forest clearance and farming in lake sediment cores from Awenda Provincial Park, Ontario. Canadian Journal of Earth Sciences, volume 23, pp. 43-54.

Burger, D.
1966 Palynology of uppermost Jurassic and lowermost Cretaceous strata in the eastern Netherlands. Leidse Geology of Mededlingen, volume 35, pp. 209-276 pl. 1-39.

Cookson, I. C.
1953 Difference in microspore composition of some samples from a bore at Comaum, South Australia. Australian Journal of Botany, volume 1, pp. 462-473.

Cookson, I. C. and Dettmann, M. E.
1958 Some trilete spores from Upper Mesozoic deposits in the eastern Australian Region. Proceedings of the Royal Society of Victoria, volume 70 (2), pp. 95-128, plates 14-19.

1959 On *Schizosporis*, a new form genus from Australian Cretaceous deposits. Micropaleontology, volume 5 (2) pp. 213-216.

1961 Reappraisal of the Mesozoic microspores genus Aquitriradites. Palaeontology, volume 4, pp. 425-427, plate 52.

Cookson, I. C. and Eisenack, A.
1962 Some Cretaceous and Tertiary micorfossils from western Australia. Proceedings of the Royal Society of Victoria, volume 75, pp. 269-273.

Couper, R. A.
1953 Upper Mesozoic and Cenozoic spores and pollen grains form New Zealand. New Zealand Geological Survey of Palaeontology. Bulletin 22, 72 pp. pl. 1-9.

1958 British Mesozoic microspores and pollen grains, a systematic and stratigraphic study. Palaeontographica, volume 103B, pp.75-179, pl. 15-31.

Crane, P. R., Friis, E. M., and Pedersen, K. R.
1995 The origin and early diversification of angiosperms. Nature, volume 374, pp.27-33.

Davies, E. H., Akande, S. O. and Zentilli, M.
1984 Early Cretaceous deposits in the Gays River lead-zinc mine, Nova Scotia. In: Current Research, Part A, Geological Survey of Canada, Paper 84-1A, pp. 353-358

Delcourt, A. F., Dettmann, M. E., and Huges, N. F.
1963 Revision of some Lower Cretaceous microspores from Belgium. Palaeontology, volume 6, pp. 282-292, plates, 42-45.

Delcourt, A. F. and Sprumont, G.
1955 Les spores et grains de pollen du Wealdien du Hainaut. Memoire de la Societé belge de géologie, paléontologie, hydrologie, n. s. volume 4(5) pp. 1-73, plates 1-4.

Dettmann, M. E.
1963 Upper Mesozoic microfloras from southeastern Australia. Proceedings of the Royal Society of Victoria, volume 77, pp. 1-148, plates 1-27

Dickie, G.B.
1987 Cretaceous Deposits of Nova Scotia. Nova Scotia Department of Mines and Energy Paper 86-1, 54 pp.

Dolye, J. A., Van Campo, M. and Lugardon, B.
1975 Observations on exine structure of Eucommiidites and Lower Cretaceous angiosperm pollen. Pollen et Spores, volume 17 (3), pp. 429-486.

Döring, V. H.
1964 Trilete sporen aus dem Oberen Jura und dem Wealden Norddeutschlands. Mitteilung aus dem Zentralen Geologischen Institute, Berlin, volume 13, pp. 1099-1130.

Erdtman, G.
1948 Did dicotyledonous plants exist in early Jurassic times? Geologiska Foreningers i Stockholm Forhandlingar, volume 70, pp. 265-271.

Evitt, W. R.
1961 Observations of the morphology of fossil dinoflagellates. Micropaleontology, volume 7(4), pp.385-420.

1963 A discussion and proposals concerning fossil dinoflagellates, hystrichospheres, and acritarchs. National Academy of Sciences, volume 49 (2 and 3) pp.158-164, 298-302.

1985 Sporopollenin Dinoflagellate Cysts. American Association of Stratigrpahic Palynologists Foundation, Hart Graphics, Texas, USA.

Farr, K. M
1989 Palynomorph and palynodebris distributions in modern British and Irish estuarine sediments. In: Batten, D. J and Keen, M. C. Morthwestern European Micropalaentology and Palynology, pp.265-285. Ellis Horton Limited, West Sussex, England.

Fensome, R. A.
1983 Miospores from the Jurassic-Cretaceous Boundary Beds, Aklavik Range, Northwest Territories, Canada. PhD thesis, University of Saskatchewan.

Fensome, R. A. and Norris, G.
1982 Palynostratigraphic comparison of Cretaceous of the Moose River Basin, Ontario, with marginal marine assemblages from the Scotia Shelf and Alberta. Ontario Geological Survey Miscellaneous Paper 103, pp. 37-42.

Fensome, R. A., Riding, J. B. and Taylor, F. J. R.
1996 Chapter 6: Dinoflagellates. In: Jansonius, J. and McGregor, D. C. (editors.) Palynology: Principles and Applications, Volume 1, pp.107-169. American Association of Stratigraphic Palynologists Foundation, Dallas U.S.A.

Fensome, R. A., Taylor, F. J. R., Norris, G., Sarjeant, W. A. S., Wharton, D. I., and Williams, G. L.
1993 A Classification of living and fossil dinoflagellates. Micropaleotology, Special Publication No. 27, –pp.

Finck, P. W., Stea, R. R., and Dwyer, D. F.
1994 Preliminary results of drilling Quaternary and Cretaceous sediments near Shubenacadie Nova Scotia. Nova Scotia Department of Natural Resources, Open File Report 94-026, 31 pp.

Fowler, J. H.
1972 Clay and Sand Deposits at Elmsvale, Halifax County. Nova Scotia Geological Division Department of Mines. 31 pp.

Fowler, J. H. and Stea, R.
1978 Cretaceous deposits in Nova Scotia. Nova Scotia Department of Mines Report, 79-1, pp. 9-13.

Gradstein, F., Agterberg, F., Ogg, J., Hardenbol, J. Van Veen, P. Thiery, J., and Huang, Z.
1995 A Triassic, Jurassic, and Cretaceous time scale. In:Berggren, W., Kent, A., Aubry, M., and Hardenbol, J. (editors), Geochronology, Time Scales and Global Stratigraphic Correlation. Society for Sedimentary Geology Special Publication No. 54, pp. 95-126.

Grenfell, H. R.
1995 Probable fossil zygnematacean algal spore genera. Review of Paleobotany and Palynology, volume 84, pp. 201-220.

Grist, A. and Zentilli, M.
2000 Apatite fission track constraints on a widespread early Late Cretaceous heating episode in the Canadian Atlantic margin: added effect of a climatic perturbed gradient? 9th International Conference of Fission Track Dating and Thermochronology.

Guy-Ohlson, D.
1992 *Botryococcus* as an aid in the interpretation of palaeoenvironment and depositional processes. Review of Paleobotany and Palynology volume 71, pp. 1-15.

Harland, W. B., Armstrong, R. L., Cox, A. V., Craig, L. E., Smith, A. G., Smith, D. G.
1990 A Geologic Time Scale. 263 pp.; Cambridge University Press, U. S. A.

Hickey, L. J. and Doyle, J. A
1977 Early Cretaceous fossil evidence fro angiosperm evolution. The Botanical Review volume 43, No 1, pp. 3-104.

Hill, G. T.
1976 Mineralization and Coal Petrology of the Shubenacadie Clay Deposit, Nova Scotia. BSc Honours thesis Dalhousie University. 97 pp.

Jansonius, J. and Hills
1976-1990 Genera File of Fossil Spores and Pollen. Specieal Publication, Department of Geology, University of Calagary, Calgary, Canada. (Includes 10 supplements)

Jansonius , J. and McGregor, D. C.
1996 Chapter 1. In: Jansonius, J. and McGregor, D. C. (editors), Palynology: Principals and Applications; Volume 1 pp. 1-10; American Association of Stratigraphic Palynologists Foundation, Dallas, U. S. A.

Jarzen, D. M. and Nichols, D. J.
1996 Chapter 9: Pollen. In: Jansonius, J. and McGregor, D. C. (editors), Palynology: Principles and Applications; Volume 1, pp. 261-291, American Association of Stratigraphic Palynologists Foundation, Dallas, U. S. A.

Kara-Murza, E. N.
1951 Mesozoic spore-pollen complexes from north-central Siberia. Trans. Geol. Inst. Acad. Sci. U. S. S. R. volume 18, pp. 1-18 (in Russian)

Kützing, F. T
1849 Species algarum. VI + 922; Leipzig.

Leschik, G.

1955 Die Keuperflora von Neuewelt bei Basel. II. Die Iso-und Mikrosporen. Schweiz. Palaeontol. Abh. volume 72, pp 1-70, plates 1-10.

Lin, C. L.

1971 Cretaceous deposits in the Musquodoboit River Valley, Nova Scotia. Canadian Journal of Earth Sciences, volume 9, pp. 1152-1154.

Maljavkina, V. S.

1949 Identification of spore and pollen of the Jurassic and Cretaceous. Trudy Vses. Neft. Nauch.-Issled. Geol. Razv. Instute Leningrad. volume 33 137 pp.

Mao, S.-Z.,Wan, C.-B., and Qiao, X.-Y.

1999 Cretaceous nonmarine dinoflagellates from northeast China. Grana, volume 38, pp. 144-161.

Monroe, J. S. and Wicander, R.

2001 Physical Geology, Exploring the Earth. Brooks/Coles, Canada, 711pp.

Nakoman, E.

1966 Contribution à l'étude palynologigue des formations tertiaires du Bassin de Thrace. Annale de la Societé Geologique du Nord, volume 46, pp. 65-107.

Naumova S. N.

1939 Spores and pollen of the coals of the U. S. S. R. International Geological Congress 17th Moscow Report, volume 1 pp. 353-364.

Nilsson, T.

1958 Über das Vorkommen eines mesozoischen Sapropelgesteins in Schonen. Lunds University Arsskrift, n. s. Avd. 2. volume 54(10), pp. 1-112.

Pierce, R. L.

1961 Lower Upper Cretaceous plant microfossils from Minnesota. Minnesota Geological Survey, Bullentin 42, 86 pp.

Pierce, S. T.

1977 A modern analog of *Schizosporis reticulatus*. Palynology, volume 1, pp.139-142.

Playford, G. and Dettmann, M.. E.

1996 Chapter 8: Spores. In: Jansonius, J. and McGregor, D. C. (editors), Palynology: Principles and Applications; Volume 1, pp.227-260; American Association of Stratigraphic Palynologists Foundation, Dallas, U. S. A.

Pocock, S. A. J

1962 Microfloral analysis and age determination of strata at the Jurassic-Cretaceous boundary in the western Canada plains. Palaeontographica, Band 111, Abt. B Liefg. 1-3, pp. 1-95.

1965 Pollen and spores of the Chlamydospermidae and Schizaeaceae from Upper Mannville strata of the Saskatoon area of Saskatchewan. Grana Palynology, volume 5, pp. 129-209.

1970 Palynology of the Jurassic sediments of western Canada: part 1, terrestrial species. Palaeontographica, volume 5, pp. 129-136.

Potoniè, R

1951 Revision stratigraphisch wichtiger Sporomorphen des mitteleuropäischen Tertiärs. Palaeontographic, a volume 91 B, pp. 131-151.

1956 Synopsis der Gattungen der sporae dispersae. I Teil: Sporites. Beihefte zum Geologischen Jahrbueh, volume 23, 103 pp plates 1-11.

Potonié, R. and Gelletich, J.

1933 Uber Pteridophytensporen einer eozänen Braunkohle aus Dorog in Ungarn. Sitzungsberichte der Gesellschaft Naturforschender Freundee zu Berlin, volume 33, pp. 517-526.

Reissinger, A.

1950 Die “Pollen-Analyse”, asgedehnt auf alle Sedimentgesteine der geologischen Vergangenheit. Palaeontographica, volume 90B, pp. 99-126, plates 11-19

Ross, N. -E.

1949 On a Cretaceous pollen and spore bearing clay deposit of Scania. Bulletin, Geological Institute, University Uppsala, volume 34, pp. 25-43, plates 1-3.

Schrank, E. and Mahmood, M. S.

2002 Barremian angiosperm pollen and associated palynomorphs from the Dakhla Oasis area, Egypt. Palaeontology, volume 45, Part 1, pp. 33-56.

Singh, C.

1964 Microflora of the Lower Cretaceous Mannville Group, east-central Alberta. Research Council of Alberta, Bulletin 15, 239 pp.

1971 Lower Cretaceous microfloras of the Peace River area, northwestern Alberta. Research Council of Alberta, Bulletin 28, volume 1, 299 pp.

Srivastava, S. K.

1972 Systematic description of some spores from the Edmonton Formation (Maastrichtian), Alberta, Canada. Palaeontographica, volume 139B, pp.1-46.

Stevenson, I. M.

1959 Shubenacadie and Kennetcook map-areas, Colchester, Hants and Halifax Counties, Nova Scotia. Geological Survey of Canada, Memoir 302, 85 pp.

Stevenson, I.M. and McGregor, D.C.

1963 Cretaceous sediments in central Nova Scotia, Canada. Geological Society of America Bulletin, volume 74, pp.355-356.

Stea, R. R. and Pullan, S. E.

1997 Post-Early Cretaceous faulting in the Musquodoboit Valley, Nova Scotia. Nova Scotia Department of Natural Resources Report of Activities, pp. 135-143.

Stea, R. R. and Pullan, S. E.

2001 Hidden Cretaceous basins in Nova Scotia. Canadian Journal of Earth Sciences, volume 38, pp. 1335-1354.

Stea R. R., Finck, P.W., Pullen,S. E. and Corey, M. C.

1996 Cretaceous deposits of kaolin and silica sand in the Shubencadie and Musquodoboit Valleys, Nova Scotia, Canada. Nova Scotia Department of Natural Resources, Mineral and Energy Branch, Minerals and Energy Branch, Open File Report 96-003, 32 pp.

Stea, R. R. and Fowler, J. H.

1981 Petrology of Lower Cretaceous silica sands at Brazil Lake, Hants County, Nova Scotia. Nova Scotia Department of Mines and Energy Report, 81-1, pp. 47-64.

Stelck, C. R. and Koke, K. R.
1987 Foraminiferal zonation of the Viking interval in the Hasler Shale (Albian), northeastern British Columbia. Canadian Journal of Earth Sciences, Vol. 24, pp.2254-2278.

Strother, P. K.
1996 Acritarchs. In: Jansonius, J. and McGregor, D. C. (editors), Palynology: Principles and Applications; Volume 1, pp.81-106; American Association of Stratigraphic Palynologists Foundation, Dallas, U. S. A.

Thiergart, F.
1949 Der stratigraphische Wert meszozoischer Pollen and Sporen. Palaeontographica, volume 89B, pp. 1-34, plates 1-5.

Traverse, A.
1988 Paleopalynology. pp.600; Unwin Hyman, London, England.

Thomson, P. W. and Pflug, H.
1953 Pollen und Sporen des mitteleuropäischen Tertiärs. Palaeontographica, Band 94 B, pp. 1-138.

van Geel, B. and Grenfell, H.R.
1996 Chapter 7A. Spores of *Zygnemataceae*. In: Jansonius, J. and McGregor, D. C. (editors) Palynology: Principles and Applications; Volume 1, pp.173-179; American Association of Stratigraphic Palynologists Foundation, Dallas U.S.A.

Venkatachala, B. S., Kar, R. K. and Raza, S.
1969 Palynology of the Mesozoic sediments of Kutch, W. India–3. Morphological study and revision of the spore genus *Trilobosporites* Pant ex Potonié. The Palaeobotanist, volume 17 (2), pp.123-127.

Verbitskaya, Z. I.
1962 The spore and pollen assemblages in the Cretaceous deposits of the Suchan Coal Basin. Trans. Uglya Geology Lab, Academy of Science U.S.S.R. volume 8, pp. 314-322, 6 plates (in Russian).

Wade, J. A. and MacLean, B. C.
1990 Chapter 5 The geology of the southeastern margin of Canada. In: M. J. Keen and G. L Williams Geology of the continental Margin of Eastern Canada, Geology of Canada No. 2, pp. 176-238;Geological Survey of Canada, Ottawa, Canada.

Warringer, J.
1996 Cretaceous Marginal Marine and Freshwater Rhizopods from Central Nova Scotia, Canada. (Unpublished). Undergraduate Honours thesis, Dalhousie University, Halifax, Nova Scotia.

Weyland, H. H. and Krieger, W.
1953 Die Sporen und Pollen der Aachener Kreide und ihre Bedeutung für die Charakterisierung des Mittleren Senons. Palaeontographica, Band 95B, pp. 6-29.

Wilson, L. R. and Webster, R. M.
1946 Plant microfossils from a Fort Union Coal of Montana. American Journal of Botany, volume 33, pp. 271-278.

Zippi, P. A.
1998 Freshwater algae from the Mattagami Formation (Albian), Ontario: paleoecology, botanical affinities, and systematic taxonomy. Micropaleontology, volume 44 supplemental 1, pp.1-78.

Zippi, P.A. and Bajc, A. F.
1990 Recognition of a Cretaceous outlier in northwestern Ontario. Canadian Journal of Earth Sciences, volume 27, pp. 306-311.

Plates

The following plates use the following location information:

Location	GSC Atlantic location number
Shubenacadie SHU94-3	D2826
Shubenacadie SHU94-4	D4293
Shubenacadie SHU94-5	D4294
Musquodoboit MUS95-2	D3152

Plates captions are labeled with species name, location information, slide number on which the specimen is located, coordinates on the slide “X” x “Y”, objective lens that the image was taken with. SEM images are described in the same manner. Most images were taken using a Zeiss Opto-photo Photo Microscope Serial Number 031873. However, a few were taken with a Zeiss Photo Microscope II Serial Number 046949 at the Geological Survey of Canada (Atlantic). These images are noted in the plate captions.

Plate 1

1	*Cicatricosisporites australiensis*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35088, coordinates 99.9x3.0 (40X).
3,9	*Cicatricosisporites minutaestriatus*. Musquodoboit MUS95-2 D3152. 2, GSA Atlantic slide number P35087, coordinates 115.9×3.7 (40X). 9, GAC Atlantic stub number P35087, coordinates -2606x-5939 (SEM)
2	*Cicatricosisporites abacus*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35087, coordinates 109.8x3.2 (40X).
5, 10-11	*Cicatricosporites* sp. 5, Shubenacadie SHU94-4 D4293, GAC Atlantic slide number P37834, coordinates 103.4x10.0 (40X). 10, Shubenacadie SHU94-3 D2826, GSC Atlantic slide number P33927, coordinates 115.5x13.2 (40X). 11, Shubenacadie SHU94-4 D4293, GSC Atlantic slide number P37834, coordinates 113.6x2.3 (40X).
4, 7	Appendicisporites sp. Shubenacadie SHU94-3 D2826, GSC Atlantic slide number P33927. 4, coordinates 114.0x6.0 (40 X). 7, coordinates 111.2x11.9 (40X).
6, 8	Plicatella sp. Shubenacadie SHU94-3 D2826, GSC Atlantic slide number P33927. 6, coordinates 111.0x4.6 (40X). 8, 111.4x4.6 (40X).

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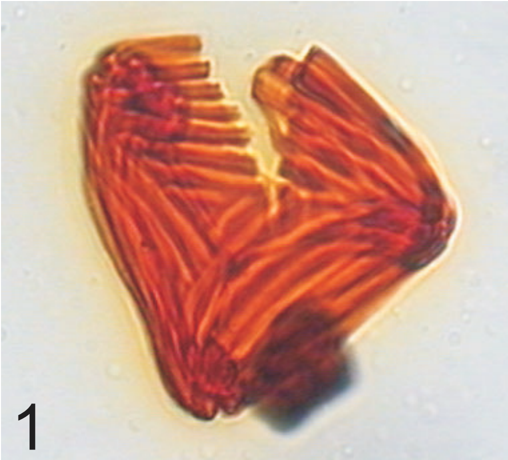
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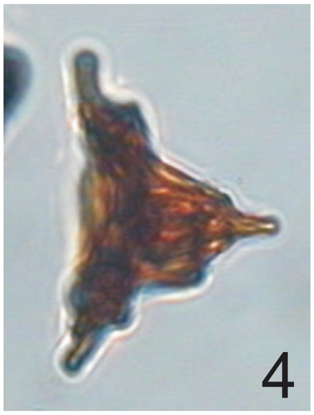
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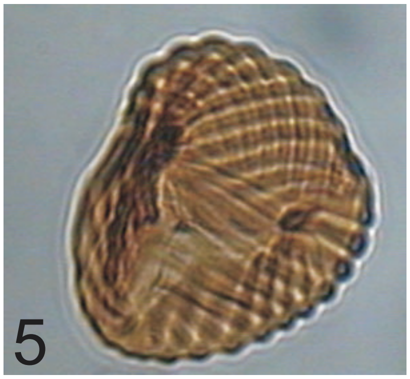
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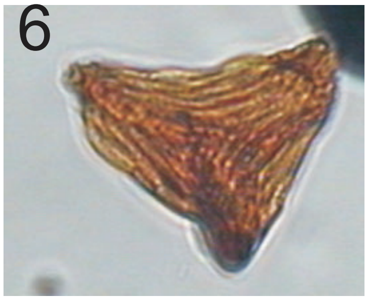
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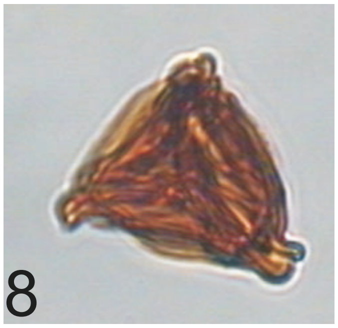
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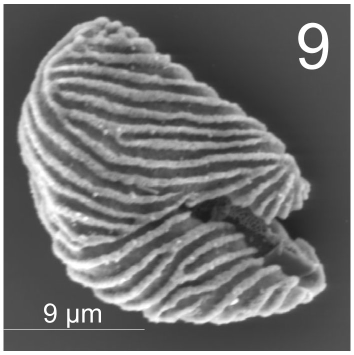
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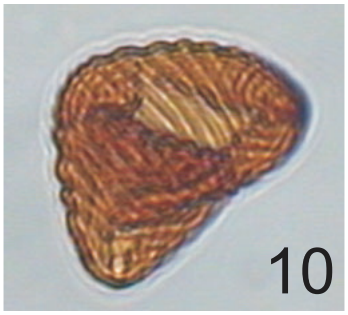
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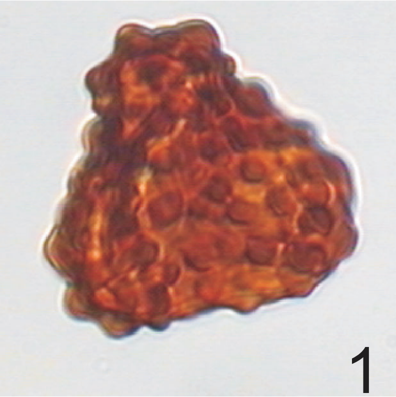
11

25μm

Plate 2

1-2, 4	*Concavissimisporites montuosus*. Shubenacadie SHU94-5 D4294, GSC Atlantic slide number P35860, coordinates 109.6x3.3 (40X). 1, proximal. 2, distal. 4, Musquodoboit MUS95-2 D3152, GSC Atlantic stub number P35087, coordinates 1264x5079 (SEM).
3	*Concavissimisporites crassatus*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35080, coordinates 104.0x10.0 (40X).
5	*Gleicheniidites circinidites*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35083, coordinates 119.5x10.0 (40X).
6	*Gleicheniidites senonicus*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35078, coordinates 113.2x5.4 (40X).
7	*Gleicheniidites* sp. Musquodoboit MUS95-2, GSC Atlantic stub number P35079, coordinates 5447x2355 (SEM).
8-9	*Cibotiumspora sinuata*. Shubenacadie SHU94-3 D2826. 8, GSC Atlantic slide number P33920, coordinates 115.2x8.7 (40X). 9, GSC Atlantic slide number 33922, coordinates 117.0x13.1 (40X).
10	*Cibotiumspora tricuspidata*. Musquodoboit MUS95-2 D3152, GSC Atlantic P35077, coordinates 75.7x5.9 (40X).

Plate 2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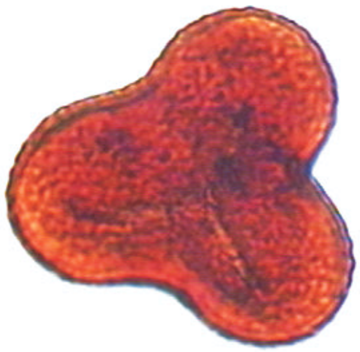
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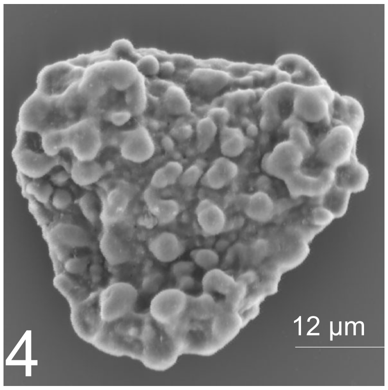

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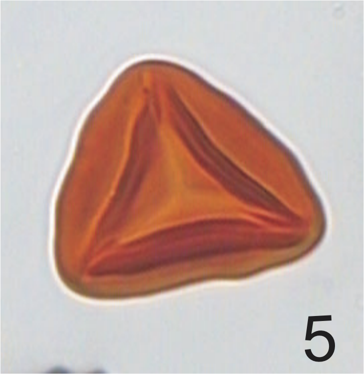
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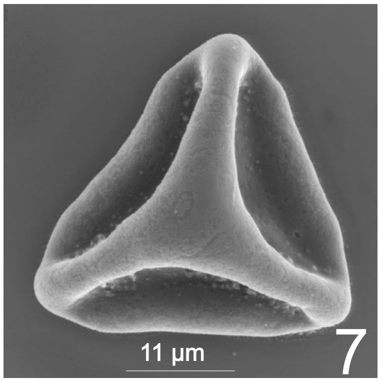

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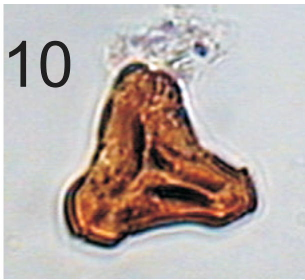
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12.5 µm

Plate 3

1 *Deltoidospora minor*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35078, coordinates 113.3x20.8 (40X).

2 *Biretisporites potoniae*. Musquodoboit MUS 95-2 D3152, GSC Atlantic slide number P35080, coordinates 115.4x4.1 (40X).

3 *Deltoidospora australis*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide P35083, coordinates 109.5x3.5 (40X).

4 *Concavisporites toralis*. Musquodoboit MUS95-2 D3153, GSC Atlantic slide P35083, coordinates 94.9x2.7 (40X).

5 *Dictyophyllidites harrissii*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide P35088, coordinates 109.0x5.5 (40X).

6 *Aequitridites verrucosus*. Shubenacadie SHU94-3 D2826, GSC Atlantic slide P33927, coordinates 107.1x2.6 (40X).

7 *Concavissimisporites asper*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35083, coordinates 96.9x2.4 (40X).

Plate 3


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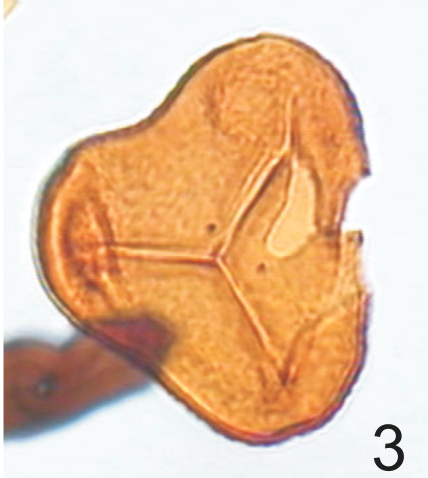
2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25 µm

Plate 4

1, 7, 9	*Impardecispora purverulenta*. Musquodoboit MUS95-2 D3152. 1, GSC Atlantic slide number P35081, coordinates 104.6x10.7 (40X). 7, GSC slide number P35082, coordiantes -1013x8526 (SEM). 9, GSC Atlantic slide number P35079, coordinates 7532x-737 (SEM).
2	*Impardecispora marylandensis*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35081, coordinates 116.2x21.8 (40X).
3	*Impardecispora gibberula*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35080, coordinates 109.5x3.4 (40X).
4,8	*Pilosisporites trichopapillosus*. 4, Shubenacadie SHU94-5 D4294, GSC Atlantic slide number P37858, coordinates 105.8x12.6 (40X). 8, Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35079, coordinates -6308x-1216 (SEM).
5	*Neorastrickia* sp.B of Fensome 1983. Musquodoboit MUS95-2 D3152. GSC Atlantic slide number P3152, coordinates 101.8x6.6 (40X).
6	*Polycingulatisporites* sp. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35075, coordinates 89.6x3.3 (40X).

Plate 4


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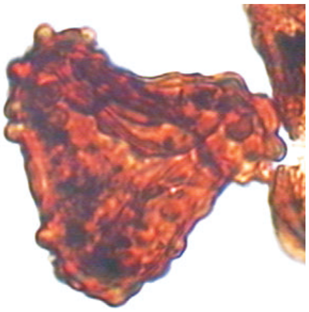
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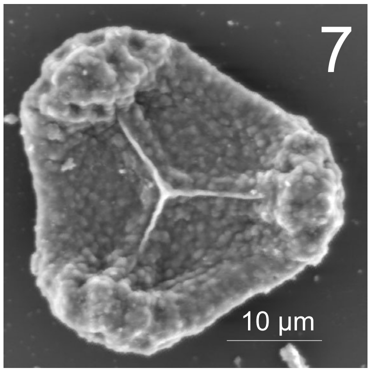
6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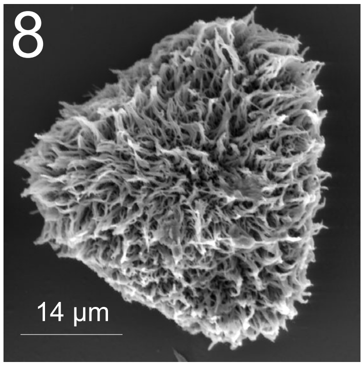
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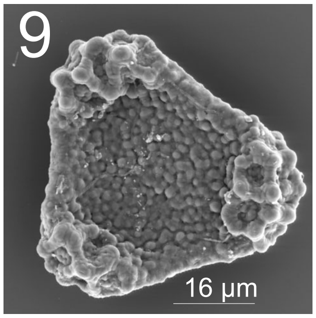
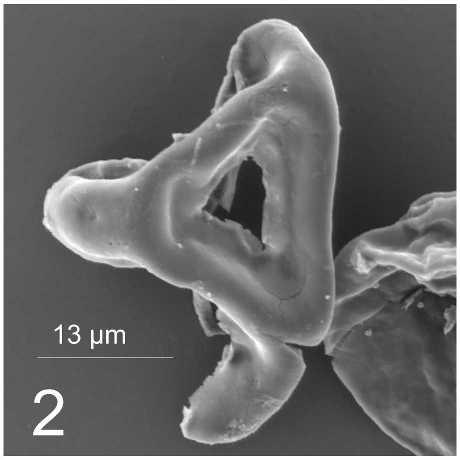

9

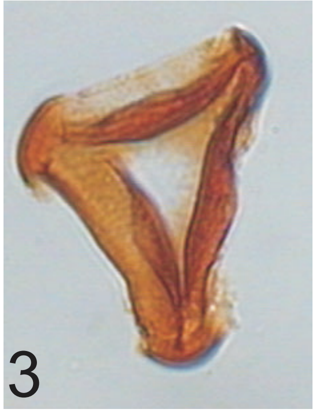
25 µm

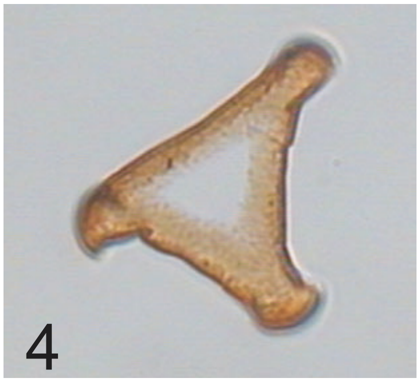
Plate 5

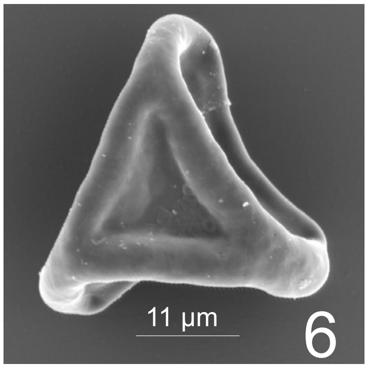
1-8 Spore A Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35085. 1, coordinates 109.5x3.6 (40X). 2, coordinates 4616x6024 (SEM). GSC Atlantic slide number P35079. 3, coordinates 120.3x6.8 (40X). 4, coordinates 110.5x6.8 (40X). 5, coordinates 100.7x11.0 (40X). 6, coordinates 5616x6364 (SEM). 7, coordinates -6646x2831 (SEM). 8, coordinates -8518x1529 (SEM).

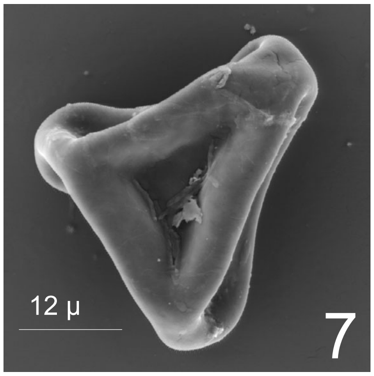
Plate 5

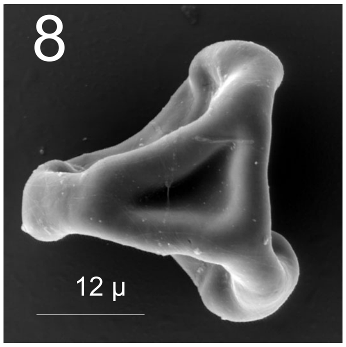












12.5 µm

Plate 6

1-6, 9-11	*Retimonocolpites peroreticulatus*. Musquodoboit MUS95-2 D3153, GSC Atlantic slide number P35080, R. A. McRae Zeiss Photo microscope II #046939. 1, coordinates 78.3x13.7 (63X), low. 2, medium. 3, high. 4, coordinates 76.2x14.2 (63X), medium. 5, high. 6, low. 9, coordinates 76.2x13.7, (63X). 10, coordinates 76.2x13.7 (63X), medium. 11, high.
7-8	*Retimonocolpites pennyi*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P335080, coordinates 76.3x15.0 (63X) high. 8, low.

Plate 6


1


2


3

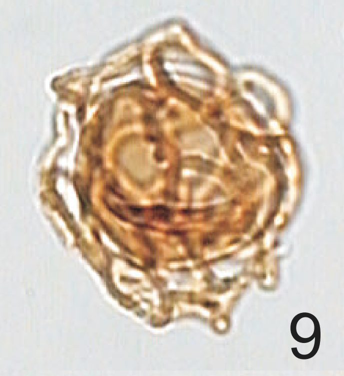

4


5


6


7


8


9

10µm

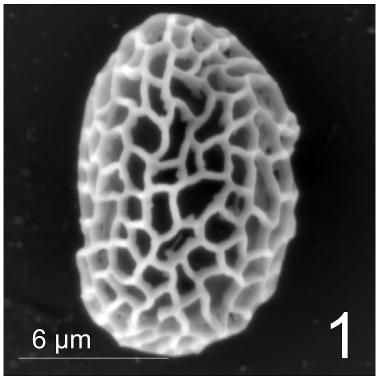

10

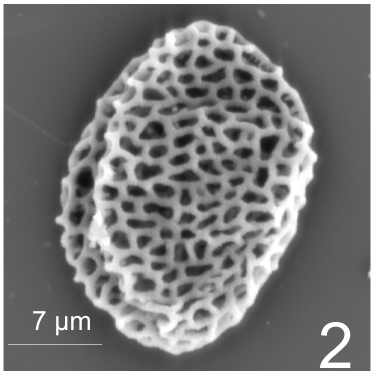

11

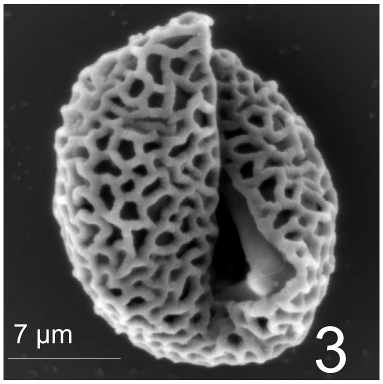
Plate 7

1-3	*Retimonocolpites pennyi*. Musquodoboit MUS95-2 D3152, GSC Atlantic stub number P35080a, SEM. 1, coordinates -3541x-2047. 2, coordinates -8860x-1404. 3, coordinates 145x7057.
4-12	*Retmonocolpites peroreticulatus*. Musquodoboit MUS95-2 D3152, GSC Atlantic stub number P35080a, SEM. 4, coordinates -6863x663, 5, coordinates -2691x1801. 6, coordinates -2943x2369. 7, coordinates 5483x2941. 8, coordinates -6030x4789. 9, coordinates 7132x4949. 10, coordinates 8385x5845. 11, coordinates -3622x6810. 12, coordinates -2189x7691.

Plate 7


6 µm
1


7 µm
2


7 µm
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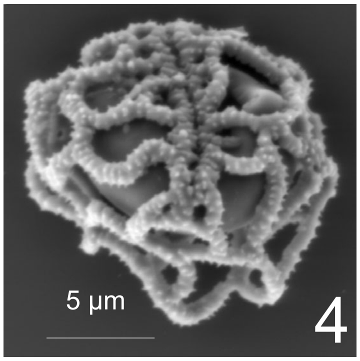
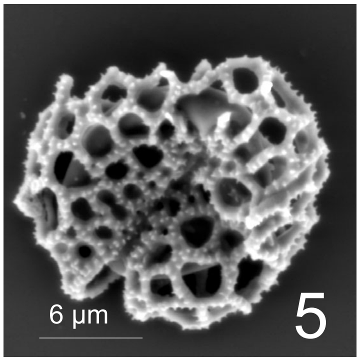
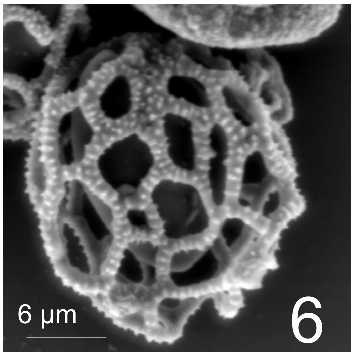
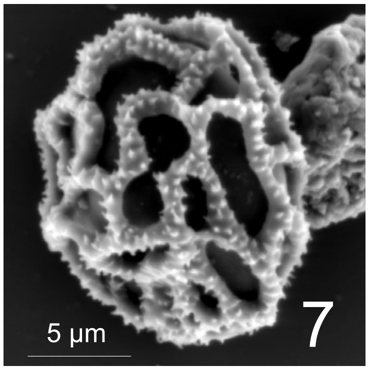
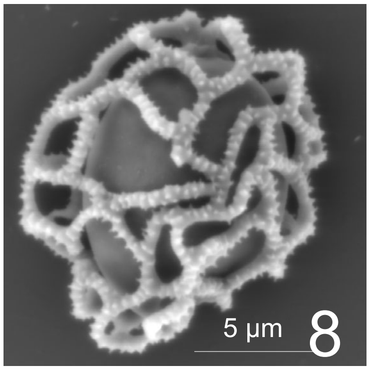
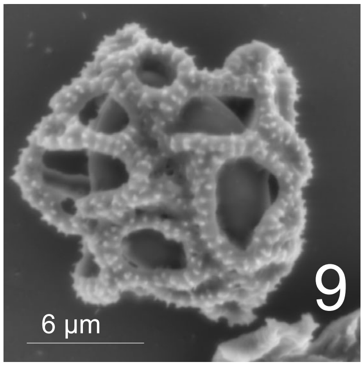

5 µm
4

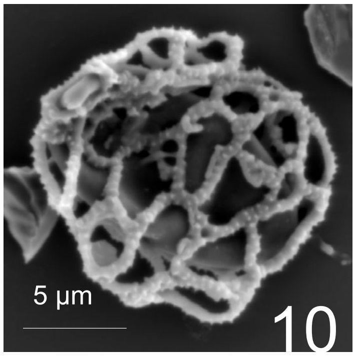

6 µm
5

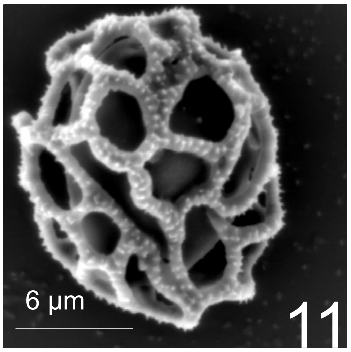

6 µm
6

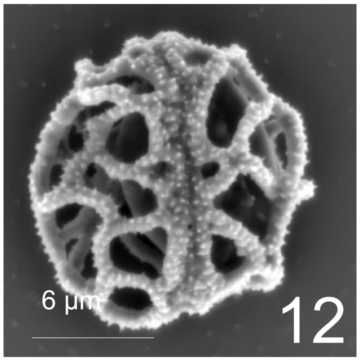

5 µm
7


5 µm
8


9
6 µm


5 µm
10

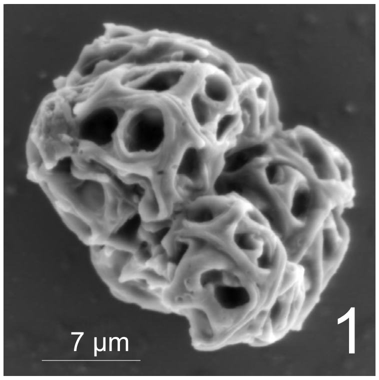

6 µm
11


6 µm
12

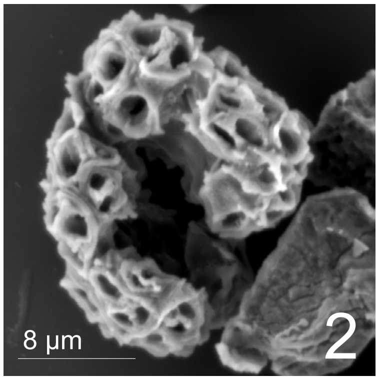
Plates 8

1-2	*Botryococcus* sp. cf *braunii*. Musquodoboit MUS95-2 D3152, GSC Atlantic stub number P35080a, SEM. 1, coordinates 10494x4136. 2, coordinates -1326x-724.
3-4	*Schizocystia rugosa*. Musquodoboit MUS95-2 D3152. 3, GSC Atlantic stub number P35079, coordinates 3865x4014 (SEM). 4,GSC Atlantic slide number P35078, coordinates 107.8x11.9 (40X).
5-8	*Schizosporis reticulatus*. Musquodoboit MUS95-2 D3152. 5, GSC Atlantic slide number P35082, coordinates 116.0x4.5 (40X). 6, GSC Atlantic stub number P35079, coordinates -8698x-735 (SEM). GSC Atlantic stub number P35082. 7, coordinates -149x-6280 (SEM). 8, close up coordinates -187x-6275 (SEM).

Plate 8



1



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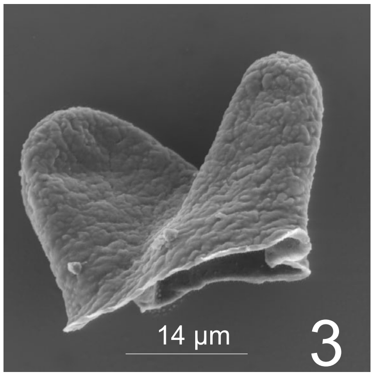
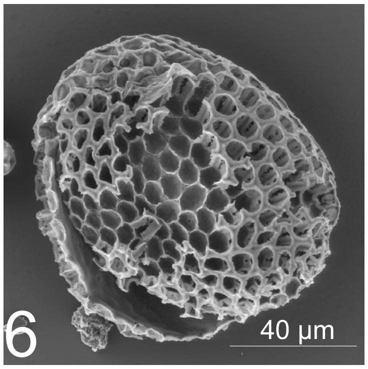


3

4

5



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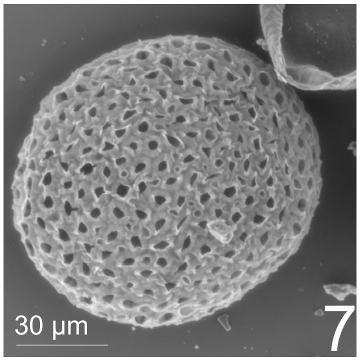

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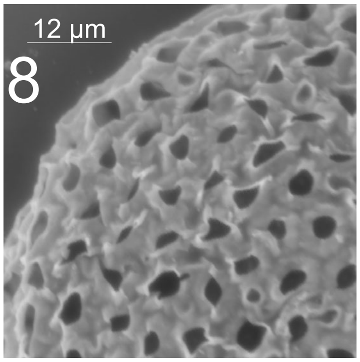


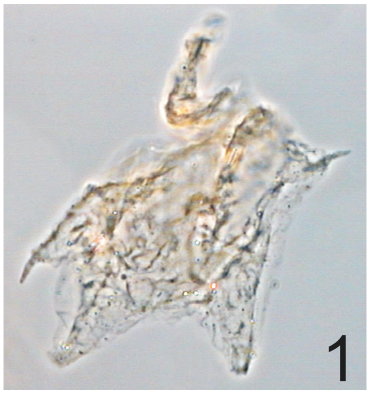
8

25 µm

Plate 9

1-5	*Nyktericysta* sp. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35078, R. A. McRae Zeiss Photo Microscope II #046939, phase contrast. 1, coordinates 0966x0082 (63X). 2, coordinates 0972x 0116 (63X). 3, coordinates 0978x0116 (63X). 4, coordinates 1122x0181 (63X). 5, coordinates 1024x0132 (63X).
6-8	*Peridinium* sp. Musquodoboit MUS 95-2 D3152, GSC Atlantic slide number P35078, R. A. McRae Zeiss Photo Microscope II #046939, coordinates 1003x0120 (63X). 6, high. 7, low. 8, low.

Plate 9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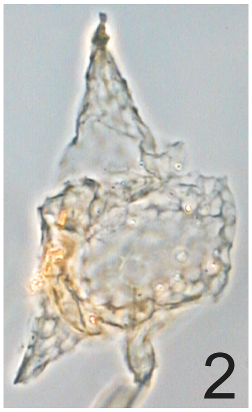
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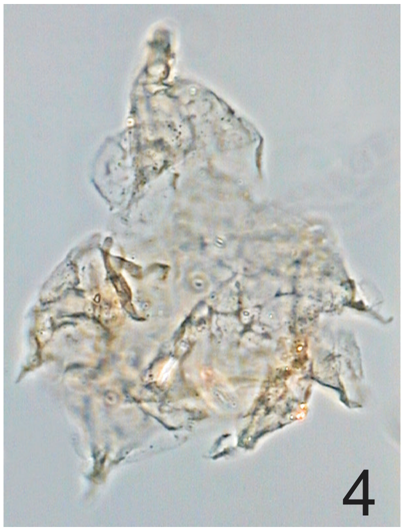
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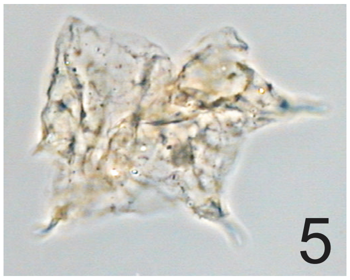
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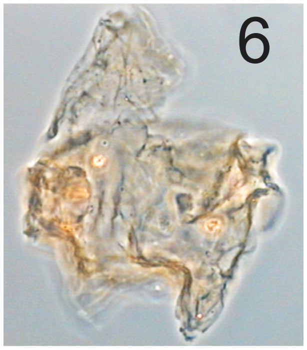
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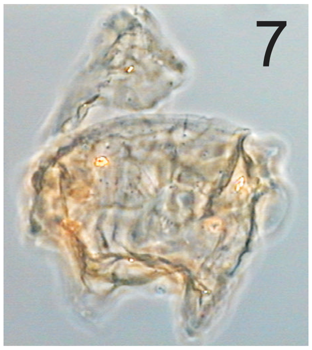
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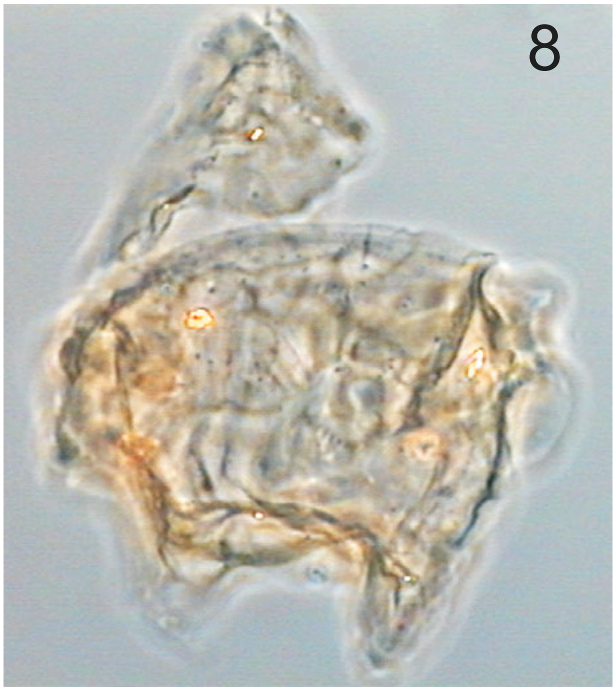

8

50 µm

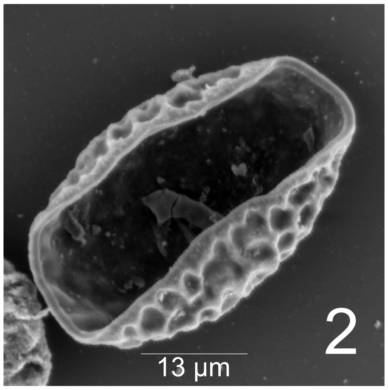
50 µm

Plate 10

1-2	*Lecaniella foveata*. 1, Shubenacadie SHU94-5 D4292, GSC Atlantic slide number P370856, coordinates 108.0x4.5 (40X). 2, Musquodoboit MUS95-2 D3152, GSC Atlantic stub number P35082, coordinatate -223x8847 (SEM).
3-4	*Lecaniella irregulis*. Musquodoboit MUS95-2 D3152. 3, GSC Atlantic slide number P35081, coordinates 111.5x4.6 (40X). 4, GSC Atlantic stub number P35082, coordinates 2491x7573 (SEM).
5, 8	*Ovoidites spriggii*. Musquodoboit MUS95-2 D3152 5, GSC Atlantic slide number P35081, coordinates 112.0x10.5 (40X). 8, GSC Atlantic slide number 35084, coordinates 90.1x2.8 (40X)
6-7,9	*Ovoidites parvus*. Musquodoboit MUS95-2 D3152. 6, GSC Atlantic slide number P35081, coordinates 117.1x5.1 (40X). 7, GSC Atlantic stub number P35082, coordinates -440x8712 (SEM). 9, GSC Atlantic stub number P35079, coordinates 2560x10639 (SEM).

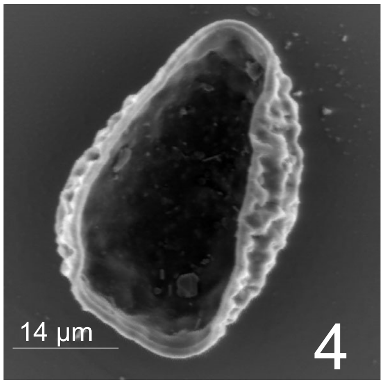
Plate 10


1



2

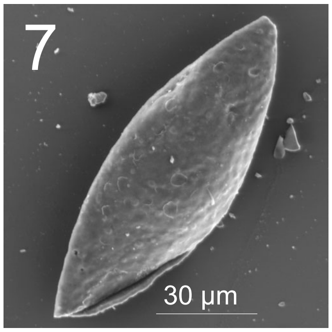

3



4


5


6


7

25 µm


8

9

Plate 11

1-2 *Spicadium* sp. Musquodobit MUS95-2 D3152, GSC Atlantic slide number P35079. 1, coordinates 116.1x13.9 (40X). 2, coordinates 110.0x12.6 (40X).

Plate 11

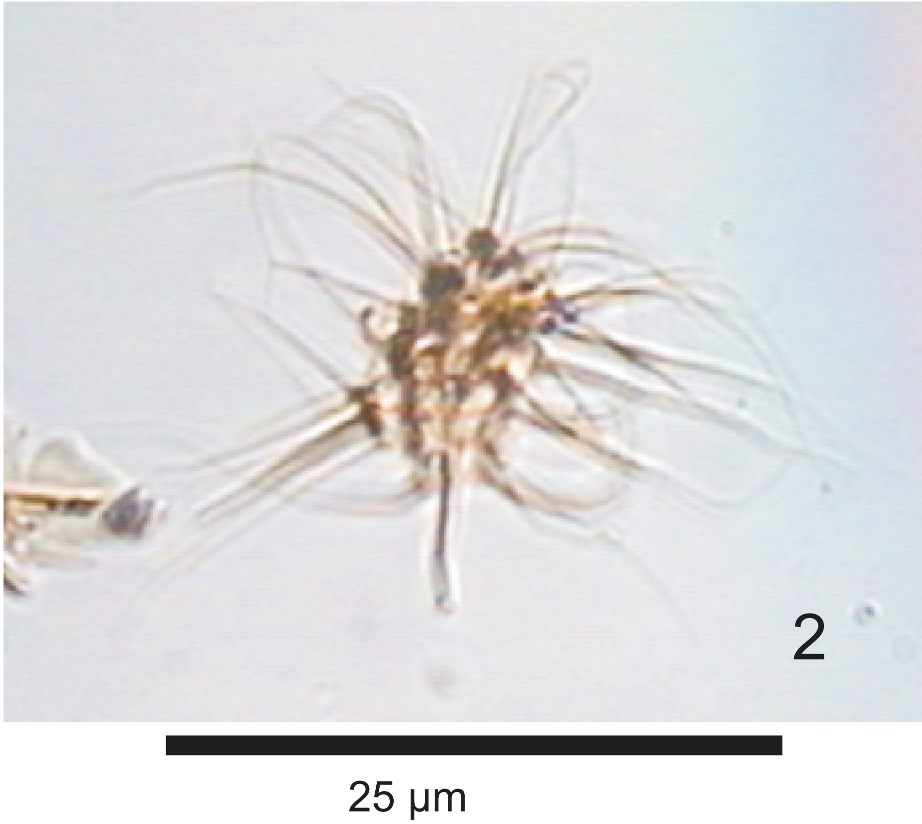


Plate 12

1	*Retitriletes singhii*. Musquodoboit MUS 95-2 D3152, GSC Atlantic slide number P35077, coordinates 76.7x8.1 (40X).
2, 7	*Undulatisporties undulapolus*. 2, Shubenacadie SHU94-4 D4293, GSC Atlantic slide number P37857, coordinates 100.2x11.7 (40X). 7, Musquodoboit MUS95-2 D3152, GSC Atlantic stub number P35079, coordinates 8268x3868 (SEM).
3	*Trilobosporites hannonicus*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35080, coordinates 105.7x7.2 (40X).
4, 8	*Trilobosporites trioreticulatus*. Musquodoboit MUS 95-2 D3152. 4, GSC Atlantic slide number P35080, coordinates 89.4x3.4 (40X). 8, GSC Atlantic stub number P35079, coordinates -5935x-435 (SEM).
5	*Retitriletes aklavikensis*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35088, coordinates 86.1x2.8 (40X).
6	*Tetraporina* sp. Shubenacadie SHU94-5, GSC Atlantic slide number P37856, coordinates 112.8x12.1 (40X).

Plate 12

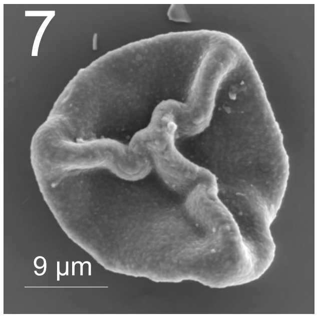

1


2


3


4


5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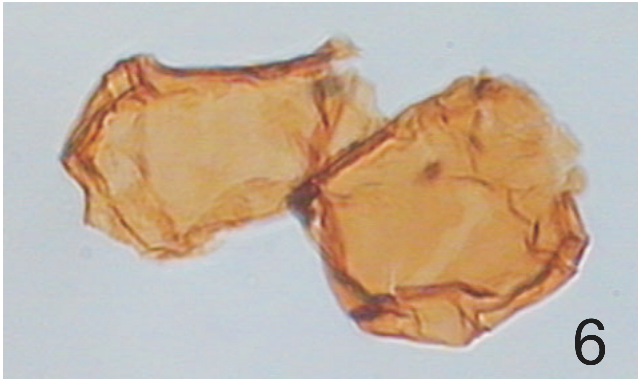
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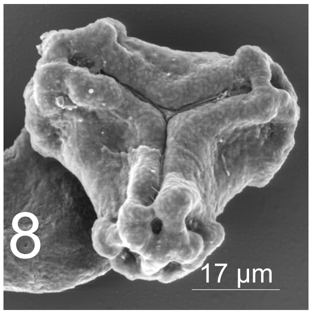
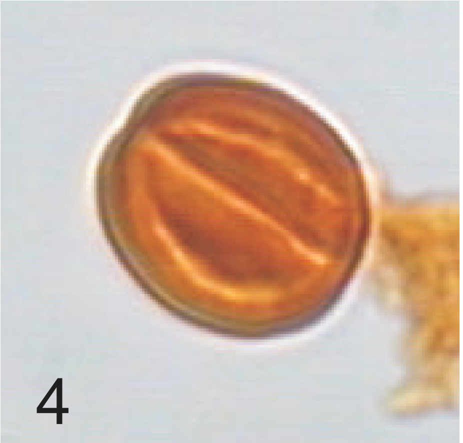

8

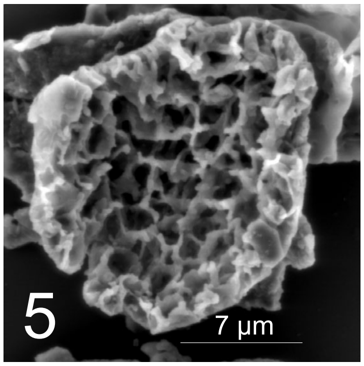
25 µm

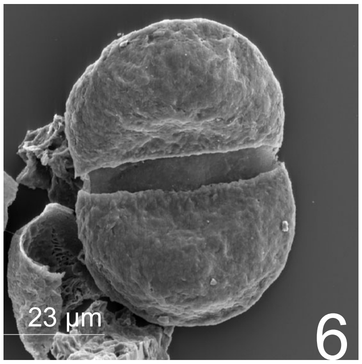
Plate 13

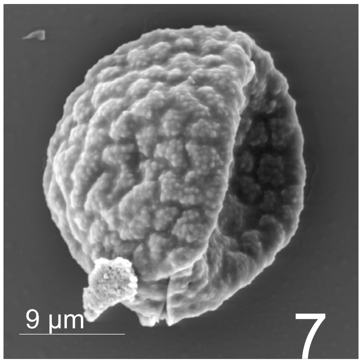
1, 5, 6	*Bisaccate* sp. Musquodoboit MUS95-2 D3152. 1, GSC Atlantic slide number P35080, coordinates 103.6x6.7 (40X). 5, (inside sacci) GSC Atlantic stub number P35080a, coordinates -1326x-724 (SEM). 6, GSC Atlantic stub number P35079, coordinates 8786x-435 (SEM).
2	*Podocarpidites* sp. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35079, coordinates 79.3x2.5 (40X).
3	*Cyadopites folicularis*. Shubenacadie SHU94-5 D4294, GSC Atlantic slide number P37860, coordinates 113.2x2.4 (40X).
4	*Eucommiidites troedssonii*. Musquodoboit MUS95-2 D3152, GSC Atlantic slide number P35083, coordinates 87.1x16.0 (40X).
7-8	*Cerbropollenites mesozoicus*. Musquodoboit MUS95-2 D3152, GSC Atlantic stub number P35079. 7, coordinates -5313x3018 (SEM). 8, 3453x-7142 (SEM).

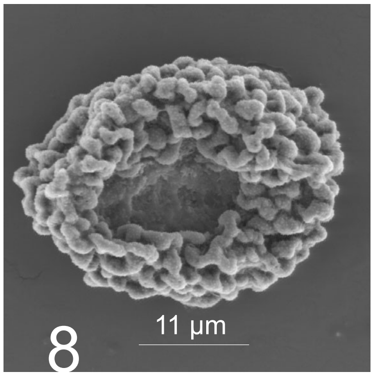
Plate 13









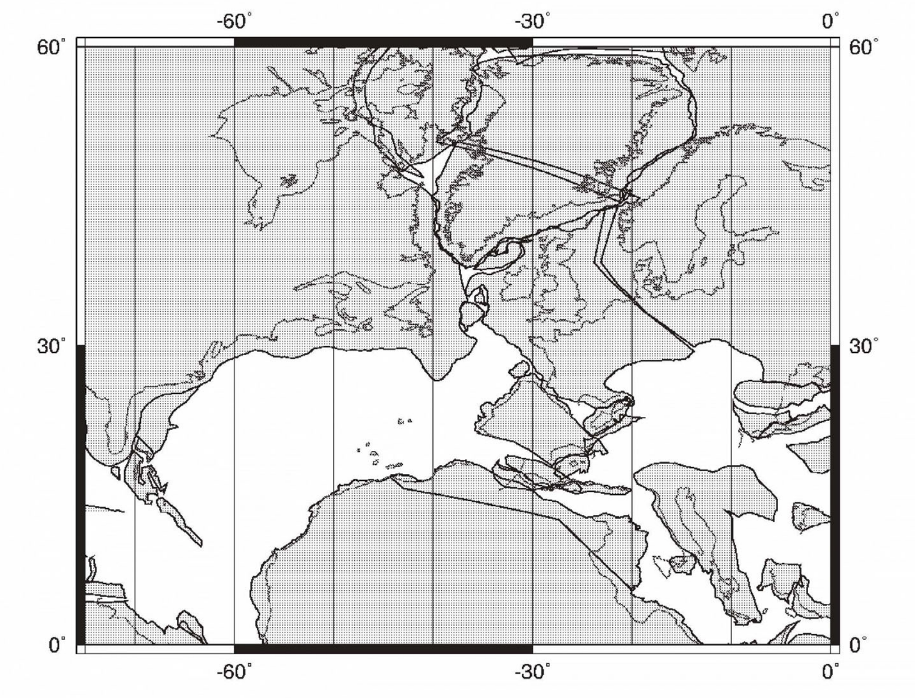


12.5 µm

25 µm

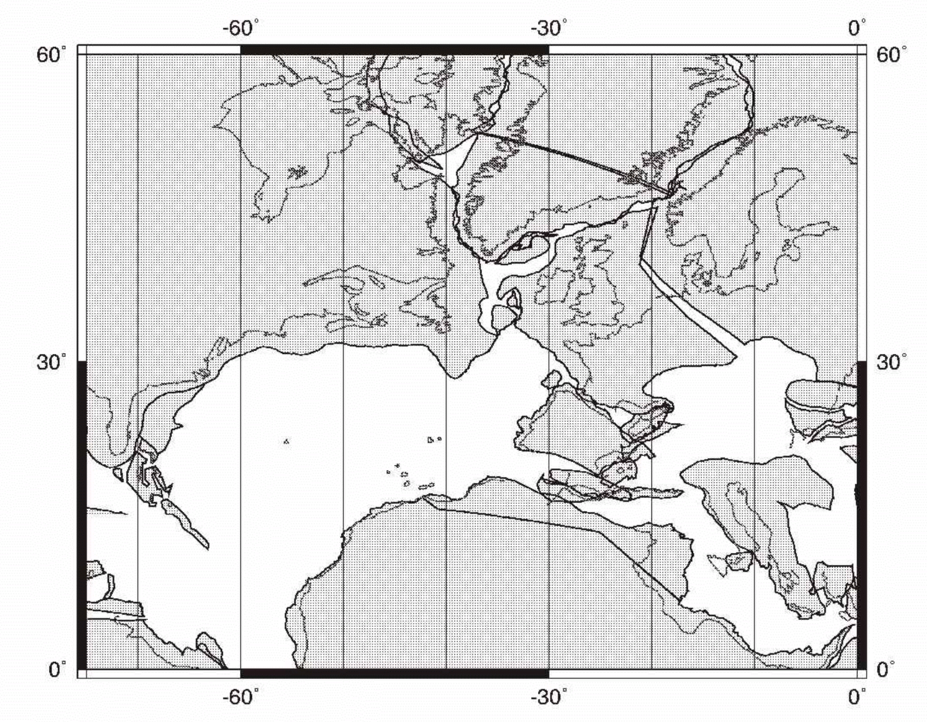
Appendix A-Paleogeographic Reconstructions

Barremian-Aptian paleogeographic reconstruction 121.0 Ma.



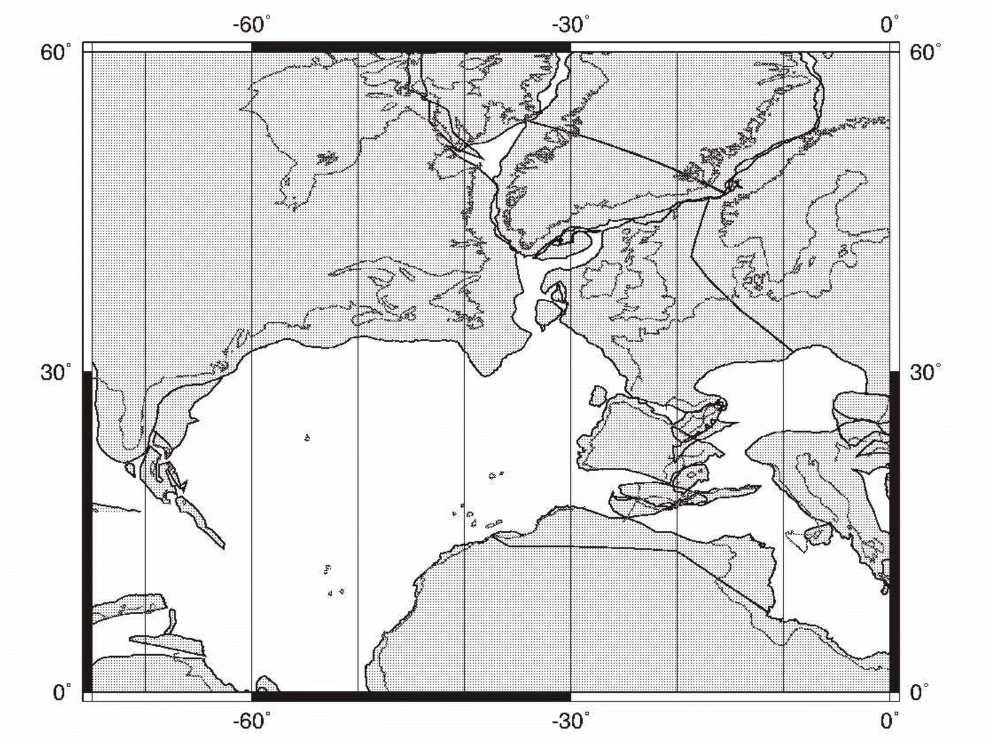
121.0 Ma Reconstruction

Aptian-Albian paleogeographic reconstruction 112.2 Ma.



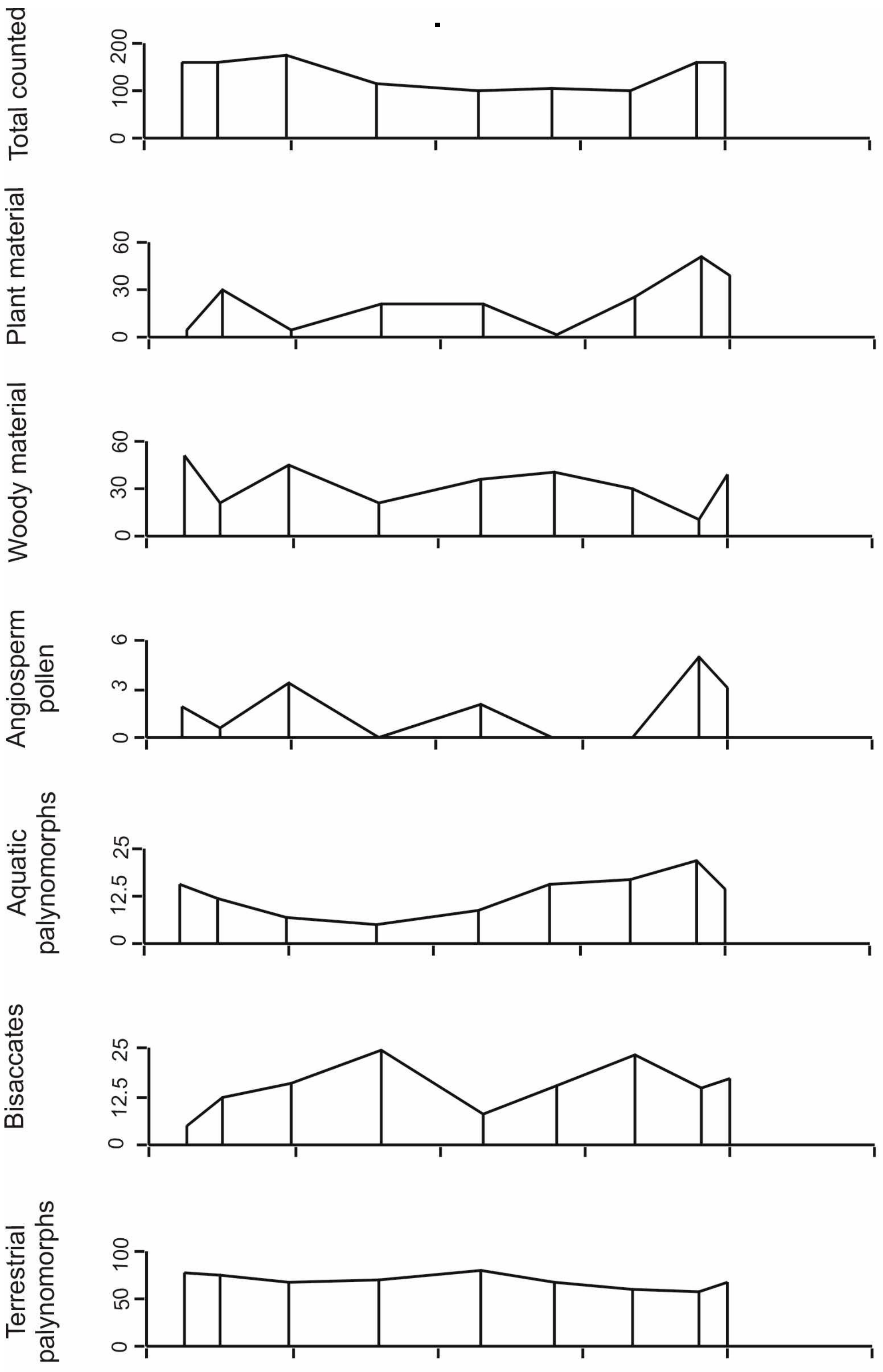
112.2 Ma Reconstruction

Albian-Cenomanian paleogeographic reconstruction 98.9 Ma.

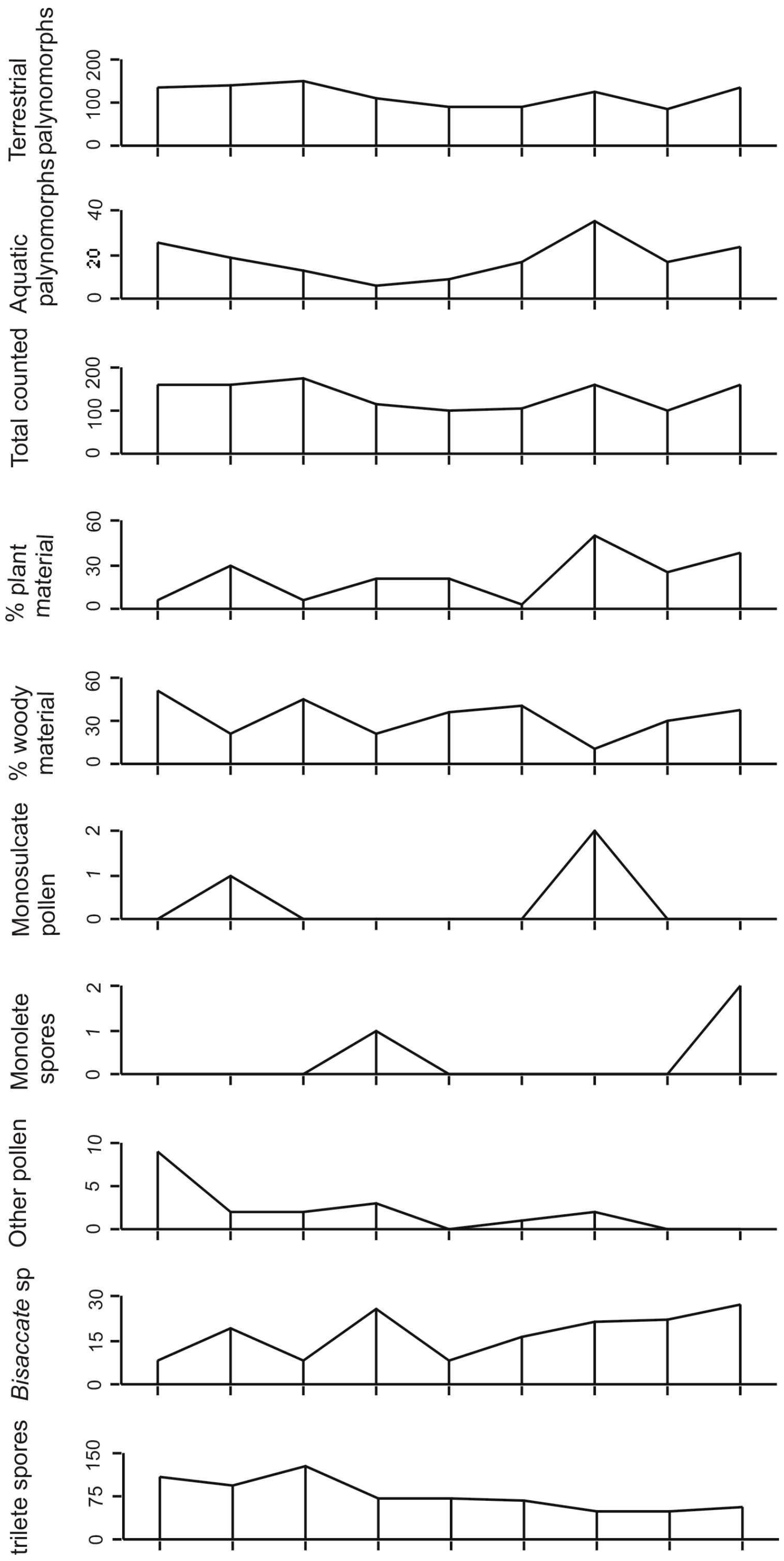


98.9 Ma Reconstruction

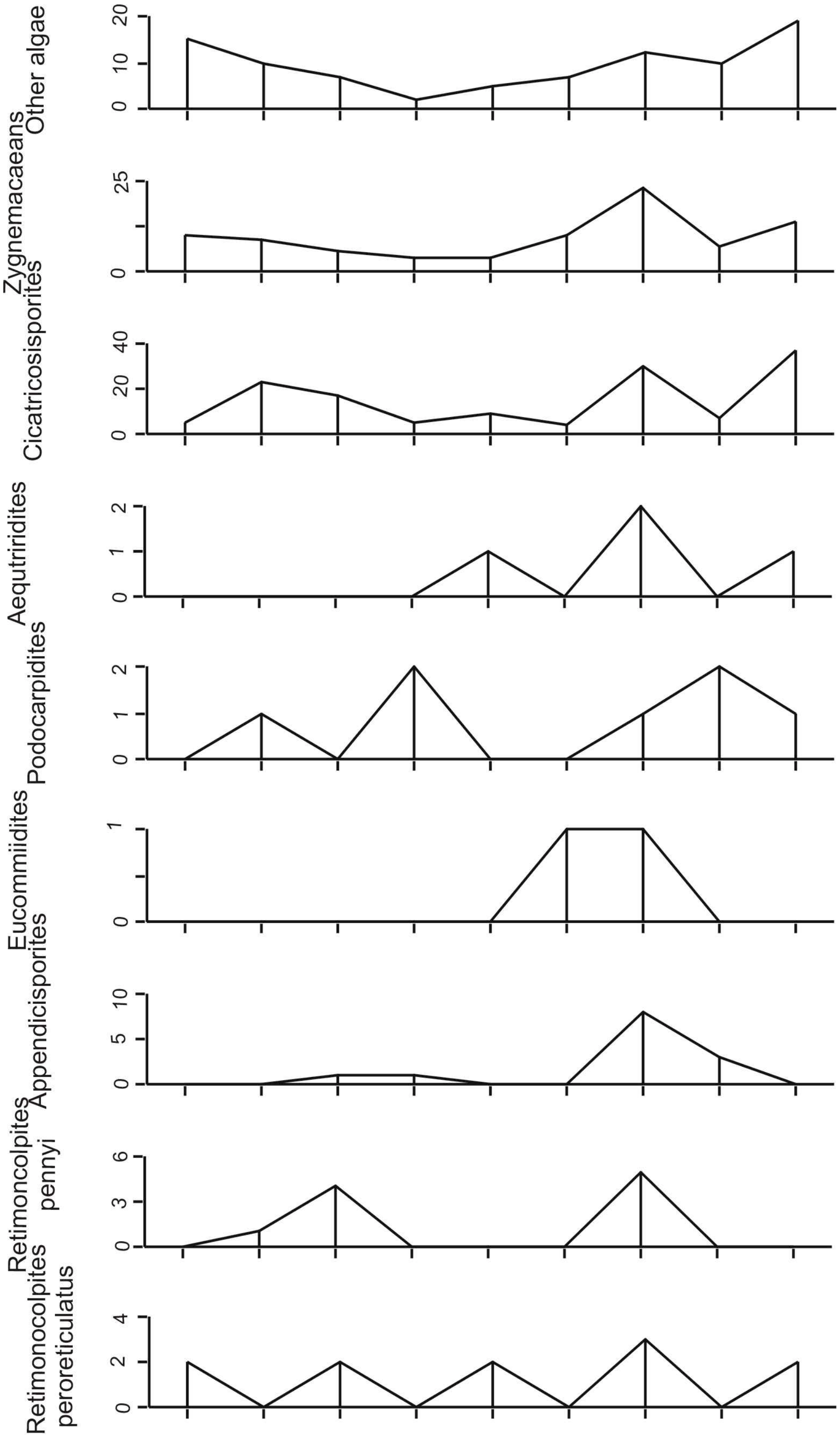
Appendix B-Counts



Counts graphed using percentages of species from core SHU94-3.



Actual counts of core SHU94-3.



Actual counts of core SHU94-3.

Palynology of the Lower Cretaceous Chaswood Formation, Elmsvale Basin and Shubenacadie Oulier, Nova Scotia

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Dalhousie University

Outline

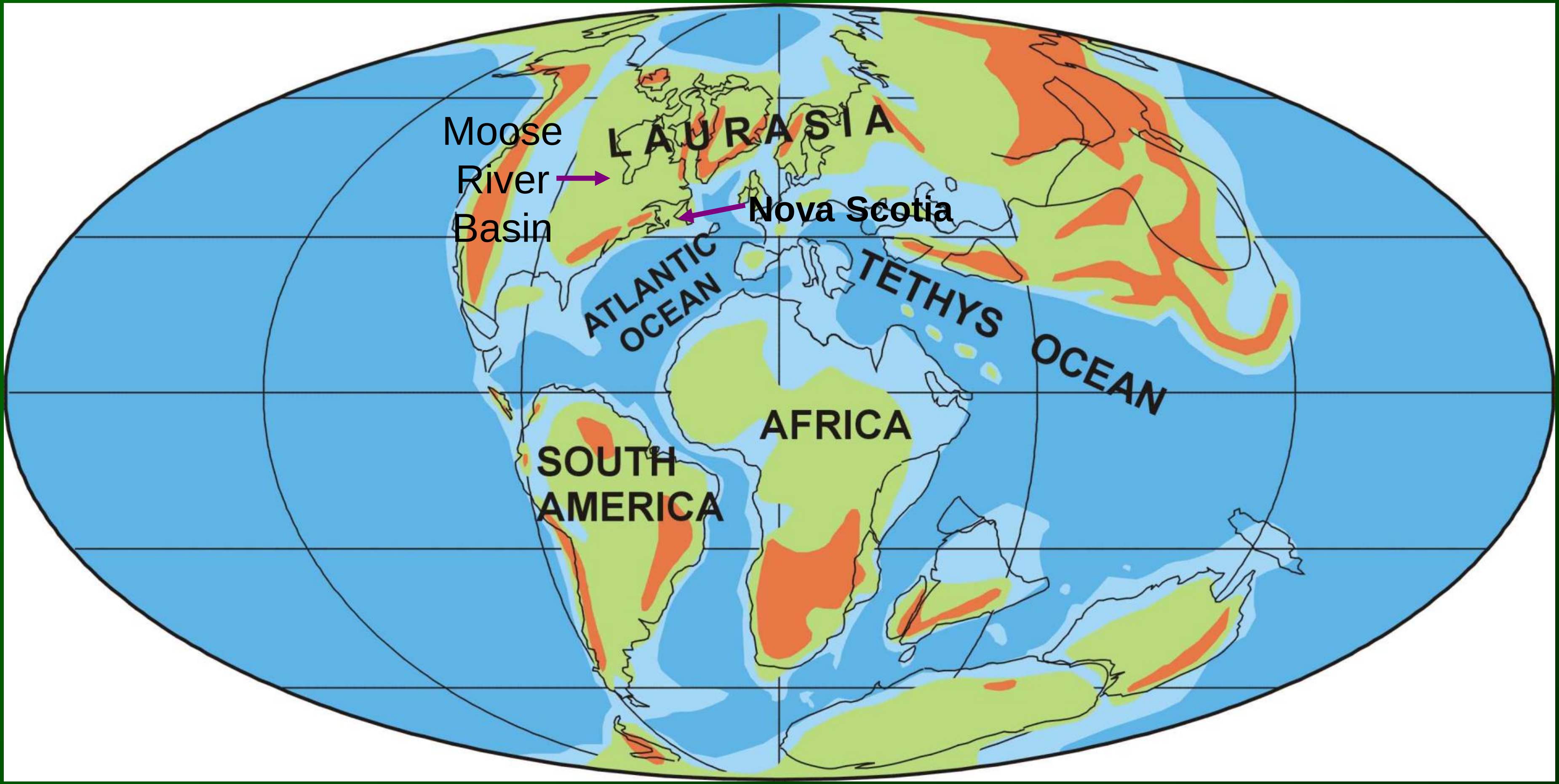
- Introduction to the Cretaceous
- Elmsvale Basin and Shubenacadie Outlier
- Sampling
- Age
- Paleoenvironment
- Conclusions
- Further Work

Thesis Objectives

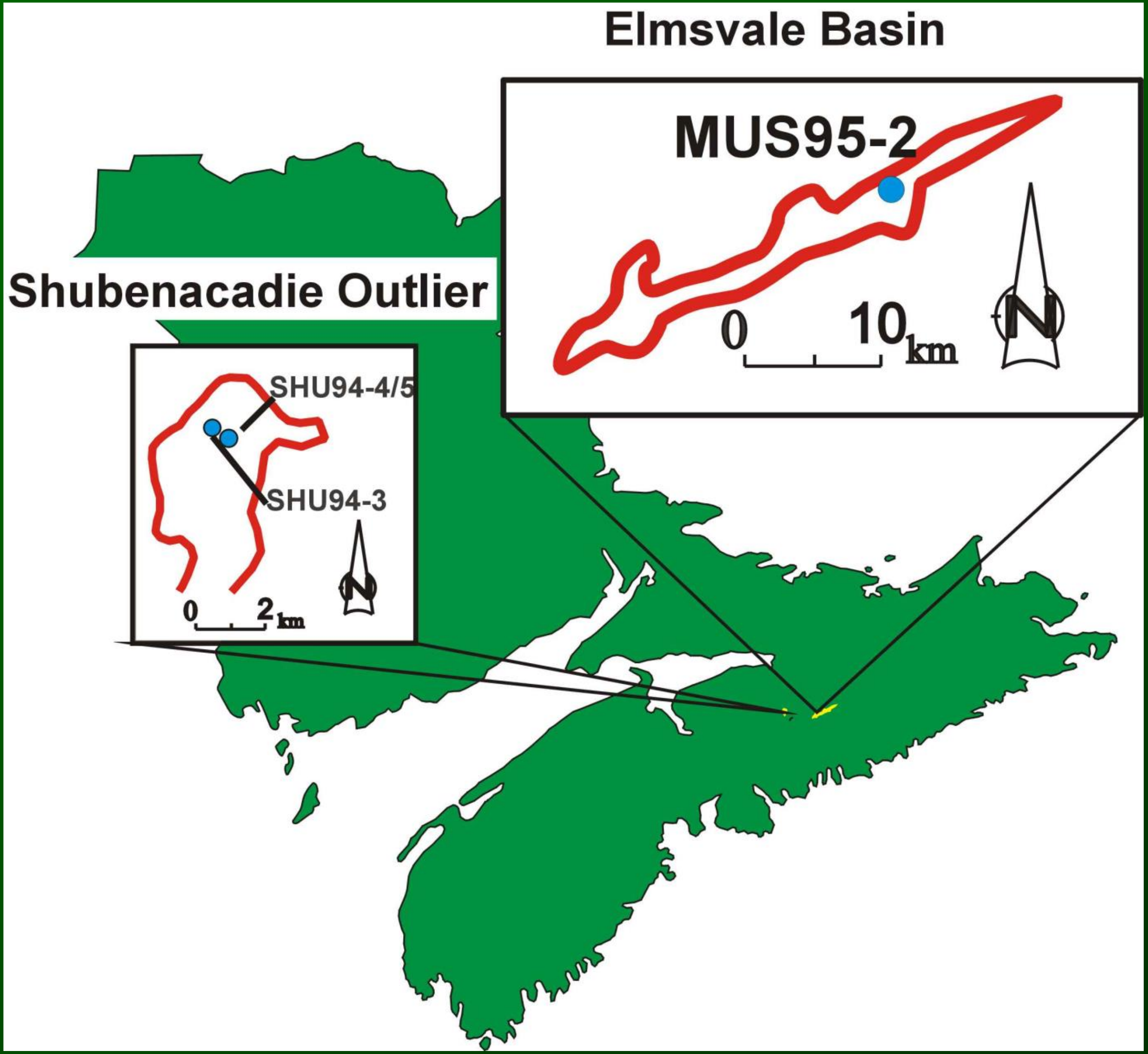
- Determine the paleoenvironment of the deposits
- Determine a more precise age of the deposits
- Test the paleoecological interpretation derived from prior studies of foraminfera
- Compare the Cretaceous deposits found in Nova Scotia with those found in other parts of North America and place them in regional and continental perspective

Shaw Resources

Albian Paleogeography (112.2-98.9 Ma)



Location of the Study Area



Shubenacadie Outlier and Elmsvale Basin

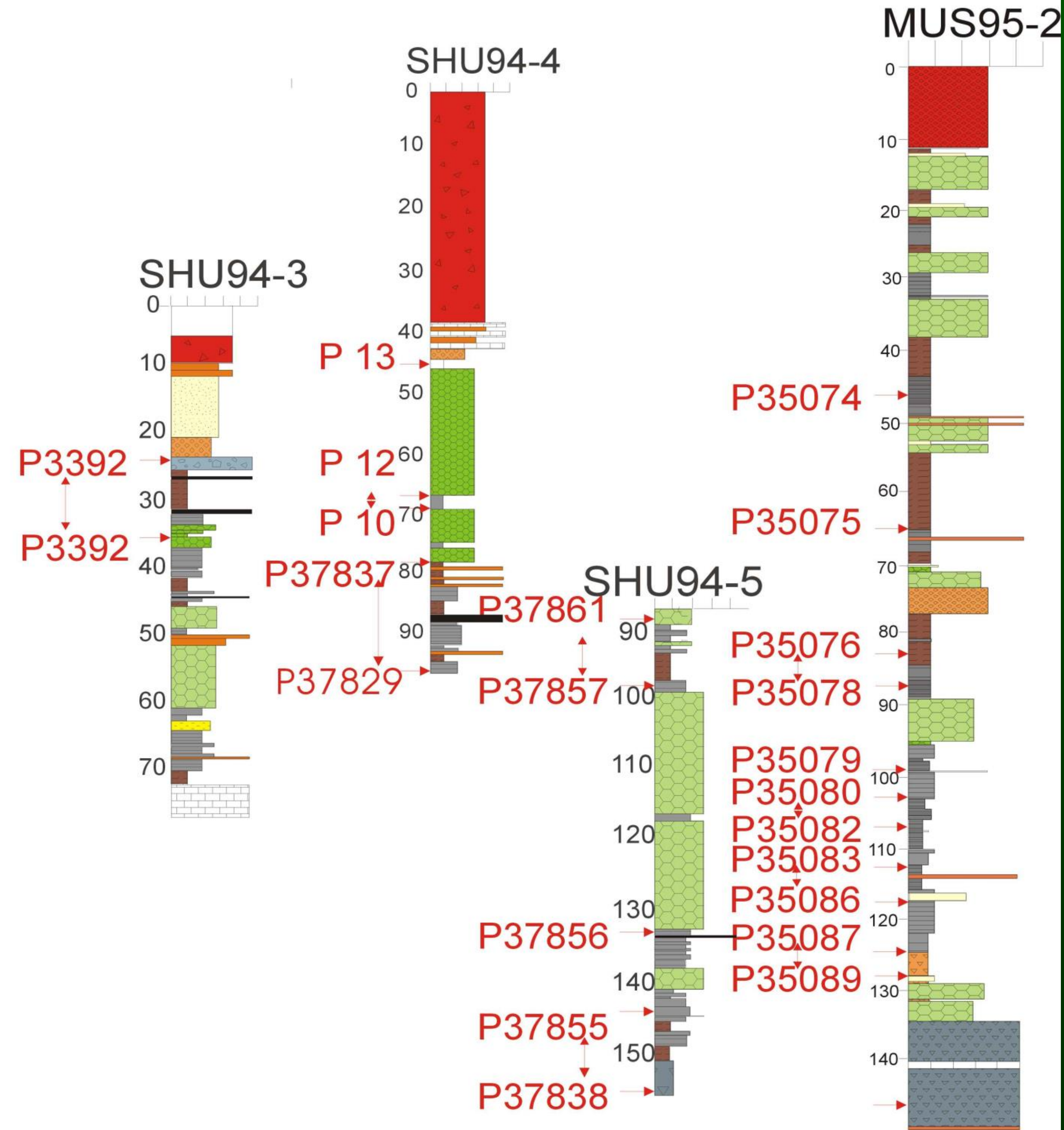
Shubenacadie Outlier

- palynomorphs include algal protists trilete spores and pollen grains (no dinos)
- proportions of palynomorphs vary in each sample
- bottoms out in a breccia and limestone zone where forams are present

Elmsvale Basin

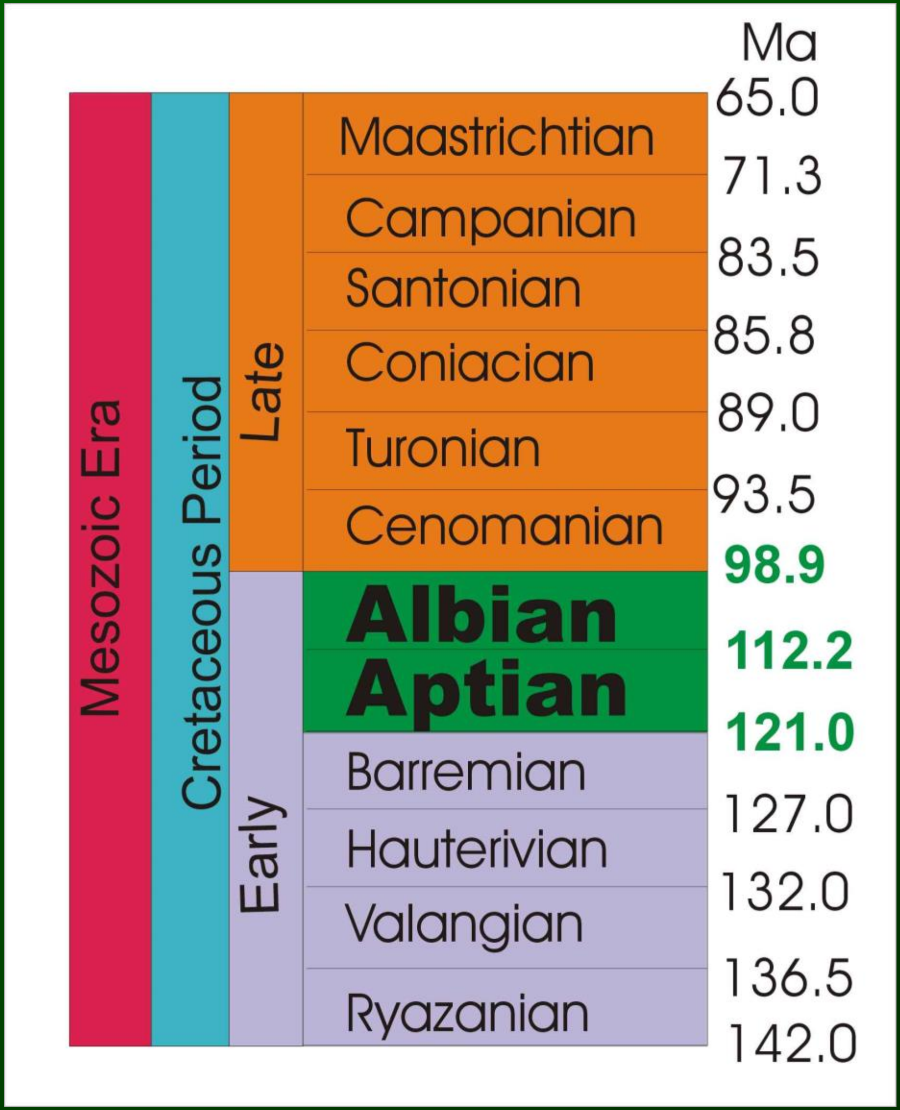
- variable palynomorph assemblages from protist (including dinos) to spore and pollen dominated
- distinct assemblages throughout the core from terrestrial (spores only) to paludal lake (protists)
- Most diverse palynomorph assemblages
- again core bottoms in limestone and breccia

Sample Locations



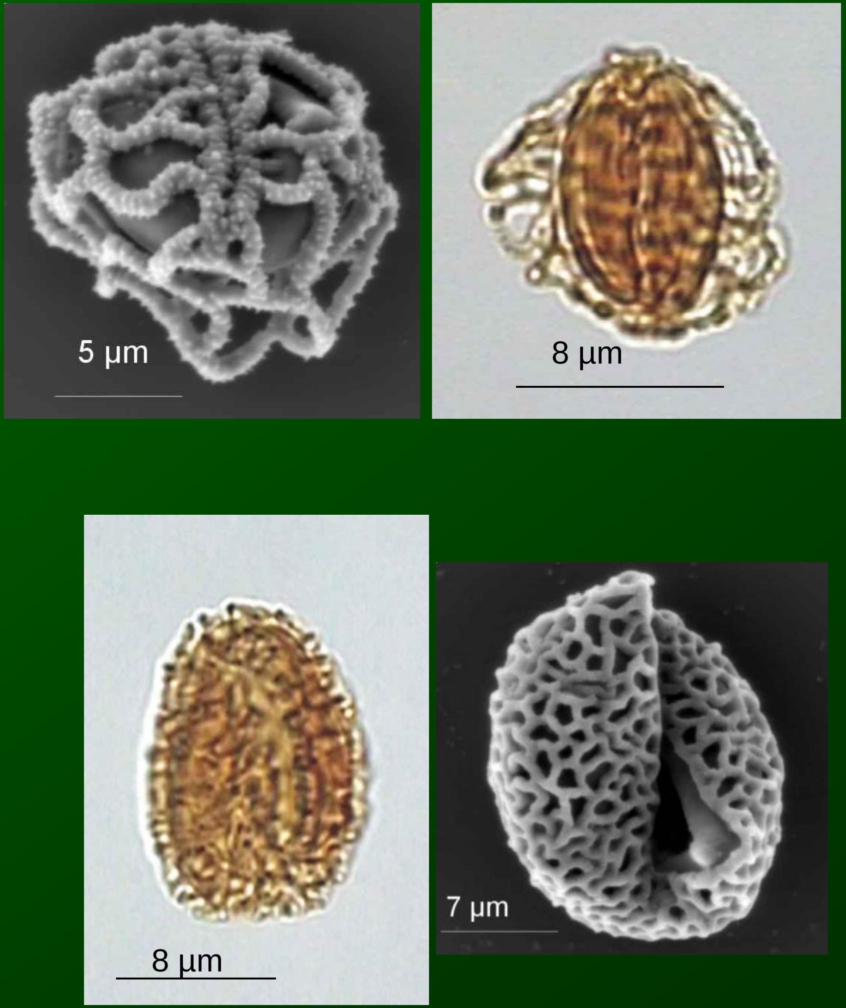
Age of the Deposits

- previous workers have assigned the deposits to the Aptian-Albian
- monosulcate angiosperm pollen found
- age of the monosulcate is not well defined
- due to the presence of monosulcate pollen and the lack of tricolpate pollen this gives a more precise age for the deposits

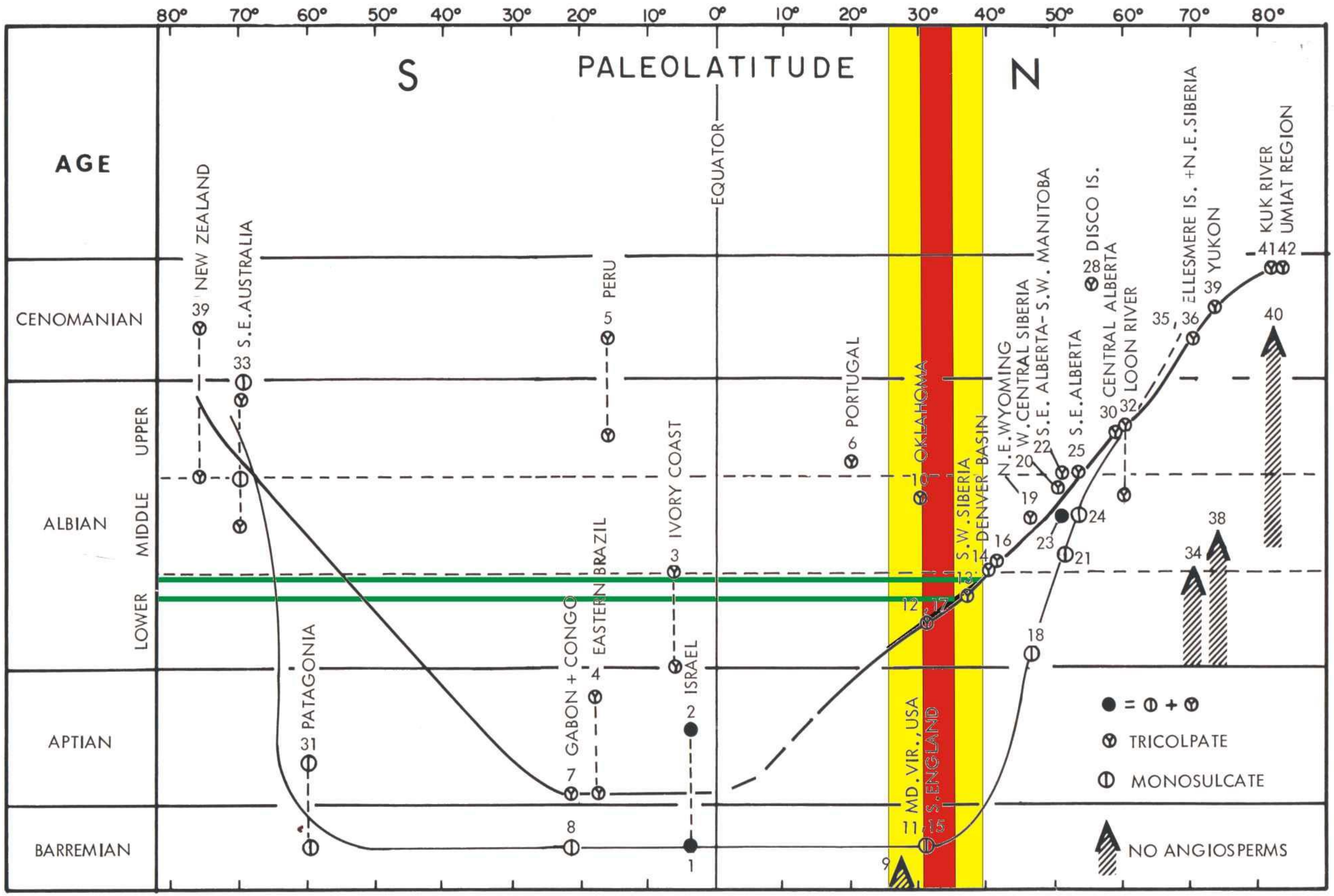

Mesozoic Era
Cretaceous Period
Late
Early
Maastrichtian
Campanian
Santonian
Coniacian
Turonian
Cenomanian
Albian
Aptian
Barremian
Hauterivian
Valangian
Ryazanian
Ma
65.0
71.3
83.5
85.8
89.0
93.5
98.9
112.2
121.0
127.0
132.0
136.5
142.0

Angiosperm Pollen Grains

- morphologically variable
- very small (6-15 µm)
- monosulcate forms present in different areas
- *Retimonocolpites peroreticulatue* and *Retimonocolpites* cf. *pennyi*
- size and type found in early stages of angiosperm evolution
- Age ranges not well defined



Age of the Deposits

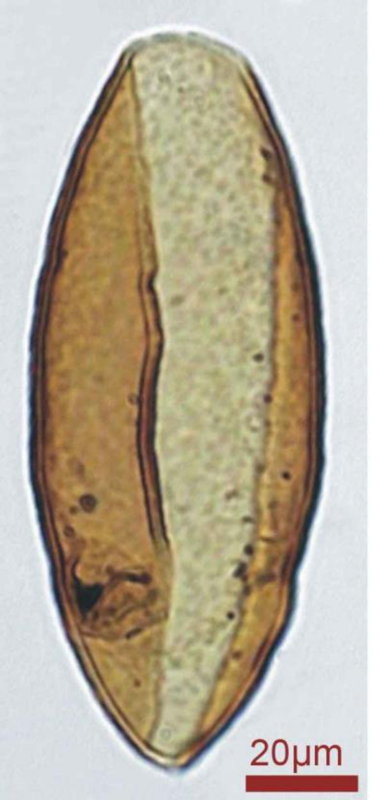


Hickey and Doyle 1977

Paleoenvironment

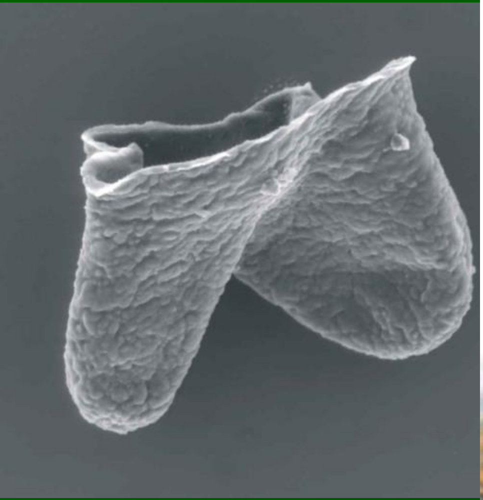
- originally thought to be fluvial or fluvial/deltaic
- Facies in cores favor this environment
- Sand dominated and clay dominated facies
- Non-marine palynomorphs—algal protists, dinoflagellates, abundant trilete spores
- palynomorphs found suggest a period of standing water (lake), floodplain deposit or marsh type environments
- Diverse trilete spore assemblage, bisaccates, bryophyte spores
- foraminifera findings suggest a marine influence
- foraminifera found at the base of the cores

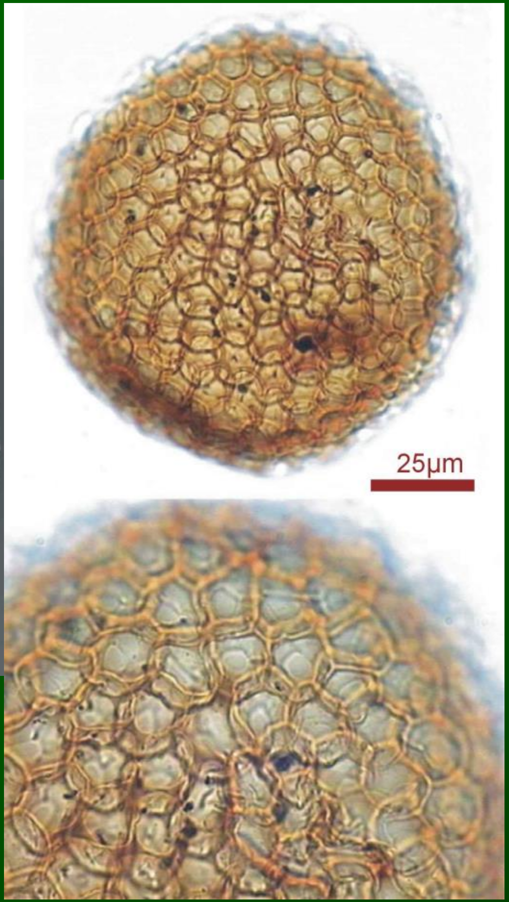
Lecaniella and *Ovoidites*



- *Lecaniella irregularis*, *Lecaniella foveata*
- *Ovoidites parvus*, *Ovoidites spriggii*
- zygnemataceans
- modern representatives common freshwater flood plain, swamp, paludal deposits

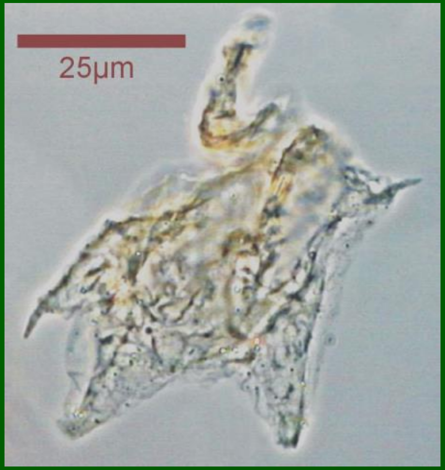
Schizosporis reticulatus and *Schizocystia rugosa*



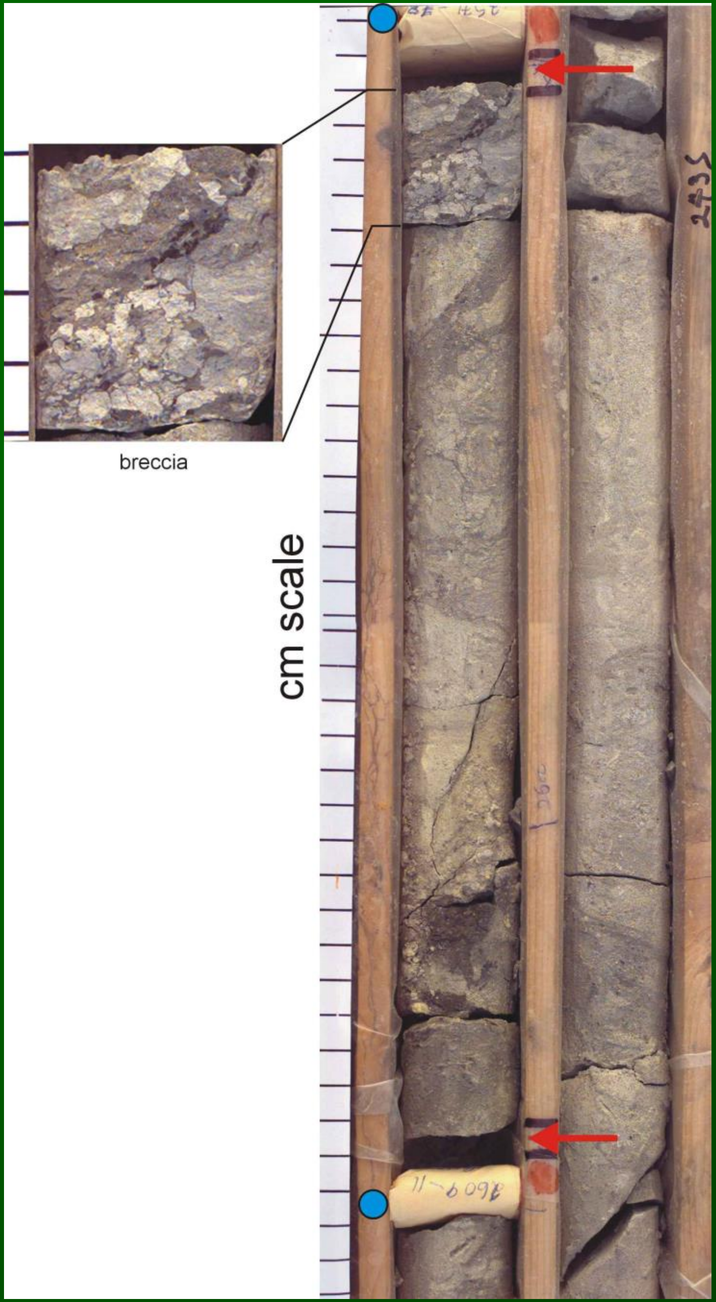


- zygnemataceans
- Pierce (1977) found possible modern representative of S. reticulatus
- found in flood plain, paludal, swamp, slow moving streams (modern)

Nyktericysta sp. and *Peridinium* sp.



- Dinoflagellates
- *Nyktericystia* sp. known from fresh water deposits in China and Moose River Basin
- *Peridinium* sp. not a species known in the marine realm of the same age
- Possible modern representatives exist non-marine paludal deposits



Breccia

- Forams found in this section of the core and not in other parts
- Only Carboniferous palynomorphs
- Possible Carboniferous age
- More work needed to determine age and environment of deposition

Conclusions

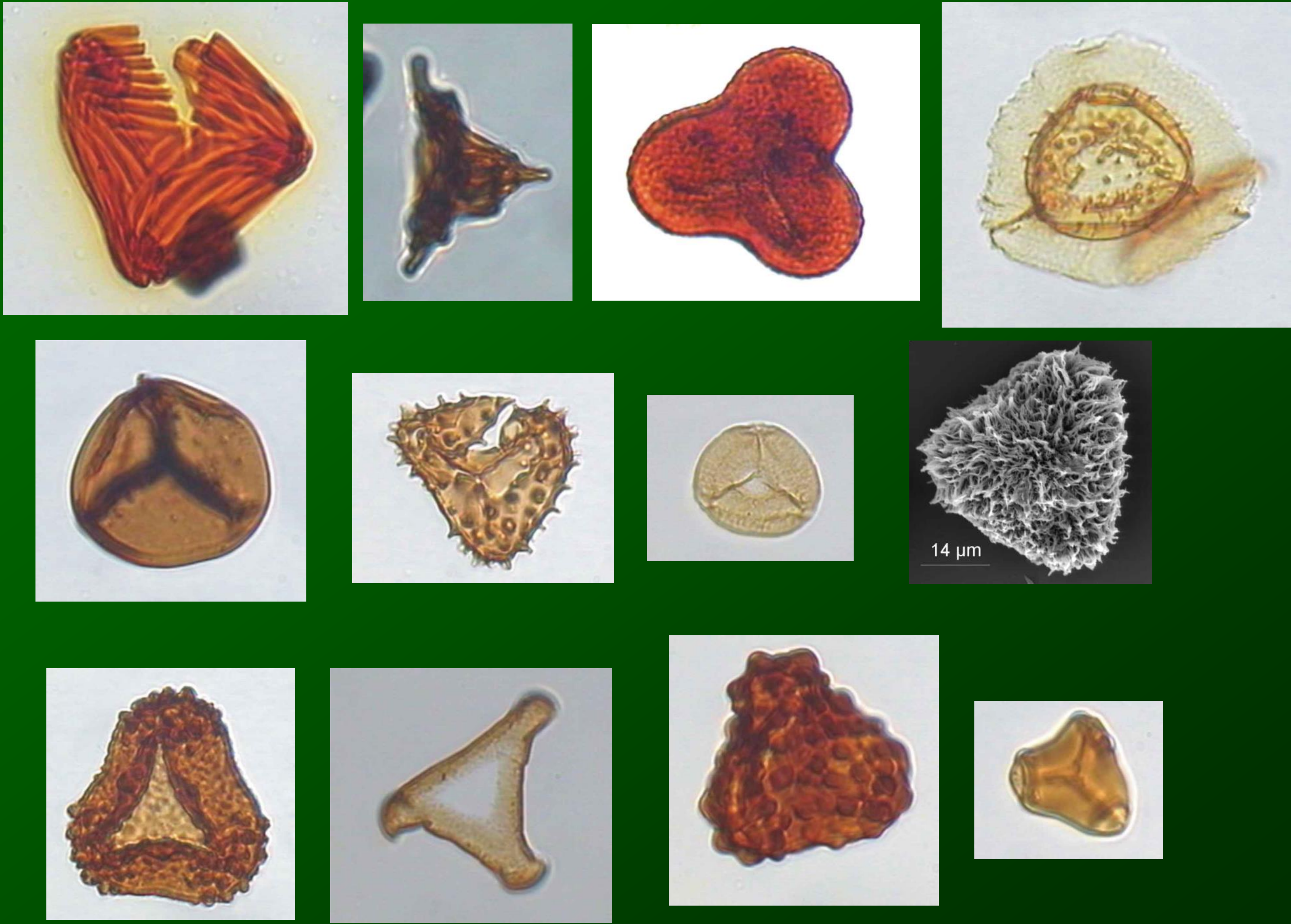
- Palynology suggests a non-marine paleoenvironment
- Different environments suggested by palynomorphs and strata
- Forams suggest a marine paleoenvironment
- Monosulcate angiosperms and the lack of tricolpate grains suggests an Lower Albian-Aptian age but an older age cannot be rules out

Future Work

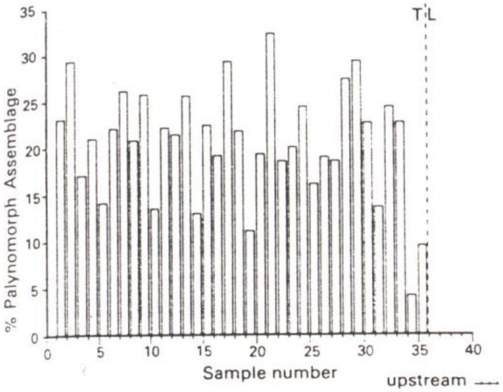
- Due a comprehensive study of the palynomorphs and forams to better determine the paleoenvironment
- Look at other cores in the study areas to determine if the same trends exist
- Compare this work with the other Cretaceous Basins in the Maritimes
- Compare the findings to modern environments

Acknowledgements

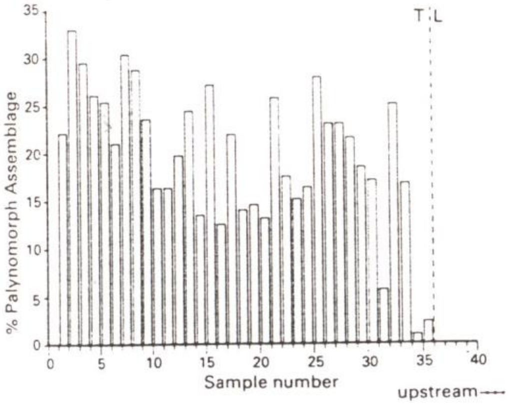
- Rob Fensome and Andrew MacRae, GSC Atlantic
- Dave Scott, Dalhousie University
- Bill McMillian, Frank Thomas, Bernie Crilley, GSC Atlantic
- Ralph Stea, Department of Natural Resources
- Marcos Zentilli, Dalhousie University


14 µm

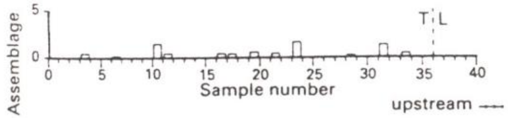
① OPERCULODINIUM CENTROCARPUM



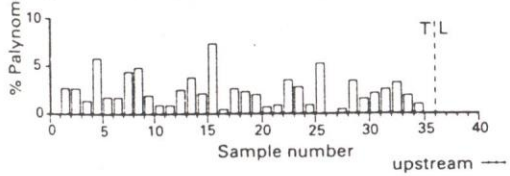
② SPINIFERITES SPP.



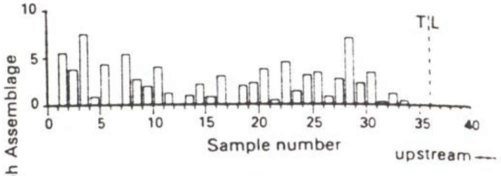
③ TRINOVANTEDINIUM CAPITATUM



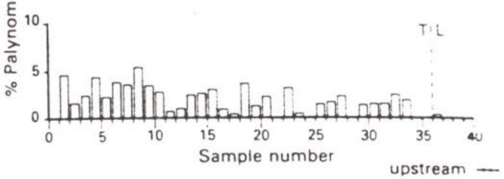
④ BITECTATODINIUM TEPIKIENSE



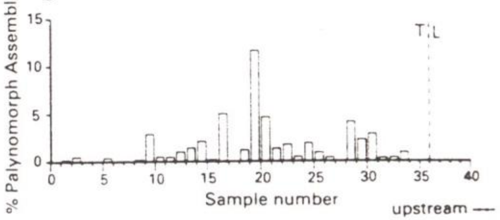
⑤ POLYKRIKOS SCHWARTZII



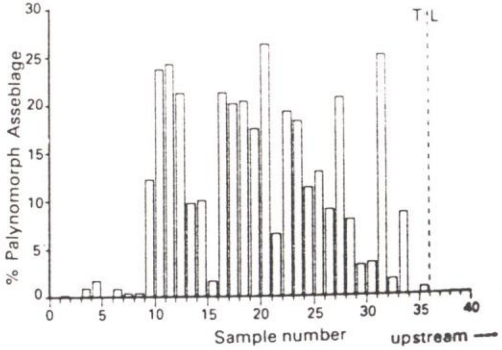
⑥ ROUND BROWN CYSTS



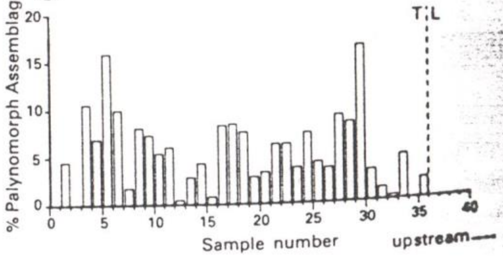
⑦ IMPLETOSPHAERIDIUM SP.

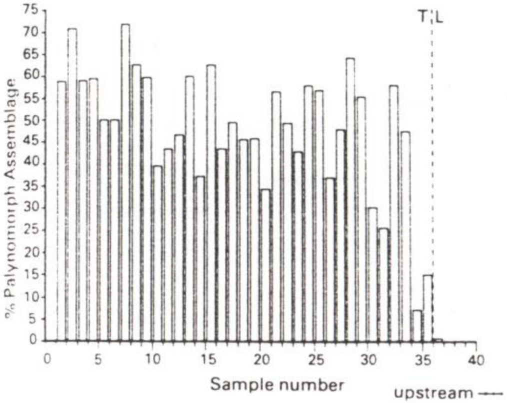


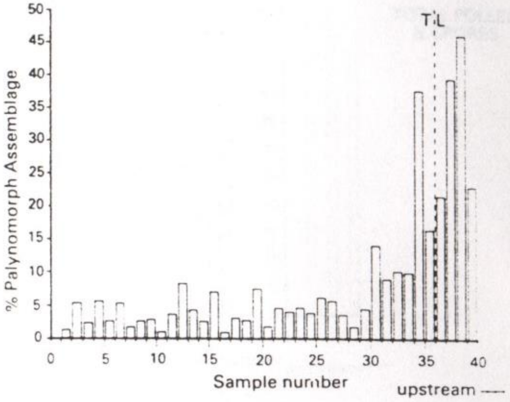
⑧ CYST A (HARLAND)

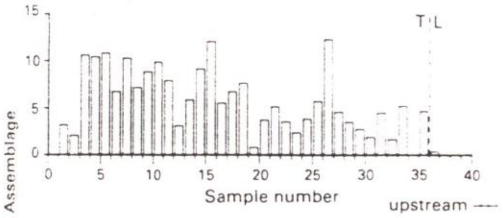


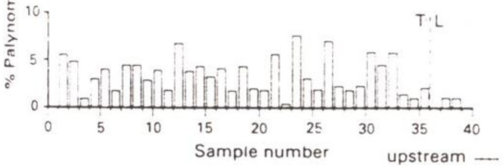
⑨ PALYNOMORPH Y

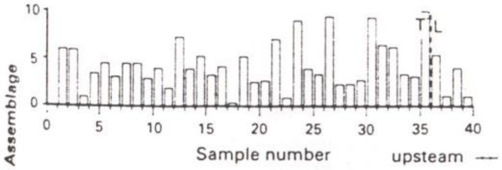


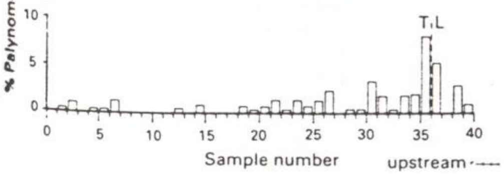

⑩ TOTAL DINOCYSTS

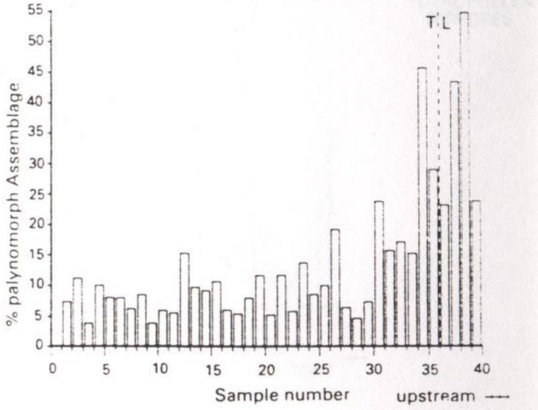

⑮ TOTAL NON-ARBOREAL POLLEN

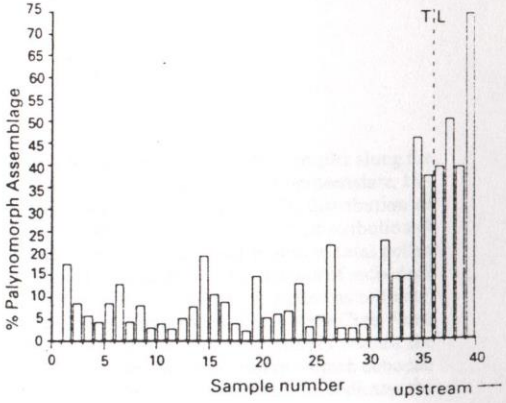

⑪ TOTAL FORAM LININGS

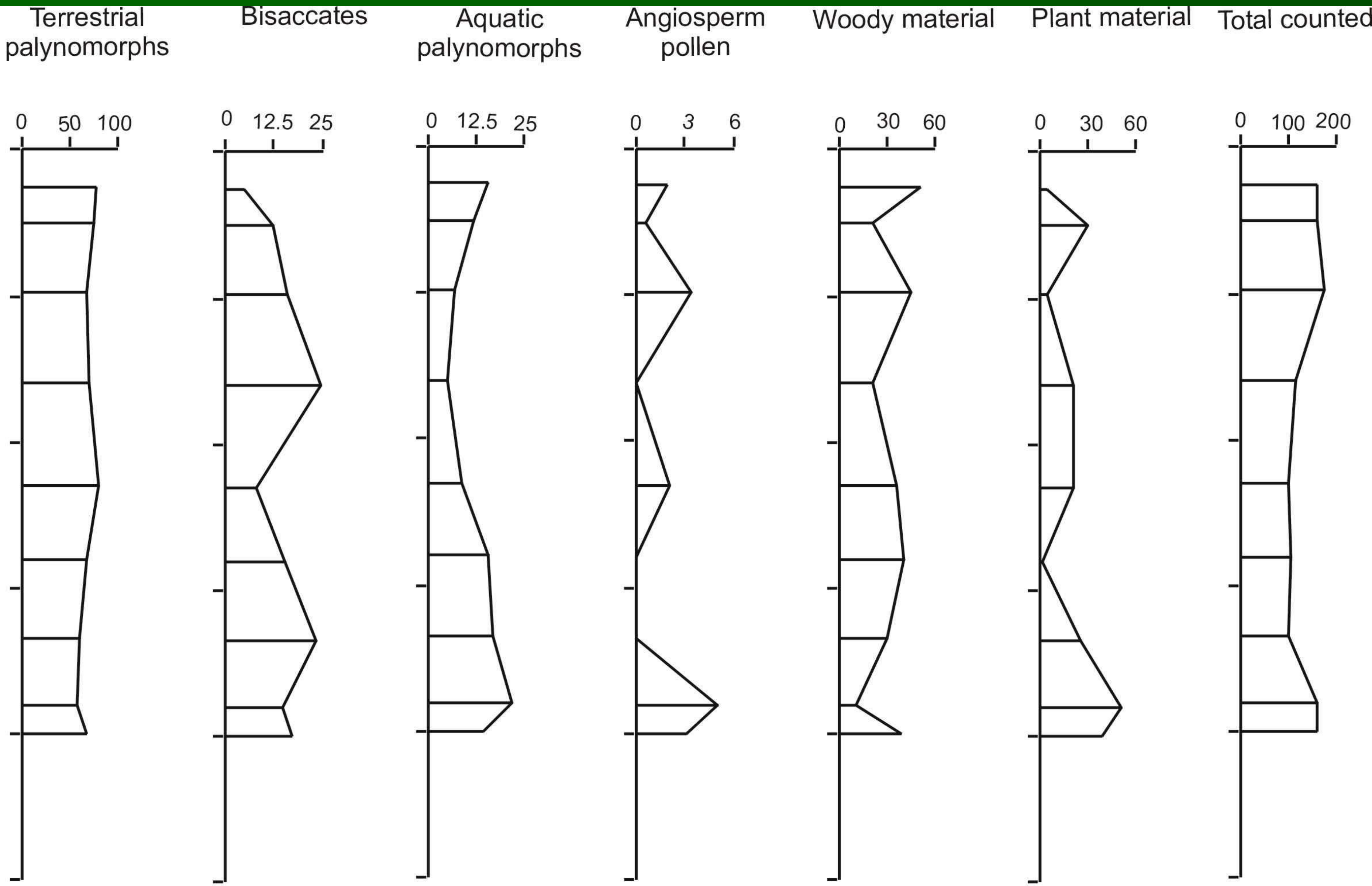

⑫ PINUS SYLVESTRIS

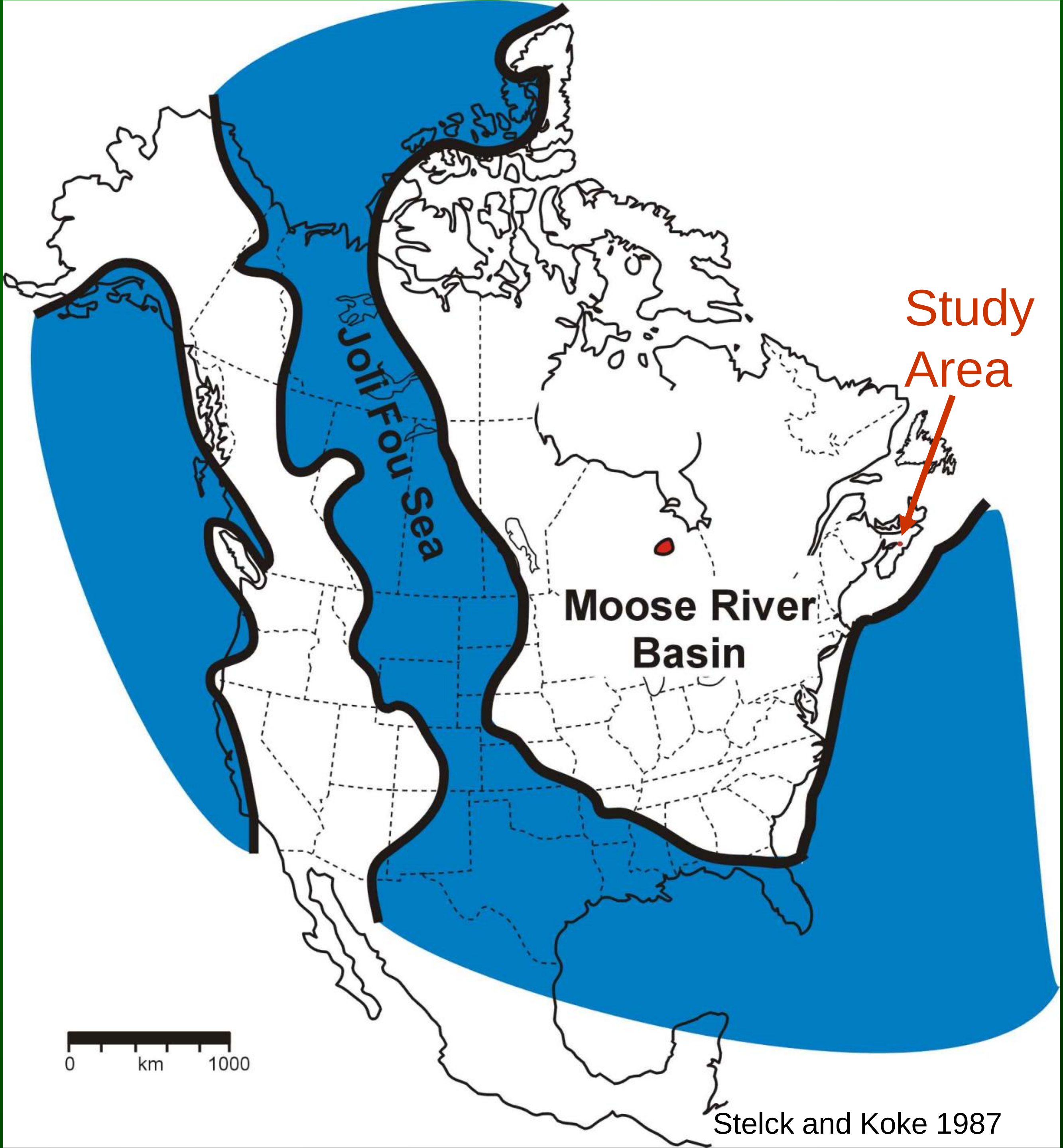

⑬ TOTAL ARBOREAL POLLEN


⑭ TOTAL ARBOREAL POLLEN LESS PINUS

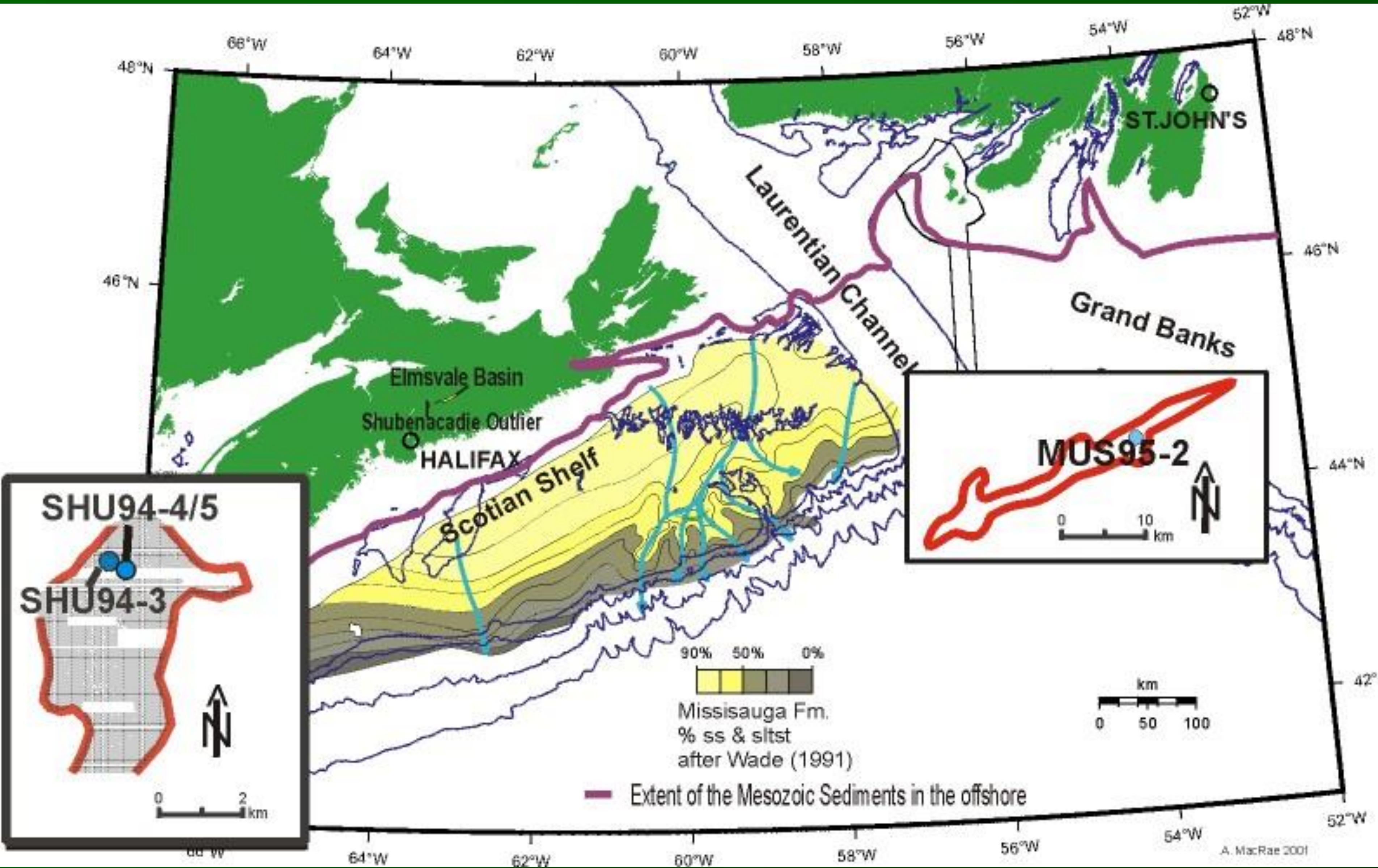

⑯ TOTAL POLLEN AND SPORES


⑰ TOTAL FUNGAL PALYNOMORPHS


Terrestrial palynomorphs
0 50 100
Bisaccates
0 12.5 25
Aquatic palynomorphs
0 12.5 25
Angiosperm pollen
0 3 6
Woody material
0 30 60
Plant material
0 30 60
Total counted
0 100 200



Stelck and Koke 1987



66°W
64°W
62°W
60°W
58°W
56°W
54°W
52°W
48°N
46°N
44°N
42°N
ST.JOHN'S
Laurentian Channel
Grand Banks
Elmsvale Basin
Shubenacadie Outlier
HALIFAX
Scotian Shelf
MUS95-2
N
0
10
km
SHU94-4/5
SHU94-3
N
0
2
km
90%
50%
0%
Missisauga Fm.
% ss & sltst
after Wade (1991)
km
0
50
100
Extent of the Mesozoic Sediments in the offshore
A. MacRae 2001