SEDIMENTOLOGY AND PALEONTOLOGY OF THE LOWER JURASSIC SCOTS BAY FORMATION, BAY OF FUNDY, NOVA SCOTIA, CANADA

A THESIS PRESENTED

BY

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CONTENTS

LIST OF TABLES

LIST OF PLATES

LIST OF FIGURES

ABSTRACT

The rocks of Scots Bay Formation occur only along the south shore of the Bay of Fundy where they are exposed in small coves from east of Baxters Harbour to west of Scots Bay, Nova Scotia. Lithologically, the Scots Bay Formation is dominated by clastic sediments, including sandstone, silty sandstone, conglomeratic sandstone, and shale. Carbonate and silicified carbonate rocks include calcareous sandstone, packstone, mudstone, wackestone, and stromatolitic limestone. Jasperoid chert nodules and bedded cherts are common throughout much of the formation.

Phreatic and vadose meteoric cements make up most of the cements of Scots Bay limestones. Three types of calcite cements occur in the Scots Bay Formation: drusy mosaic, blocky, and minscus cement. The chert is principally early diagenetic in origin and consists of chalcedony and microcrystalline quartz that formed as pore filling cement and replacements of carbonate sediments and calcareous fossils. The source of the silica was hot-spring fluids associated with the underlying basaltic volcanic flows.

Four environmental facies are recognized in ascending order : (1) marginal channeling facies, (2) shoreline facies, (3) nearshore facies (basal and upper units), and (4) offshore facies. These facies record a regressive phase overall for the Scots Bay sequence. Siliciclastic fine-grained sediment was deposited in the lake offshore. This was followed by deposition of mixed carbonate and siliciclastic units in nearshore environments.

Meanwhile, litharenitic sandstone was deposited along the shoreline which is present now as the top unit of the Scots Bay sequence.

Fossils in the Jurassic Scots Bay Formation are rare and mostly silicified. They include a relatively low diversity of ostracodes, small gastropods, small clams, invertebrate burrows, fragments of charophyte stems, freshwater stromatolites, rare ferns, and log and wood fragments. Three genera of small ostracodes have been identified: *Darwinula, Timiriasevia*, and *Metacypris*. T. aff. *digitalis* and *M. ridgensis* n. sp. have been identified. *Darwinula* is represented by at least three species: *Darwinula sarytirmenensis, Darwinula* aff. D. *liassica*, and *Darwinula acadiaensis* n. sp. A new genus of a unique "giant" ostracode, identified as *Megawoodworthia salemi* n. sp., occurs only in a calcareous sandstone bed at Woodworth Cove. A new small bivalve identified as *Naiadites scotsbayensis* n. sp., has been found in the Scots Bay Formation. The gastropod genera are represented by small species of *Gyraulus*, *Valvata*, and *Hydrobia*.

Sedimentary facies in the Scots Bay Formation do not vary widely from outcrop to outcrop; for example, the offshore facies can be traced in all outcrops except West Broad Cove and the brown sandstone of the shoreline facies appears to cap most the outcrops of the Scots Bay Formation. Interpretation of their depositional environments is based on paleoecological and sedimentological criteria.

The fossil assemblages and the stratigraphic position of the Scots Bay Formation suggest an Early Jurassic age.

ACKNOWLEDGMENTS

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CHAPTER ONE
INTRODUCTION

Lacustrine deposits like those of the Fundy Group of Nova Scotia are common in some paleoenvironmental sequences and have become increasingly important to study because of their potential economic significance, particularly as sources of petroleum in some regions. For example, the Red Wash oil field in Utah had the lacustrine Paleocene-Eocene Green River Formation as its source rock (Fouch and Walter, 1982). The lacustrine Triassic-Jurassic basins in Virginia have also yielded some crude oil (AAPG, Explorer, 1985).

The Triassic-Jurassic Fundy Group rocks are exposed along the south and north shores of the Bay of Fundy. They record arid conditions (Ackermann, Schlische, and Olsen, 1995) unlike analogous and time-equivalent basins in the United States where organic-rich shales and coals are present (Brown and Grantham, 1992). The Fundy Group along the south shore of the Bay of Fundy consists of four nonmarine formations which, in ascending order, are the Wolfville, Blomidon, North Mountain Basalt, and the Scots Bay formations. At the top of the Fundy Group, the Scots Bay Formation along the south shore is believed to be time-equivalent to the McCoy Brook Formation along the north shore (Olsen, 1987). The little studied Scots Bay Formation is unique because it is a chert-bearing mixed carbonate and siliciclastic unit.

In outcrop, as originally defined (Power, 1916), the Scots Bay Formation reaches a maximum thickness of about 7 meters, being exposed in small coves from east of Baxters Harbour to west of Scots Bay, Nova Scotia (Cameron, 1986). In the subsurface beneath the Bay of Fundy, time-equivalent McCoy Brook-like sediments reach 2500 m in thickness and are all referred to as the Scots Bay Formation by Wade and others (1996, p. 218).

The Scots Bay Formation in the original sense, as used herein, is composed of different types of lithofacies of which siliciclastics dominate, including feldspathic sandstones, conglomeratic sandstones, silty sandstones. The carbonate rocks consist of calcareous sandstones, packstones, wackestones, and bioclastic limestones. Chert beds and jasperoid nodules are common.

The Scots Bay Formation is characterized by an assemblage of silicified freshwater lacustrine ostracodes, micromollusks, algae, stromatolites, rare dinosaur footprints, plant fragments and rare fish (Cameron, 1985, 1986; Cameron and Jones, 1988, 1990). The rare dinosaur footprints occur in coarse, cross-bedded sandstones that indicate a possible fluvial or shoreline paleoenvironment at the top of the Scots Bay Formation. The silicification and tufa-like structures suggest hot spring environments (Birney-De Wet and Hubert, 1989). The fossils indicate a Jurassic age for the Scots Bay Formation (Cameron and Jones, 1990).

1.1 PURPOSE OF THE STUDY

The lithologies and paleoenvironments of the Scots Bay Formation are not consistently described and understood, so various authors disagree on basic observations. The purposes of this study are to develop a better understanding of the sedimentology, paleontology, paleoenvironments and stratigraphy of the Scots Bay Formation. My major efforts will concentrate on 1) studying microfossil assemblages, 2) measuring, describing and classifying the sedimentary rocks, 3) interpreting their depositional environments based on fossils, sedimentary structures and lithology, 4) conducting a microfacies analysis of the paleolacustrine environment, 5) determining the age of Scots Bay Formation based on fossil content and stratigraphic position, 6) studying the nature of the contact between the Scots Bay Formation and the North Mountain Basalt, 7) studying the extensive silicification and diagenesis, and 8) conducting a systematic study of the nonmarine ostracodes. The author will redescribe the lithologies of the Scots Bay Formation by noting the mixed siliciclastic and carbonate sedimentology and the affects of silicification. A depositional model will be constructed to indicate the stratigraphic relationships between the environmental facies.

1.2 LOCATION AND ACCESS

The Bay of Fundy Basin is bounded by the Cobequid Fault Zone on the north and by Triassic-Jurassic strata of Fundy Group on the south. The Scots Bay Formation occurs in about six major and some minor topographically low syncline-like structures on the top of the North Mountain Basalt Formation. These outcrops are located along the shoreline southwest of Scots Bay village to near Baxters Harbour. The study area is bounded by latitudes 64° 14′ W , and 45° 14′ N and 45° 17′ N and longitudes 64° 30′ W. The main outcrops of the Scots Bay Formation are, from north to south, Davidson Cove, East Broad Cove, Central Broad Cove, West Broad Cove, Lime Cove and Woodworth Cove (Fig. 1-1). The last five coves can be reached by driving down Ross Creek Road, which is an unpaved road leading down to Scots Bay. At the mouth of Ross Creek, Woodworth Cove is located exactly to the left (west), while the rest of the coves can be reached by walking to the right (northeast). Davidson Cove can be reached after walking 2 km along the beach northeast of East Broad Cove.

1.3 METHODS OF STUDY

Field work involved describing and measuring several sections in each cove and taking samples from each outcrop for paleontologic and sedimentologic laboratory descriptions and analyses. Structural features, such as laminations, bedding attitudes, cross-bedding,

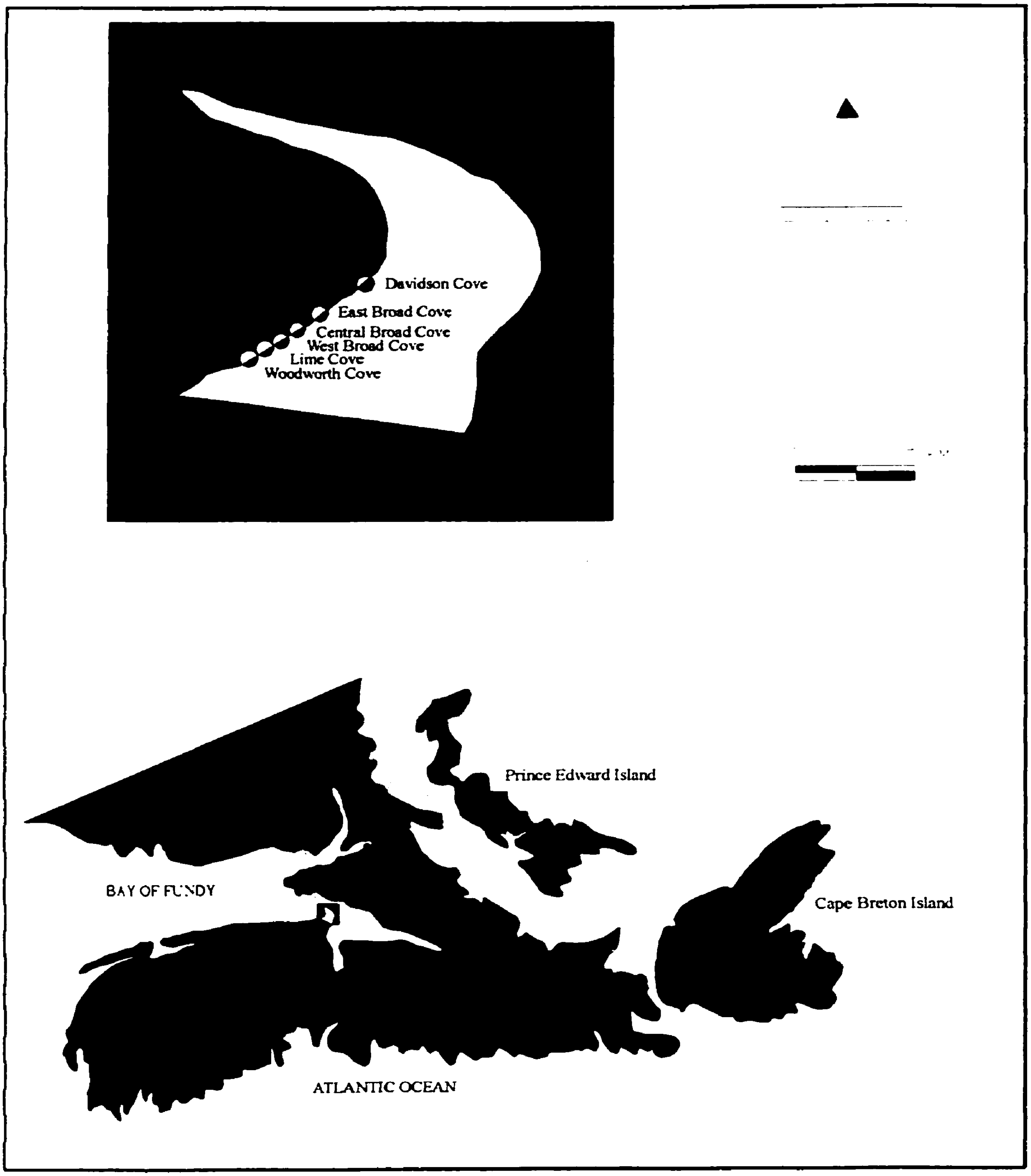


Figure 1-1. Location map of the study area. A, the Bay of Fundy northern Nova Scotia, B, the main outcrops of the Scota Bay Formation (modified after Birney & Hubert, 1989)

etc., and the irregular surface between the Scots Bay Formation and North Mountain Basalt were studied. Photographs were taken at each cove to document structures and stratigraphic relationships. Field equipment used in this study included, for example, a Brunton compass, topographic maps of the study area, a geologic hammer, a hand lens, a pocket measuring tape, notebooks, etc.

The laboratory work included descriptions and identifications of rocks in hand specimen and 75 thin section. Low power photomicrography was done to study rock texture. Oracet Blue 2R was used in thin section preparations and point counts made to determine porosity, Alizarin Red S solution was used for the dolomite identification, and Feigl's solution was used for distinguishing aragonite from calcite. Acetate peels of selected samples were examined with a binocular microscope. The faunal content was studied from acid insoluble residues by using different types of microscopes (binocular, petrographic and SEM).

CHAPTER TWO
PREVIOUS WORK

The Scots Bay sedimentary rocks were first studied by Ells (1894), who described 4 feet of green sandy looking shale overlying amygdaloidal basalt in Woodworth Bay. Haycock (1900) examined the Scots Bay rocks and suggested a Cretaceous age for them based on his fossil collection which included fish scales, teeth and "fucoids."

Fletcher (1911) first mapped this area geologically. He mapped the Minas Basin area for the Geological Survey of Canada and showed five outcrops of the Scots Bay Formation on the Bay of Fundy shore in the vicinity of Scots Bay. Powers (1916) proposed the name Scots Bay Formation for the outcrops in five small synclines along the Fundy shore where it rests on the North Mountain Basalt. He also reported plant remains, "worm" burrows, fish scales and bones from the Scots Bay Formation .

Klein (1954) reported that the Scots Bay Formation outcrops in six small synclines and rests disconformably on the basalt. He also suggested that the Scots Bay Formation was deposited in a tidal lagoon and that the source for the clastic materials was interpreted as coming from southerly and easterly directions. Klein (1962) reported that in the eastern outcrops, sand-sized materials dominate, while in the central outcrops limestones dominate. In western outcrops, clayey limestone and claystone dominate. Huntec Limited of Toronto (1965), Brown (1992), and Wade and others (1996) who conducted seismic surveys in the Minas Basin and the north shore region, reported that rocks equivalent to the Scots Bay Formation occur under the entire floor of Bay of Fundy and reach thicknesses of 2500 m.

During the 1970's, the Scots Bay Formation received little attention except for a thesis by Thompson (1974). Blakeney (1971) studied and described the stratigraphic section of Scots Bay Formation at Lime Cove. Thompson (1974) studied the geochemistry of the Scots Bay Formation and found that the carbonate is composed of 99.49 per cent Ca CO_3 and 0.42 per cent $MnCO_3$. He also noted that the chert nodules have fewer clay impurities than the chert bands.

Cornet (1977) studied the pollen and spores of upper Triassic to lower Jurassic rocks of the Fundy Basin in the Annapolis Valley region and was able to locate the Triassic-Jurassic boundary within the upper Blomidon Formation just beneath the base of the North Mountain Basalt.

Over the next decade, interest shifted to the north shore of the Minas Basin and to the underlying units. Liew (1976), in his thesis, studied the structure, geochemistry, and stratigraphy of the Triassic rocks along the north shore of the Minas Basin. Stevens (1980) studied the Mesozoic volcanism and structure in the northern Bay of Fundy region. He stated that a thick Jurassic sequence of coarse continental clastics overlies the basalt and comprises the floor of the Bay of Fundy. The upper part of these sediments are believed to be a time-equivalent clastic facies of the Scots Bay Formation.

Interest was renewed in the Scots Bay Formation in the 1980's. Cameron and Colwell (1983, 1985) reported tree trunks as the nuclei of some large chert nodules. Cameron and others (1985) made a preliminary study of the silicification and silicified microfossils and stromatolites from the Scots Bay Formation. Birney (1985), in her thesis, studied the sedimentology and petrology of the Scots Bay Formation and concluded that the lake contained hot springs, was oligotrophic to eutrophic and that the freshwater had good circulation. Cameron (1985, 1986) and Cameron and Jones (1988) conducted a preliminary paleontological study (pers. comm., 1998) by extracting some of the silicified fossils from chert-bearing, mixed carbonate and siliciclastic lithologies. Cameron (1986) suggested that the Scots Bay Formation probably represents a nearshore carbonate facies of the more widespread siliciclastic lacustrine McCoy Brook Formation on the north shore of the Bay of Fundy. He also suggested that the early silicification suggests hot spring environments. Brown (1986b) reported that the tholeiitic North Mountain Basalt, which is up to 250 m thick, covered the region and was followed by deposition of lacustrine-playa siltstone, shales, limestone and eolian sandstones of the Scots Bay and McCoy Brook formations. He also stated that potential source rocks of the Scots Bay and Blomidon formations are thermally mature (TAI= 2.5-3.5), though sufficiently organic-rich sediments are yet to be encountered.

Olsen and others (1987), from studies of reptile footprint assemblages, suggested an Early Jurassic age for the McCoy Brook and Scots Bay formations. Birney-De Wet and

Hubert (1989) suggested that the carbonate rocks of the Scots Bay Formation were deposited in a lacustrine littoral zone. They indicated that silica-rich hydrothermal springs and seeps around and on the floor of the lake precipitated siliceous tufa and silicified adjacent carbonate strata. They were mainly concerned just with the silicification and carbonate paleoenvironments and did not emphasize the role of siliciclastic sedimentation in the Scots Bay Formation. They even referred to the Scots Bay Formation as Scots Bay Limestone (Birney-De Wet and Hubert 1989, P. 857)

Cameron and Jones (1990) identified the age of Scots Bay Formation as Early Jurassic based on invertebrates, vertebrates and trace fossils. Cameron (1986) and Cameron and Jones (1990) described three new microgastropods, including a high-spired, axially ribbed form tentatively assigned to *Hydrobia*, a nearly planispiral planorbid assigned to *Gyraulis* and a freshwater prosobranch with a smooth, umbilicate and low-spired shell belonging to *Valvata*. The *Hydrobia* identification was also suggested by Thompson (1974), who observed it in thin section. Good and others (1994) reported that the mollusk fauna is composed of two species of gastropods, including the low-spired *Valvata* sp. and a single species of small bivalve. Good (1994) also reported that there are four species of gastropods representing the families Valvatidae, Hydrobiidae, Planorbidae and a species of bivalve.

Brown and Grantham (1992) extended the age range of the lower Mesozoic sediments in the Fundy Rift system from the Anisian (lower middle Triassic) to at least

Sinemurian (middle early Jurassic) age. Thompson (1974) and Birney-De Wet and Hubert (1989) described the lithologies of the Scots Bay Formation, but their stratigraphic sections do not agree very well. For example, Thompson described Central Broad Cove from bottom to top as varying from coarse-grained sandstone channel fill at the base through varying interbeds of buff to green limestone and green sand to a medium-grained brown sandstone at the top. Individual units vary widely from almost pure limestone to sandstone with very little carbonate cement. In contrast to Thompson's (1974) description, Birney-De Wet and Hubert (1989) described the Central Broad Cove exposure from bottom to top as siltstone overlain by 5 m of limestone containing numerous brown to red silicified logs. These limestones become coarser upward, grading from wackestones into fine to medium-grained packstones. Above the limestone, there is a brownish-red chert, including tufa, up to 1.25 m in thickness. This unit is overlain, in turn, by sandstone and limestone, and sandstone marks the top of the section. Another example of obviously different stratigraphic columns by various authors is illustrated in Figure 2-1. Here, East Broad Cove is shown as described by Klein (1960), Thompson (1974), Olsen (1989), and Birney-De Wet and Hubert (1989).

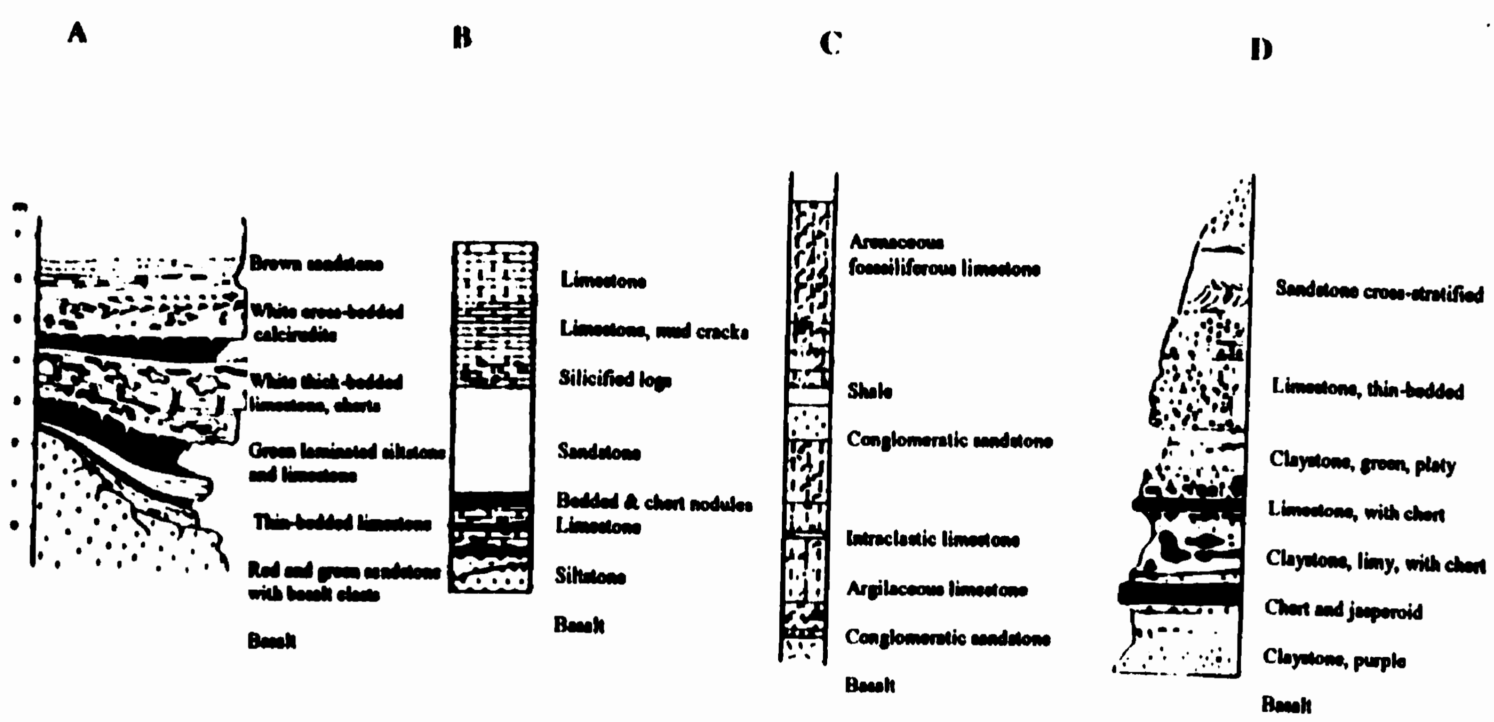


Figure 2-1. Stratigraphic sections of the Scots Bay Formation in East Broad Cove. Note the different descriptions from different authors: section A by Olsen (1989) section B by Birney-De Wet and Hubert (1989), section C by Thompson (1974), section D by Klein (1960).

CHAPTER THREE
REGIONAL GEOLOGY

The Meguma Group metasedimentary rocks of southwestern Nova Scotia underlie the younger sedimentary rocks and form a terrane that comprises most of southern Nova Scotia. The Late Paleozoic-Early Mesozoic stratigraphic succession can be considered as four depositional packages which are due to tectonic events, climatic changes and the consequent variations in sedimentation. These are: (1) Late Devonian to Early Namurian, Pre-Horton Strata, Horton, Windsor and Canso groups; (2) Late Namurian (Westphalian A) Riversdale Group; (3) Westphalian B to Early Permian, Cumberland and Pictou Groups and (4) the Late Triassic to Early Jurassic Fundy Group (Boehner and others, 1986).

3.1 STRATIGRAPHY AND ORIGIN OF BAY OF FUNDY

The Bay of Fundy trends east-northeast, is approximately 170 km long, and has a maximum width of over 70 km. The basin is bounded by a normal fault system on the north and west side (Klein 1963), making it like a half graben. Almost all of the Fundy Rift is located in the Bay of Fundy, but coastal exposures are extensive. It is found south of the Cobequid Fault Zone and rests on the Meguma Terrane. This rift was initiated during the break up of Pangaea in the Late Triassic (Brown and Grantham, 1992). The Mesozoic rocks in the Bay of Fundy (Fig. 3-1) are known as the Fundy Group (Olsen, 1980) which consists of four formations along the south shore. In ascending order (Fig. 3-2), they are the Wolfville Formation (up to 370 m), the Blomidon Formation (up to 370 m), the North Mountain Basalt Formation (ca. 250 m), and the Scots Bay Formation (up to 8 m) (Colwell and Cameron, 1985).

Koons (1942), in his study of the origin of the Bay of Fundy, reported that the Fundy embayment is a submerged Triassic lowland produced by subaerial agencies and bounded by fault-line scarps. Seismic profiles taken across the Bay of Fundy show that the Triassic strata extend beyond its mouth for a distance of about 120 km into the Gulf of Maine and dip gently toward the axis of the bay (Tagg and Uchupi, 1966). More recent seismic and regional geologic data suggest that the Bay of Fundy is genetically similar to other Early Mesozoic basins in the southern Appalachians, having formed at the edge of a reactivated, Paleozoic basement thrust fault (Brown, 1986a).

The Bay of Fundy half graben is one of the largest Triassic – Jurassic basins in eastern North America. The Fundy Basin in northern Nova Scotia and southern New Brunswick consists of three subdivisions : Minas sub-basin trending to the east, Chignecto sub-basin trending to the northeast, and the Fundy Basin proper (Fig 3-1).

Greenough (1995) reported that a period of lithospheric extension and collapse ensued during the Middle to Late Triassic and formed many grabens and half grabens, one of the most northerly being the Fundy half graben.

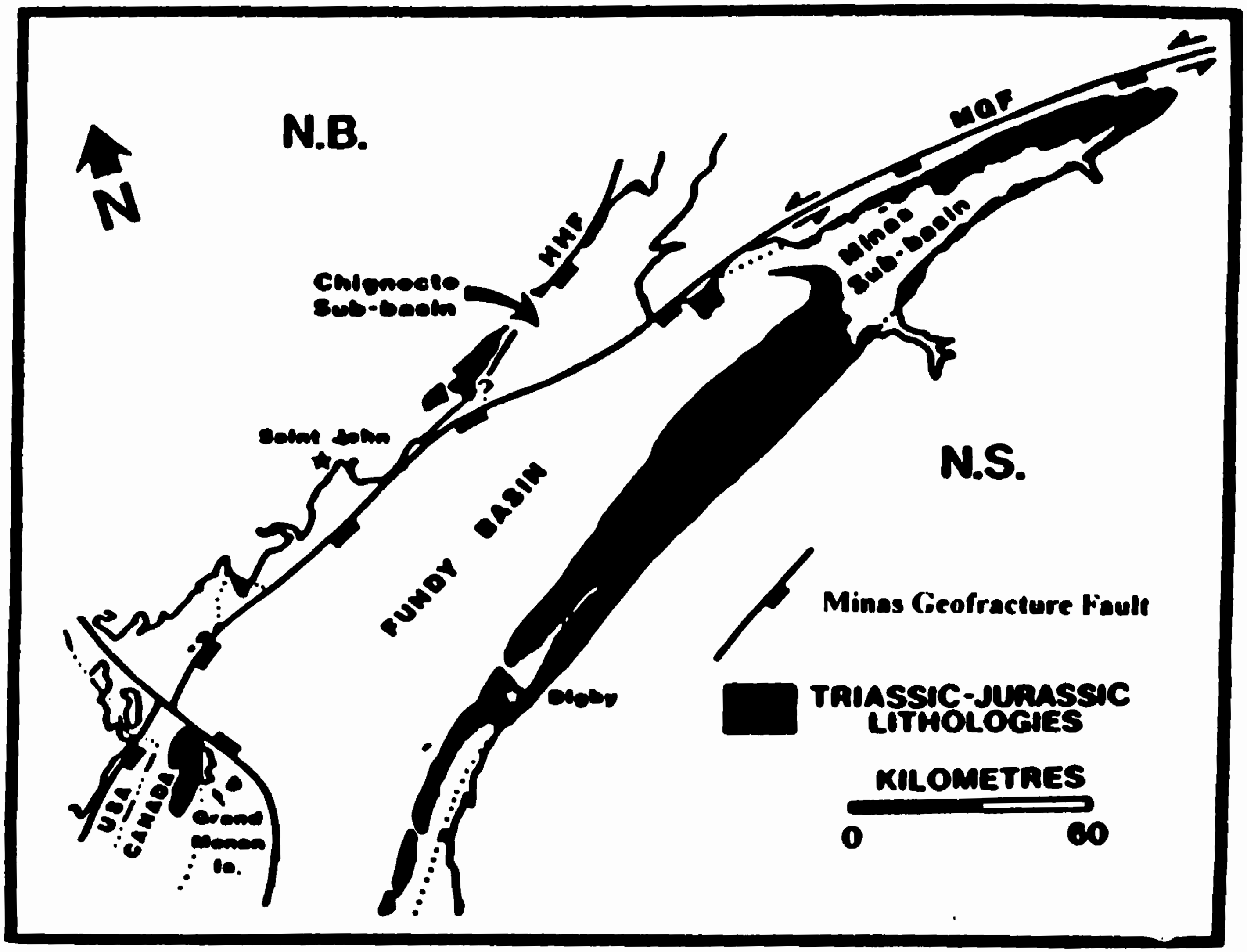


Figure 3-1. Distribution of Triassic-Jurassic rocks in the Bay of Fundy area: Minas Sub-basin trending to the east, Chignecto Sub-basin trending to the northeast, and the Fundy Basin proper (Modified after Brown and Grantham, 1992).

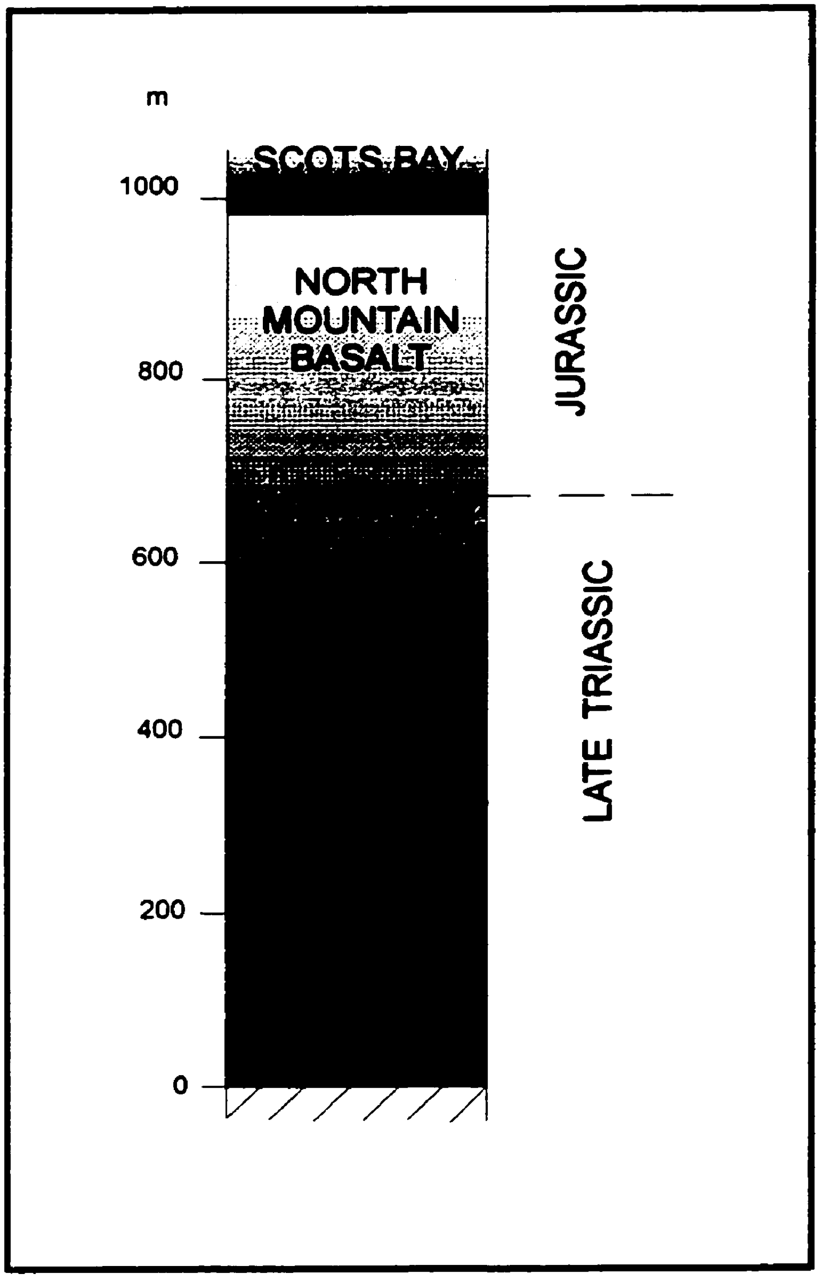


Figure 3-2. Generalized stratigraphic section for the Mesozoic rocks of the Annapolis Valley and North Mountain region of Nova Scotia (Modified after Cameron and Jones, 1988)

During the Late Triassic to Early Jurassic, the partial melting and thermal uplift that initiated the Atlantic ocean (Manspeizer and others, 1978) produced the tholeiitic North Mountain Basalt in the Fundy Basin. Hydrothermal solutions rich in silica may have been produced by the underlying magma and deposited silica in fractures in the basalt and Scots Bay Formation, as indicated by silica veins in both of these formations. The geological and geophysical study by Withjack, Schlische, and Olsen (1998) indicated that in maritime Canada the rift-drift transition of the Atlantic Ocean occurred after eastern North American magmatic activity and synrift deposition in the Early Jurassic and before postrift deposition in the early Middle Jurassic (~185 Ma).

A brief description of the broad characteristics of the Bay of Fundy south shore formations of the Fundy Group is presented in the following sections.

3.1.1 Wolfville Formation

The name for this 60 to 400 m thick formation was introduced by Powers (1916) as the lower member of his Annapolis Formation. It is composed of coarse to medium-grained quartz arenites, arkose, subarkose with brownish-red hematitic and limonitic colouration (Stevens, 1985). Poorly sorted conglomerates, siltstones and mudstones also occur in the Wolfville Formation (Cameron and Jong, 1985). It disconformably overlies Devonian granite in Annapolis County and is conformably overlain by Blomidon shales or North Mountain Basalt according to Stevens (1985).

3.1.2 Blomidon Formation

The name Blomidon was used by Powers (1916) for the upper member of his Annapolis Formation. It is composed of red, calcareous, massive, playa lake mudstones and sandstones (Cameron and Jong, 1985; Cameron and Jones, 1987). Gypsum nodules and very fissile shales are present at some horizons. Klein (1962) reported a thickness varying between 8 m in the center of the Annapolis Valley to about 363 m at the type locality. Cameron and Jong (1985), using cores, disputed this thinning in the Annapolis Valley. It conformably overlies the Wolfville Formation and disconformably underlies the Early Jurassic North Mountain Basalt (Stevens, 1985).

3.1.3 North Mountain Basalt

Powers (1916) named the North Mountain Basalt, which consists of many tholeiitic lava flows. Massive and columnar jointed basalt and dolerite are present as well as thin amygdaloidal flows, especially at the top of the formation (Stevens, 1985). The maximum thickness of 350 m is reached on the Cape Split peninsula (Stevens, 1987). The North Mountain Basalt disconformably overlies the Blomidon Formation and is unconformably overlain by arenaceous limestones and red clastics of the Scots Bay Formation (Stevens, 1985).

3.1.4 Scots Bay Formation

The Scots Bay Formation was introduced by Powers (1916) for the mixed carbonate and siliciclastic rocks above the North Mountain Basalt that occur west of the village of

Scots Bay. It consists of sandstone, calcareous sandstone, silty sandy limestone, and limestone as well as jasperoid chert nodules and chert beds. The maximum thickness is about 7 meters in outcrop. The Scots Bay Formation disconformably overlies the North Mountain Basalt; its top is covered by Pleistocene and Recent sediments and soil.

3.2 STRUCTURAL GEOLOGY

The Bay of Fundy occurs in a faulted basin that trends northeast-southwest between Nova Scotia and New Brunswick. It is bounded on the north by the Cobequid Fault and on the south by the southern "highlands" of Nova Scotia, i.e., the South Mountain Range. The Minas Geofracture, a major east-west transverse fault, is the major structural feature that affected the basin's development (Brown 1986b). The Minas Geofracture was considered by Bromley (1987) as the actual boundary between the Meguma and Avalon terranes.

The breakup of the supercontinent Pangea occurred during the Late Triassic to Early Jurassic. It had been heated, tectonically thickened, and highly elevated through continental plate convergence from the Late Paleozoic to the beginning of the Late Triassic (Manspeizer, 1994). The opening of the Atlantic occurred during Middle to Late Triassic and continued into the Early Jurassic, according to most workers (e.g., Olsen 1981; Manspeizer, 1994; Withjack, Schlische, and Olsen, 1998). This rifting produced large grabens along the eastern margin of North America. These grabens received a great thickness of subaerial clastic sediments during subsidence, plus basalt flows, dikes and sills (Stevens, 1989). Small, shallow, synclinal fold-like structures are thought to be associated with the deformation in the Bay of Fundy syncline (Brown and Grantham, 1992).

The evidence for the Early Mesozoic separation of North America and Africa is documented in rocks of Late Triassic to Early Jurassic age in eastern North America and Morocco (Warren and others, 1978). Lindholm (1978) reported that Early-Middle Jurassic sediments and igneous rocks are distributed along eastern North America in elongate basins that are separated by normal faults. These faults indicate regional extension at the time of formation. They were very important to sedimentation processes and basin distribution along eastern North America.

A study by Huntec Limited (1965) shows that the Scots Bay Formation is gently folded and dips to the northwest under Scots Bay, becoming horizontal at the main axis of the Fundy syncline, and then dips gently to the southeast on the northern limb. The beds of the Scots Bay Formation appear to be locally folded, but regional dip ranges from 4° to 23° degrees to the northwest or northeast. The syncline-like structures preserved today in small coves have axes oriented in north west and south east direction (Fig. 3-3), being 311° at Woodworth Cove, 314° at Lime Cove, 348° at West Broad Cove, 317° at East Broad Cove is, 323° at Central Broad Cove and 287° at Davidson Cove. Three syncline-like structure plunges northwest and two southeast and the general range of synclinal plunges is 4° to 19°.

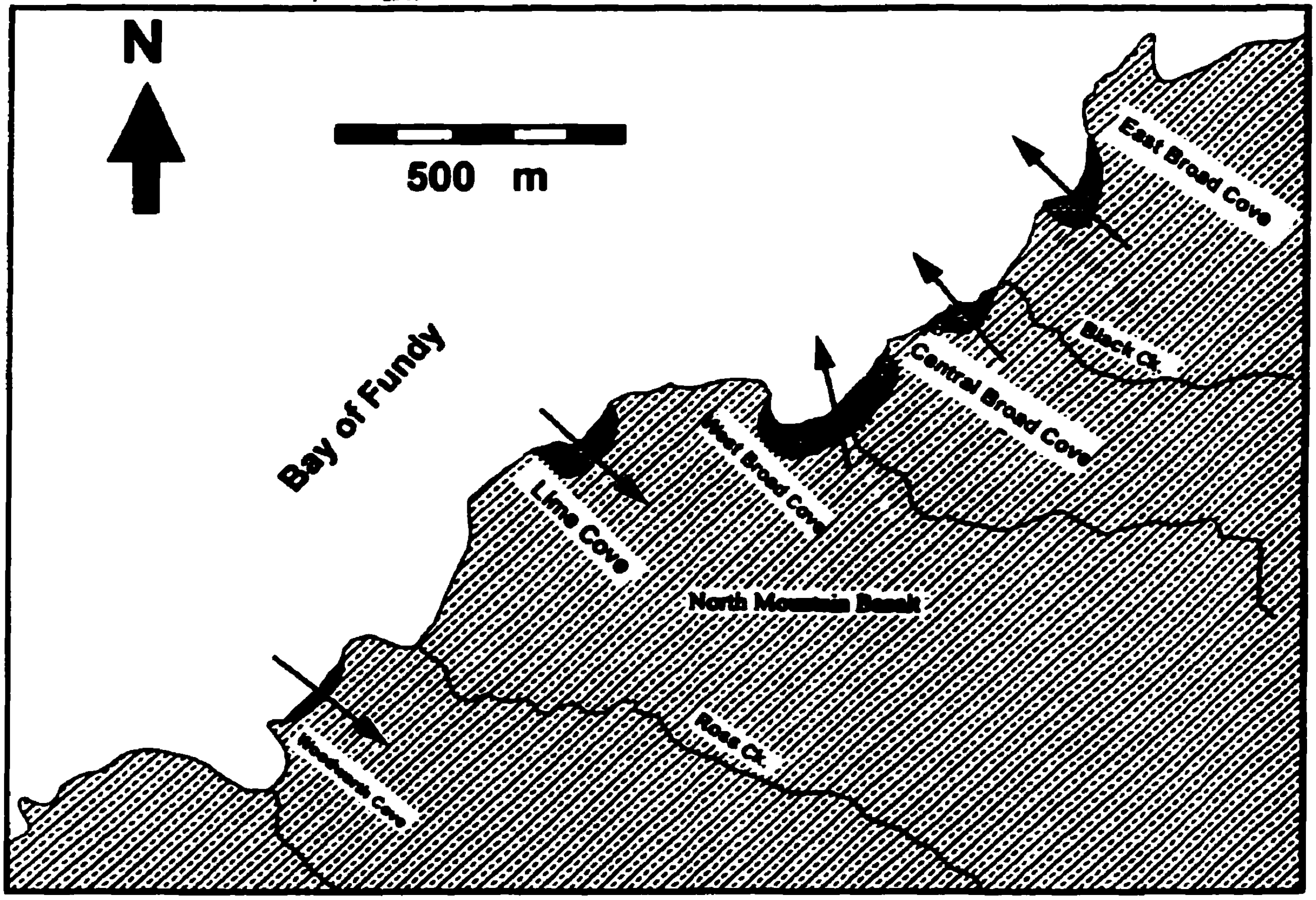


Figure 3-3. Geologic map of the south shore of the Bay of Fundy in the Scots Bay showing the orientation of the synclinal axes of the Scots Bay outcrops.

CHAPTER FOUR
STRATIGRAPHY AND SEDIMENTOLOGY

4.1 Introduction

The overall purpose of this chapter is to describe the stratigraphy and sedimentological characteristics of the Scots Bay Formation and decipher its paleoenvironments. Sedimentary facies models, vertical sequence data, petrography and paleontology are used for interpretation and reconstruction of the ancient depositional environments of this formation.

The Early Jurassic lacustrine Scots Bay Formation is one of the smallest Mesozoic lacustrine deposits in eastern North America, ranging in exposed thickness from 2.5 to 7 m. It is fossiliferous and overlies the last lava flow at the top of the Early Jurassic North Mountain Basalt. Wade and others (1996) stated that facies projections suggest that the upper part of Blomidon Formation and the Scots Bay Formation have the potential for appreciable quantities of hydrocarbons at the depocenter under the Bay of Fundy. In this study, no signs of hydrocarbon have been observed in the exposed outcrops.

The deposition of mixed siliciclastic and carbonate rocks occurred in topographic lows on the top of eroded and weathered basalts. Their environments were littoral lacustrine and fluvial which coexisted with hot springs that were responsible for their silicification.

4.2 LOWER CONTACT

The lower boundary of the Scots Bay Formation is a nonconformity with the top of the North Mountain Basalt which is indicated by evidence of weathering and erosion that produced topographic surface irregularities, microrelief and an old soil zone. Birney (1985) reported that this lower contact has 5 to 10 cm of irregular relief, herein called "micro-relief." The surface of the basalt is weathered and is capped by a thin, 5-10 cm, immature paleosol which contains angular fragments of weathered basalt. However, there is further evidence of deeper basalt erosion that occurs in the basal strata of the Scots Bay Formation where pebbles and cobbles of basalt up to 9 cm x 16 cm in size can be found. On a still larger scale, the paleogeographic lows in which the Scots Bay Formation is preserved are irregularly eroded surfaces that are responsible for the distribution of Scots Bay sediments in low areas that are now small coves along the southern shore of the Bay of Fundy. Truncated zones of basalt can be observed below the contact but no major onlapping units of Scots Bay sediments were observed above them. Klein (1962) interpreted these low areas as small synclines, whereas Cameron (personal communication, 1999) stated that these low areas could be collapse structures at the top of the North Mountain Basalt lava flows.

This erosion produced enough relief to control deposition (Fig. 4-1), so that the Scots Bay Formation is present only in the paleotopographic low areas on the top of the

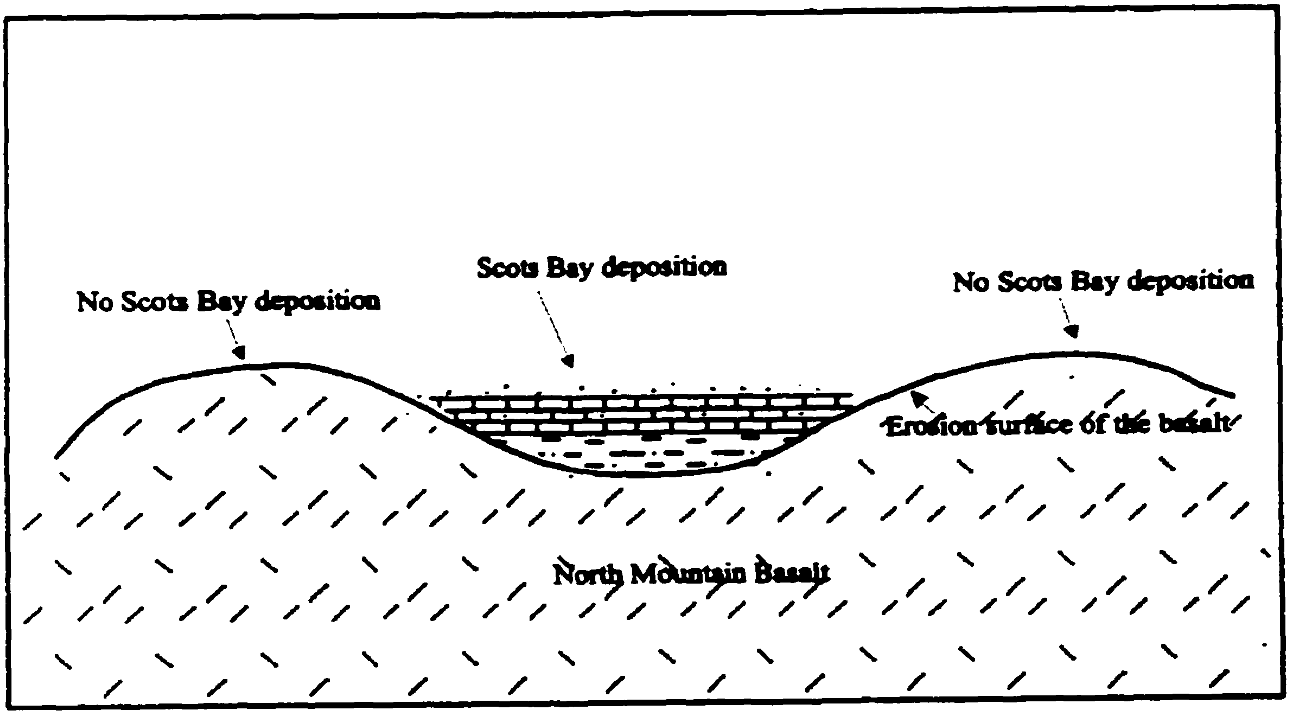


Figure 4-1. Paleogeographic model showing the irregular erosional surface between the North Mountain Basalt and the Scots Bay Formation which caused the deposition to occur in paleotopographic low areas.

North Mountain Basalt. These high basalt areas would have been small islands or peninsulas emerged above the lake level. This interpretation may explain why the stratigraphy of some beds in one cove (low area) do not match exactly those in other coves. Paleo-coastal lacustrine environments would have been diverse and changeable over short distances, e.g., 1-2 km, as today.

The McCoy Brook Formation with its complex facies along the north shore of the Bay of Fundy was deposited after early post-basalt tectonism associated with crustal adjustments following volcanism (Wade and others, 1996). However, the Scots Bay Formation, appears to have been deposited earlier on a relatively more uniform depositional surface. Then, it was deformed by minor folding during this early post-basalt tectonism.

4.3 ROCK CLASSIFICATIONS

Most of the carbonate rocks of Scots Bay Formation contain appreciable amounts of siliciclastic minerals; therefore, it is not easy to name these rocks. Different authors tend to give different rock names for the same sample.

Both sandstones and siltstones are classified here according to the sandstone nomenclature of Folk (1954). The carbonate rocks in this thesis are classified according to both Folk's (1959, 1962) classification, which emphasizes allochems, matrix (micrite) and cement (sparite), and Dunham's (1962) classification, which emphasizes rock textures and fabrics. The use of these carbonate and clastic classifications provides more informative descriptive terms and names than one classification alone because, compositionally, most rocks of Scots Bay Formation contain a mixture of both carbonate and clastic materials. The term argillaceous is used sometimes to indicate a rock that contains appreciable amounts of clay minerals. Compounding the difficulties in classifying and naming these rocks is the fact that they are often secondarily silicified due to early diagenetic alteration.

4.4 DESCRIPTION OF STRATIGRAPHIC SECTIONS

Eight general types of rock units have been recognized from all of the outcrops of the Scots Bay Formation (Table 4-1). Field macroscopic and thin-section microscopic descriptions of the lithologies from each of 6 coves were made to determine lateral and vertical facies changes.

4.4.1 Davidson Cove: This outcrop is the most northeasterly section, occurring at latitude 45° 16′ 25″ N, longitude 64° 24′ 25″ W. The lower part of this outcrop is chertified with vertical and horizontal bands and veins (Fig. 4-2). On the west side of this outcrop, a chert bed lies directly over the basalt. In some places chert dikes penetrate vertically from the underlying basalt up through the lower siliciclastic beds of the Scots Bay Formation.

Sandstone is the dominant rock type in this section (Fig. 4-3). The bottom bed is usually 20 cm of green, moderately to well-sorted, sandy siltstone that contains fine-grained, chert nodules. Above this bottom bed, there is a 55 cm thick, brown to red chert layer. Interbedded brown and green (chloritic?), calcareous sandstone interbeds occur over the next 45 cm. They contain detrital chert fragments. Next, there is a 135 cm thick brown and red chert bed that is massive and very hard whose thickness varies along the outcrop. This chert is overlain by 75 cm of light green and brown subarkosic sandstone that is medium-grained, thick bedded, and soft. It contains calcite and chert fragments. This sandstone grades upward into 72 cm of calcareous sandstone that is laminated and contains desiccation cracks. Its calcite content increases upward. Seventy centimeters of chertified limestone with silicified wood fragments occur over this calcareous sandstone. Calcareous sandstone (40 cm) reappears above the cherty limestone and grades upward into brown, litharenitic, moderately soft sandstone.

4.4.2 East Broad Cove: This outcrop is located about 2 km southwest of Davidson Cove. The bottom unit in this section is 50 cm of very fine-grained argillaceous silty sandstone (Fig. 4-4). It contains burrows, ripple-lamination, chert and chloritized volcanic clasts. In thin section, it contains biotite, partly porphyritic volcanic fragments, and detrital chert, suggesting closeness to a volcanic source rock. Above the bottom bed, there are 52 cm of bioclastic silty sandy limestone. This limestone is partly silicified and has volcanic clasts

Lithostratigraphy	Constituents	Sedimentary structures
(Top)		
Feldspathic, litharenitic sandstone unit	calcitic clasts, with common feldspar, mica and dark grains, some clay matrix	low-angle cross-stratification, ripple marks, desiccation cracks, rare dinosaur footprints
Wackestone-packstone unit	mudstone-wackestone texture, micrite, partly recrystallized, silica replacing spar	
Conglomeratic sandstone unit	pebbles composed of quartz and feldspar, with mica and chlorite, calcite and chert fragments.	
Stromatolitic calcareous sandstone unit	laterally linked hemispheroidal silicified stromatolites, peloids, common biotite	fine horizontal lamination
Bioclastic calcareous sandstone unit	chert, micrite recrystallized to microspar, cemented with calcite spar, pellets	desiccation cracks
Bioclastic, silty, sandy limestone unit	calcite, feldspar, quartz and mica grains, phosphatic clasts, some sparry cement	horizontal laminations with wavy pattern, desiccation cracks
Silty sandstone unit	fine silty sandstone, clayey materials, Chloritized volcanic clasts	fine horizontal lamination burrowed and bioturbated
(Bottom)		

Table 4-1. Summary of major lithostratigraphic units of Scots Bay Formation.

Figure 4-2. Chertification (light pink) of the lower part of the sequence in Davidson Cove. Dark green is basalt. Length of notebook is 17.8 cm.

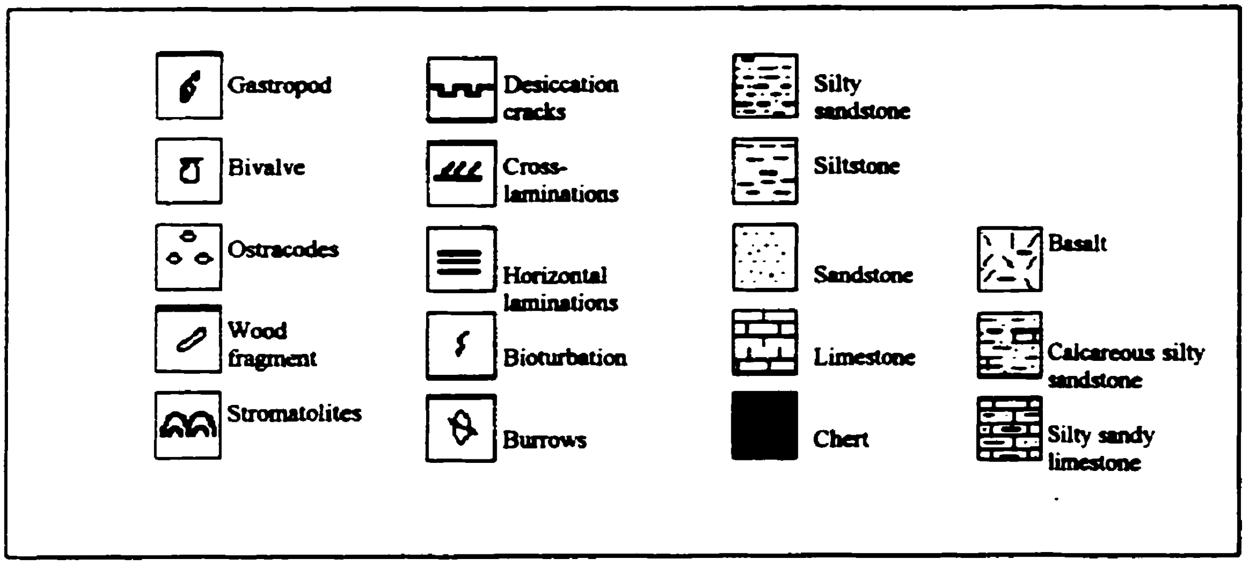


Table 4-2. Key symbols used in stratigraphic section of this chapter.

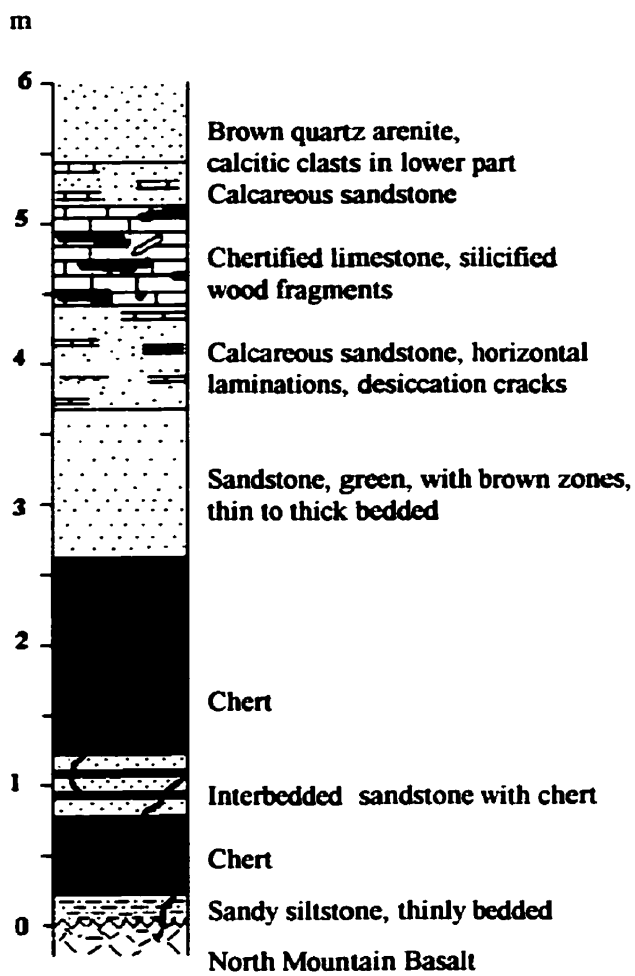


Figure 4-3. Stratigraphic section of the Scots Bay Formation at Davidson Cove.

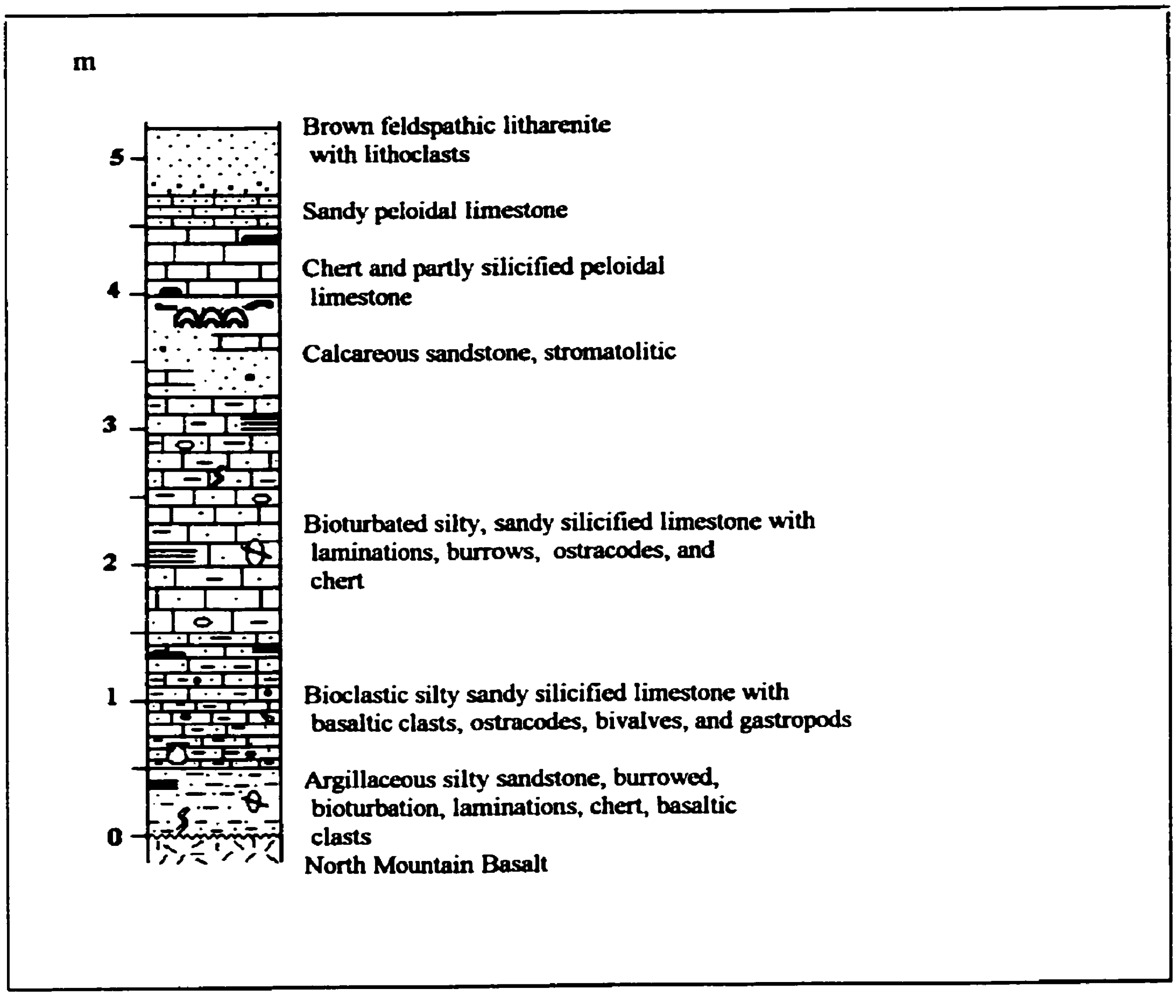


Figure 4-4. Stratigraphic section of the Scots Bay Formation at East Broad Cove.

present along with some ostracodes, gastropods and bivalves and peloids. The next unit above is the most common unit in all the outcrops of the Scots Bay Formation. It is 225 cm of partly silicified, silty sandy, bioturbated limestone. In thin section, very low contents of phosphatic and organic materials were observed. Fracture voids are filled with chemically precipitated silica and/or sparry calcite. The upper part of this unit grades into thinly laminated, very fine-grained calcareous silty sandstone and the silicification decreases. The next 65 cm is composed of calcareous stromatolitic subarkose, containing brown chert bands and nodules. Peloids are common. Above this stromatolitic unit, there are 52 cm of sandy peloid-bearing limestone which contains chert nodules and partly silicified peloids. The top of the sequence is composed of 45 cm of brown feldspathic litharenitic sandstone that contains calcitic fragments and chert detritus in the lower part.

4.4.3 Central Broad Cove: The Central Broad Cove outcrop is located between East Broad Cove and West Broad Cove (Fig 1-1). This cove was recommended for the type section of the Scots Bay Formation by Thompson (1974), as none was designated by Powers (1916). This section was measured from the west side of the cove (Fig. 4-5).

The bottom bed is 95 cm of partly silicified fine-grained limy sandy siltstone. Green, massive fractures are filled with silica. In thin section, this silt is micaceous and contains chloritized volcanic eroded clasts from the North Mountain Basalt. This unit is probably laterally equivalent to the bottom unit in East Broad Cove. One hundred and ten centimeters of bioclastic silty sandy limestone occurs above this basal unit. It is moderately

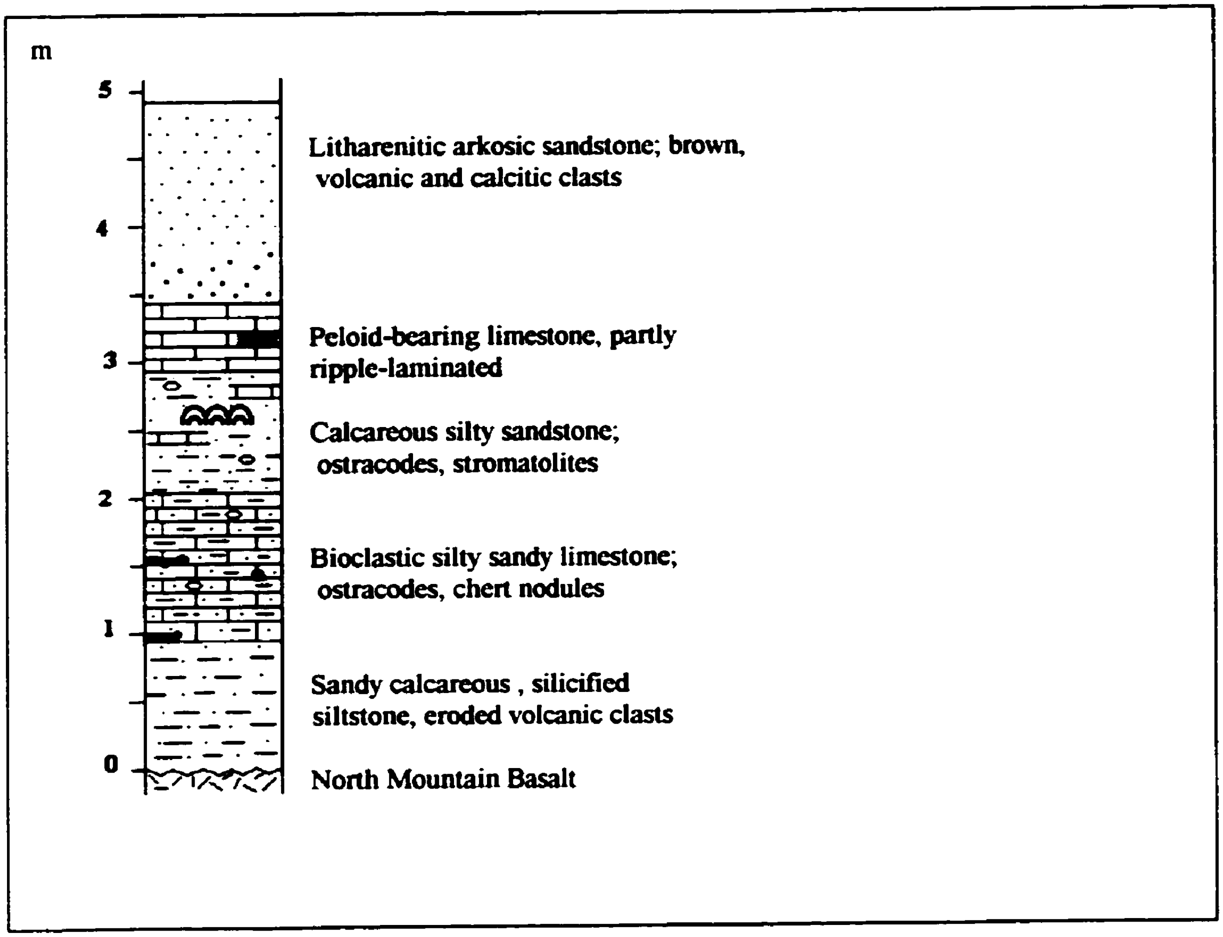


Figure 4-5. Stratigraphic section of the Scots Bay Formation at Central Broad Cove.

to well-sorted and very fine to medium grained. This unit contains pelloids, lithoclasts chert, geothitic grains, and silicified fossil fragments in a framework of grains composed mainly of quartz and feldspar. Ostracodes are common. The next 87 cm is composed of stromatolitic, green, laminated calcareous silty sandstone. This sandstone is litharenitic arkose, well-sorted and very fine to medium-grained. The next unit encountered upward is 45 cm of peloid-bearing limestone. It contains finely crystalline carbonate with mudstone-wackestone texture. Quartz and feldspar grains are common and ostracodes are present. This limestone is partly ripple-laminated, and partly recrystallized. The upper unit in this outcrop is 150 cm of brown sandstone which is similar to the top beds in Davidson and East Broad coves. Large blocks (1-2 m^3) of this massive brown sandstone from the top of the outcrop have collapsed and fallen down on to the intertidal basalt surface. The lower part (56 cm) of this sandstone is moderately-sorted, coarse-grained litharenitic arkose with calcite fragments and some clay matrix. The dark grains are partly goethitized. The top part of this unit is similar to the lower part, but it lacks the calcite lithoclasts.

4.4.4 West Broad Cove: Quaternary soil and trees slumping from the top have covered most of this outcrop. This section (Fig. 4-6) was measured at the middle of the east side of the cove. The basal bed lies directly over the North Mountain Basalt and is composed of 53 cm of stromatolitic, burrowed and bioturbated, thinly bedded, silty, sandy argillaceous, partly bioclastic limestone. Thin wispy micaceous and silty clay intercalations are present. Locally, it is silicified. The next unit is 70 cm of partly chertified, ostracode-bearing

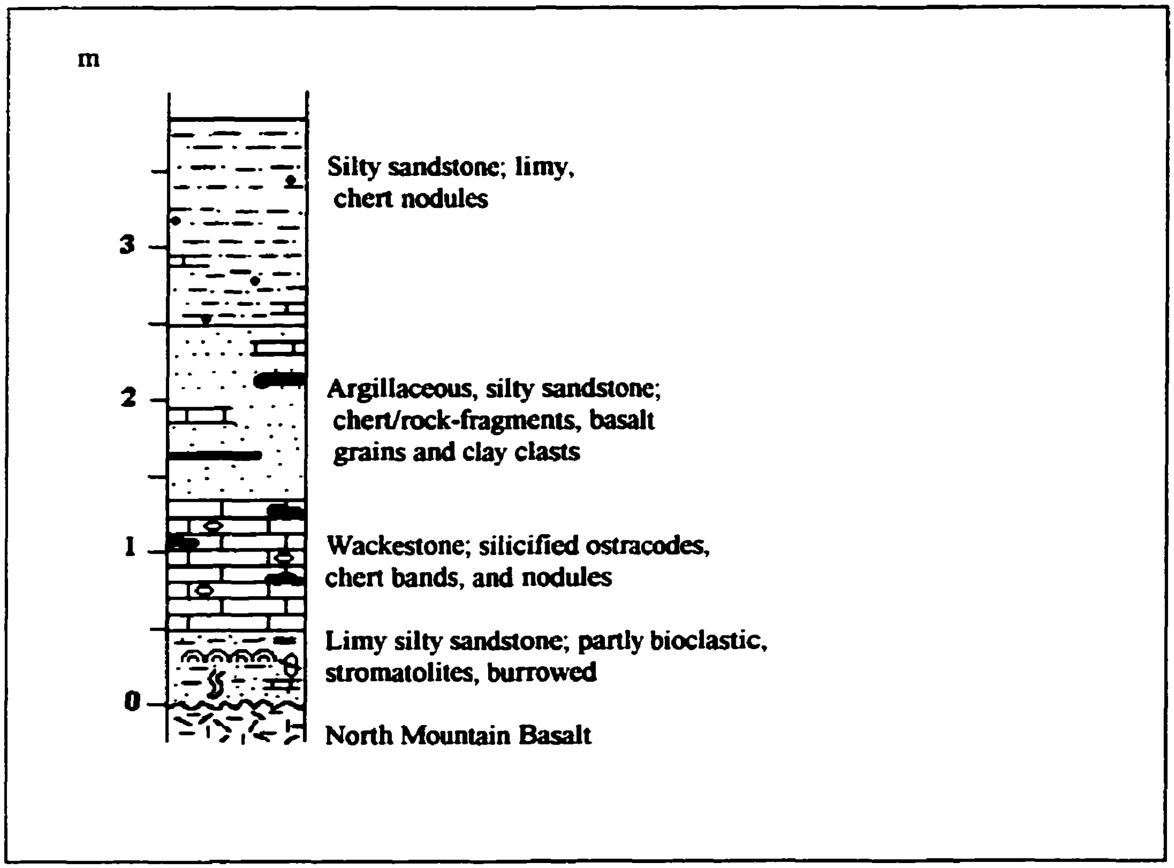


Figure 4-6. Stratigraphic section of the Scots Bay Formation at West Broad Cove.

wackestone. Ostracode shells are relatively common and some are filled with microcrystalline quartz. Above this unit, there are 120 cm of argillaceous silty arkosic sandstone which is well-sorted and very fine to medium-grained. The framework is composed of quartz and feldspar grains accompanied by mica, chert fragments, rock-fragments, basaltic grains, and clay clasts. Partly chloritized clay forms the matrix. Locally, there are concentrations of patchy diagenetic sparry cement. The top unit of this section is 120 cm thick. Overall, it resembles the underlying unit, but it is less calcareous and more siliciclastic, being a silty sandstone with some lime mud and chert nodules. The framework is dominated by fine quartz, feldspar, and mica grains. The brown sandstone that caps other outcrops is not exposed here, but eroded cobbles and boulders of it have been observed in the past (Cameron, pers. comm., 1999).

4.4.5 Lime Cove: This well-exposed outcrop is located northeast of Woodworth Cove (Fig. 1-1). About four meter of an alluvial channel-like shape is a special feature at the base of this section (Fig. 4-7) which is located at the middle-west side of the cove. It is filled with 95 cm of sandstone which is poorly cemented, moderately well-sorted fine-grained and contains subangular quartz grains, an argillaceous, ferrous oxide matrix, basaltic clasts and scattered mica flakes. The next unit is 85 cm of burrowed and bioturbated, argillaceous, silty sandstone that is well-sorted, and fine-grained with interbedded bands of thin (6 cm), red to purple shale. The framework grains of this sandstone are mainly composed of quartz and feldspar grains associated with mica,

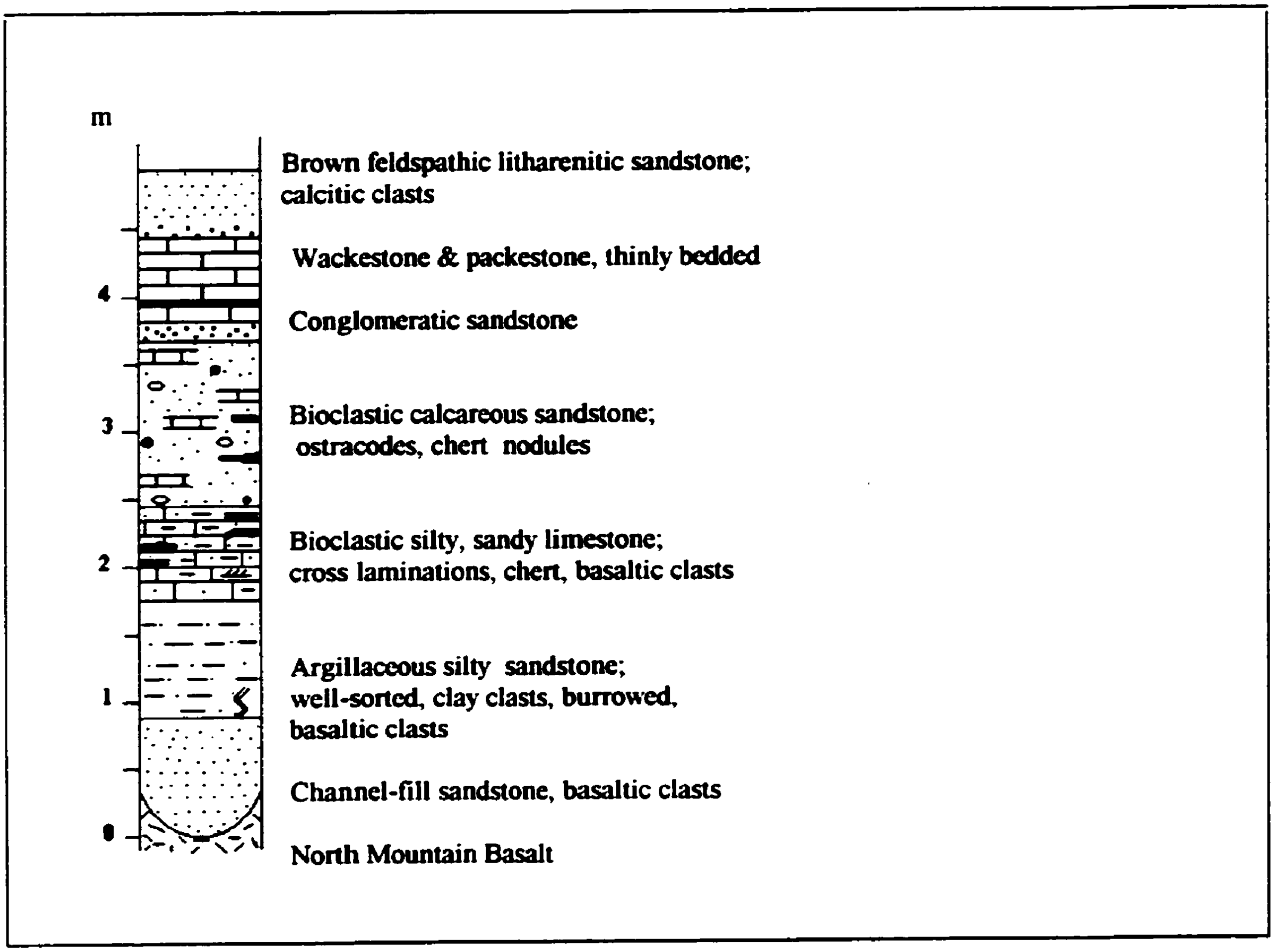


Figure 4-7. Stratigraphic section of the Scots Bay Formation at Lime Cove.

chlorite, and partly goethitic shreds of clay clasts.

The next 70 cm are indistinctly laminated or cross-laminated, bioclastic, silty, sandy limestone. It is moderately to well-sorted, very fine- to medium-grained and contains rock fragments, chert, mica and basaltic clasts. Phosphatic clasts and ostracodes are present. This unit is overlain by 130 cm of a bioclastic, calcareous sandstone that is thinly bedded, moderately sorted, and cemented with recrystallized sparry calcite. The bioclastic materials are mainly ostracode fragments. Chert nodules are common (Fig 4-8). Next, there are about 25 cm of conglomeratic arkosic sandstone that contains calcitic fragments. The next unit upward is 55 cm of thinly bedded wackestones and packstones. This limestone is the purest limestone found in the Scots Bay Formation. The top unit is 60 cm thick and composed of brown, feldspathic litharenitic, moderately to well-sorted sandstone with calcitic clasts and horizontal and cross-laminations. Its contact with the underlying limestone is very sharp.

4.4.6 Woodworth Cove: Woodworth Cove contains the most southwesterly outcrop of the Scots Bay Formation. Rocks in this section are not well exposed and soil now covers much of the east side. The section in Figure 4-9 was measured from the west side of the cove. The basal unit, which lies directly over the top of the North Mountain Basalt, is composed of 125 cm of green, silty, cherty, clayey, sandstone with little calcium carbonate. Brown and red chert bands and nodules occur scattered throughout this unit.

Figure 4-8. Chert nodules are common in the bioclastic limestone units of the Scots Bay Formation at Lime Cove.

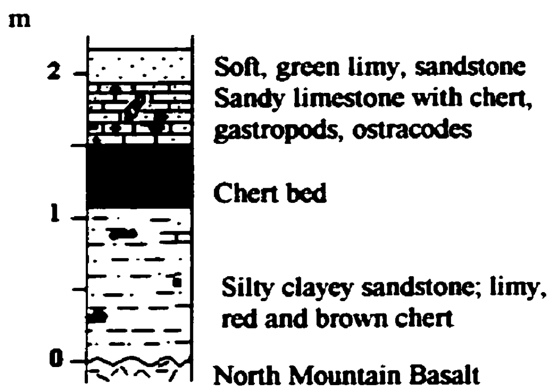


Figure 4-9. Stratigraphic section of the Scots Bay Formation at Woodworth Cove.

The next 40 cm is composed of massive brown chert. Overlying this chert are 44 cm of light green, thinly bedded sandy limestone, containing abundant silicified ostracodes, microgastropods and small clams. The top unit is about 30 cm of soft, green, limy, cherty sandstone. For more details see Figure 4-9.

4.5 SEDIMENTARY FACIES AND DEPOSIONAL ENVIRONMENTS

4.5.1 Introduction

Up to seven meters of cherty, green and white, calcareous sandstones were deposited in and around an Early Jurassic shallow lake (or lakes) on the top of the weathering and eroding North Mountain Basalt. Today, these strata comprise the Scots Bay Formation along part of the south shore of the Bay of Fundy between the village of Scots Bay and Baxters Harbour.

The Scots Bay Formation is composed of different types of lithofacies in which siliciclastics dominate. These clastic sedimentary rocks consist of quartz and feldspathic, often immature, sandstone, sandy siltstone, conglomeratic sandstone, and silty sandstones. The sandstones are mainly thinly bedded, fine to medium-grained, and light gray to green except those at the top which are brown. The silty and clayey sandstones are green and purple, thinly laminated, burrowed and occur as the basal unit in most sections. They grade upward into silty and sandy limestone. The carbonate rocks consist of calcareous sandstones, packstone, wackestones, and mudstone-wackestones. The limestones are thin to thick-bedded and thinly laminated, white and greenish gray, peloidal, stromatolitic, and often replaced by chert. Chert bands and jasperoid nodules are common.

Four main sedimentary facies are recognized: 1) Fluvial marginal channel facies; 2) Shoreline facies; 3) Nearshore facies (lower high energy and upper low energy);

4) Offshore facies (Fig. 4-10). The lake margin was composed of three facies: shoreline, nearshore and fluvial marginal channel facies. The nearshore facies is the most extensive facies in the Scots Bay Formation and can be subdivided into higher energy ana a lower energy subfacies. The shoreline facies and fluvial channeled sandstone occur only in certain outcrops. In general, the Scots Bay lacustrine facies are interpreted to have been deposited in littoral and sublittoral lacustrine environments.no evidence for profundal deposition was found in outcrop.

4.5.2 MARGINAL CHANNEL FACIES

The lowest unit at the middle-west side of Lime Cove is composed of about 95 cm of moderately sorted, mixed coarse to fine subarkosic sandstone with pebble and cobble clasts mainly composed of basalt fragments. Feldspar and quartz grains are common. This sandstone unit becomes finer upwards and is indistinctly laminated and cross-laminated. It contains purple and green bands that terminate against the basalt to the northeast. This U-shaped channel-like deposit strikes about N 55 W. Sieve analysis of this semi-consolidated unit by Thompson (1974) indicated mean diameters of 3.42 ∅ and 0.260 ∅ and standard deviations of 0.91 ∅ and 1.61 ∅, corresponding to normal channel sands (Pettijohn, 1957; Blatt and others, 1972).

The basalt fragments may indicate subaerial erosion of nearby paleooutcrops of basaltic lava flows. Pebbles and cobbles in the coarse-grained sandstones may represent

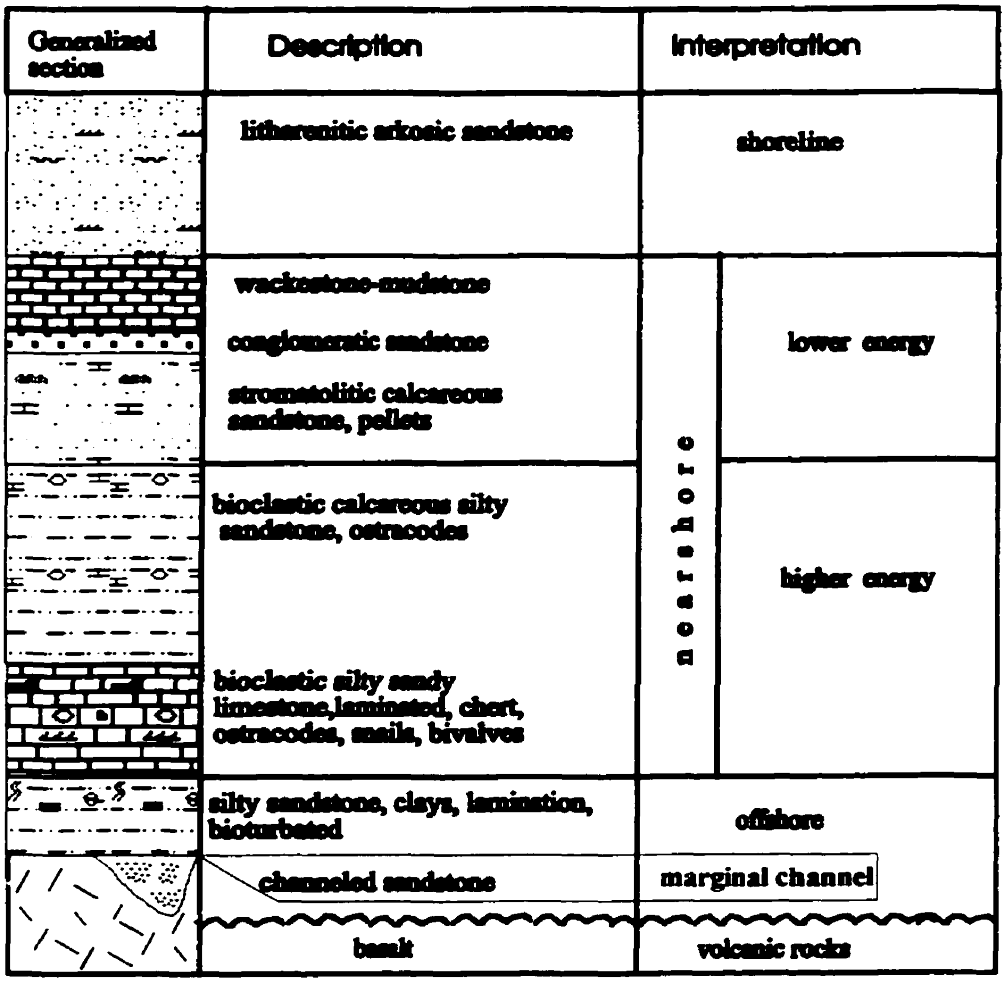


Figure 4-10. Major characteristic features of the environmetnal facies of the Scots Bay Formation.

lag conglomerates deposited in the channel (Fig. 4-11). In fluvial channel and point bar deposits, the lowest bed is coarse-grained sandstone that may contain basal pebble lag deposits, the basal contact is sharp, and sandstones become thin-bedded and finer grained upward (Pettijohn 1975). This facies is interpreted as a channel-fill deposit that may have been associated with a meandering stream.

4.5.3 OFFSHORE FACIES

This facies is represented by a silty sandstone unit that occurs at the base of most sections. Klein (1962) described these basal beds as green and purple claystone overlain by thin-bedded greenish-gray fine-grained limestone. In thin section, the framework grains are dominated by quartz and feldspar with small amounts of micas, chlorite, and goethite grains. This thinly laminated siliciclastic unit rests with erosional contact upon dark greenish basalt of the North Mountain Basalt Formation from which it derives a significant number of dark basaltic grains. This facies consists of horizontally laminated (Fig. 4-12), very fine silty sandstone, claystone, and mudrock in East Broad Cove and West Broad Cove. Burrowing is found in Lime Cove (Fig. 4-13). In some places, such as in Lime Cove, there is a thin layer of paleosol on the North Mountain Basalt underlying the Scots Bay Formation.

Basal sediments in lakes are likely to be sand, silt and clay derived from erosion of bedrock in the drainage basin (Fouch and Walter, 1982). The presence of very fine

Figure 4-11. At Lime Cove, the channel-fill sandstone at left rests directly on the eroded top of the Northern Mountain Basalt at right. Scale is hammer at contact (lower left).

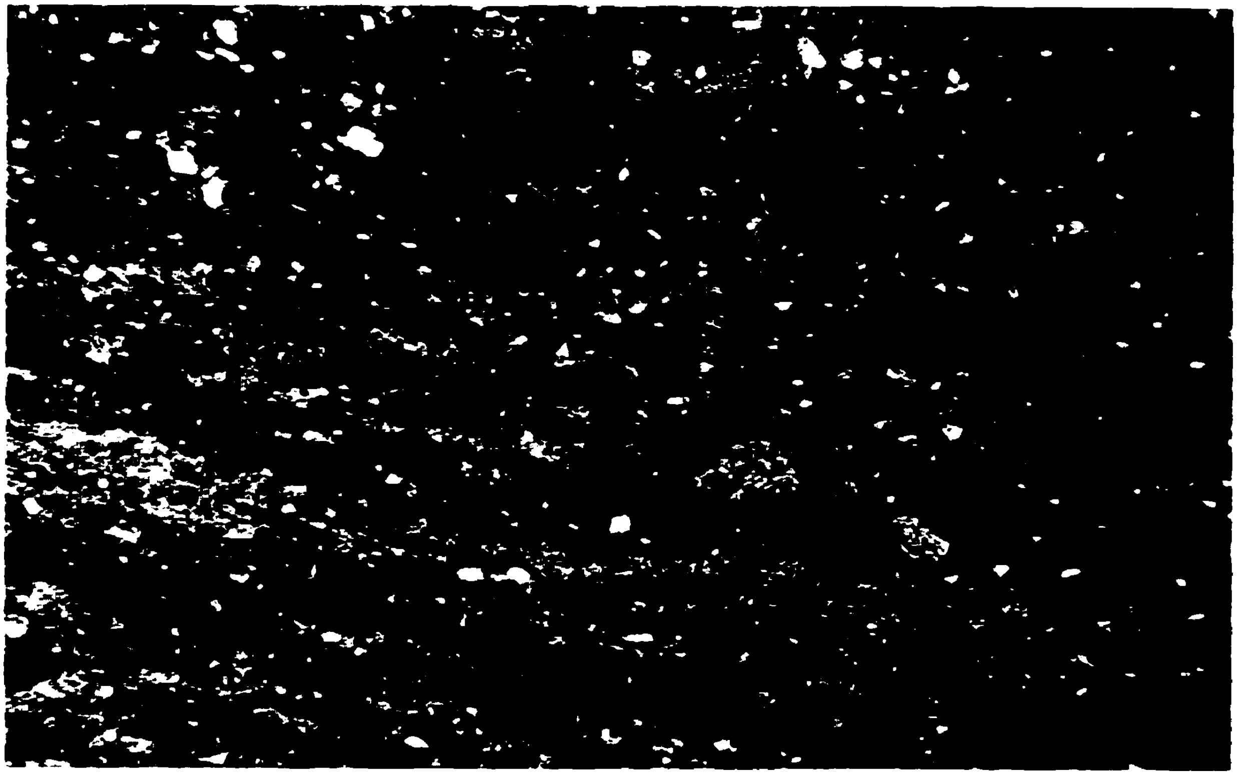


Figure 4-12. Photomicrograph of argillaceous silty sandstone from the offshore facies at West Broad cove, showing thin horizontal laminations. Crossed polars, width of field is 2.5 mm.

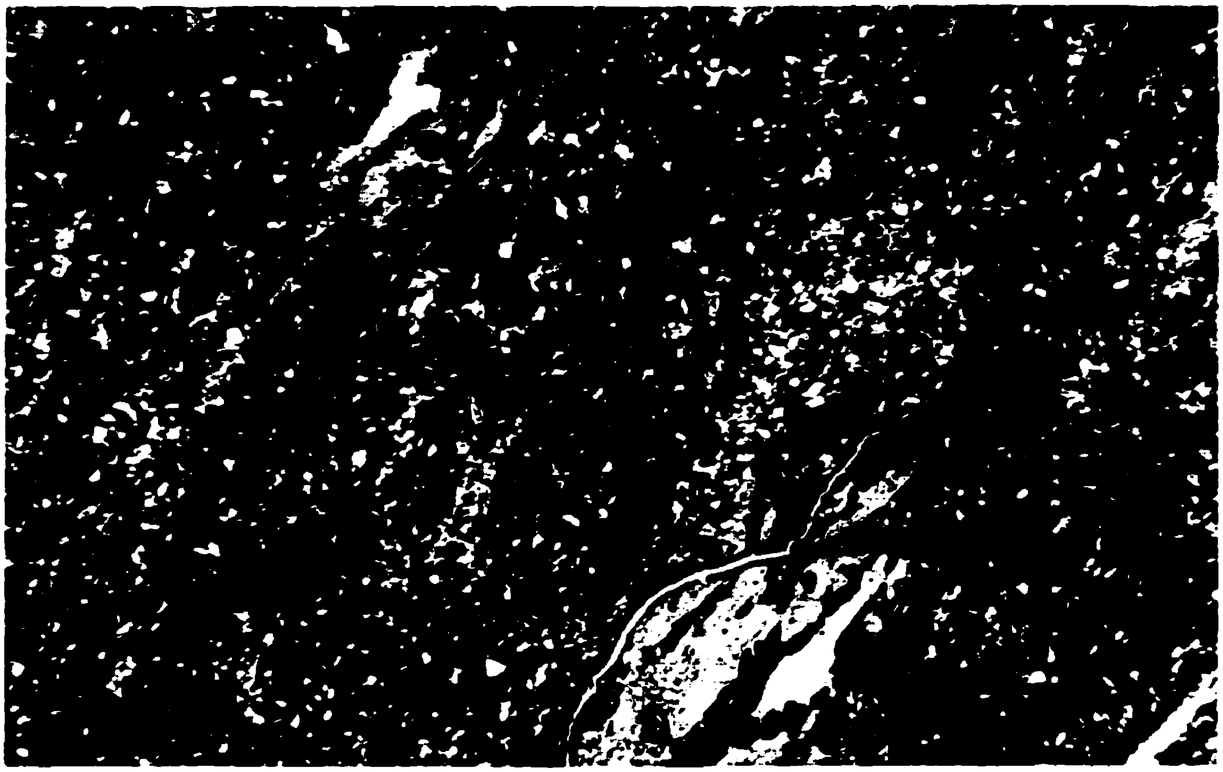


Figure 4-13. Photomicrograph of argillaceous silty claystone from the offshore facies at East Broad Cove, showing burrows and bioturbation. Crossed polars, width of field is 2.5 mm.

materials, such as claystone, suggests that deposition involved settling of at least some suspended material in a low energy environment. Coarser clastics may have been introduced during lake-level lowstands (seasonal ?).

This fine sandy claystone and silty sandstone deposition with no evidence of agitation may have occurred in an offshore environment during an influx of fine siliciclastic sediments. The presence of burrows indicate that the bottom waters and sediments were oxic (well oxygenated). Such conditions would account for the lack of organic rich shales in the offshore facies and imply that the Scots Bay lake was shallow rather than deep in the area of exposure.

4.5.4 NEARSHORE FACIES

The nearshore facies is the most extensive facies in the Scots Bay Formation; it can be found in all the cove exposures. This facies is a mixed carbonate and siliciclastic unit and is conveniently subdivided into two subfacies: the higher energy nearshore subfacies and the lower energy nearshore subfacies.

The higher energy nearshore facies consists of bioclastic, laminated, silty, sandy, peloidal limestones and calcareous sandstones. It contains desiccation cracks, horizontal laminations, rock fragments and chert. Scattered oolite grains occur in this facies, but they are not common.

The lower energy nearshore subfacies, which is the upper subfacies of the nearshore facies, is micrite dominated. It consists of a wackestone-packstone unit and a stromatolitic unit.

The nearshore facies in the Scots Bay Formation contains a higher percentage of carbonate than the offshore and shoreline facies. This is probably because of higher production rates of calcium carbonate in shallow, nearshore environments. The presence of calcareous fossils, such as ostracodes, mollusks and calcareous algae, may be the major carbonate source in this nearshore facies. Fossils in this nearshore facies of the Scots Bay Formation include gastropods represented by *Hydrobia, Valvata,* and *Gyraulus* and ostracodes represented by *Darwinula, Timiriasevia* and *Metacypris*. A giant ostracode and a small bivalve have been discovered in this study. Cameron (1986) suggested that the Scots Bay Formation probably represents a nearshore carbonate facies based on its faunal assemblage.

A decreasing siliciclastic sediment supply to the lake would allow the development and preservation of carbonate sediments, such as stromatolites and microbial mats in nearshore facies of an alkaline lake. Calcareous silts and silty sands in Lake Tanganyika are formed at depths between 0 and 10 m on nearly flat, broad, nearshore shelves (Cohen and Thuin, 1987). The nearshore facies in the Scots Bay Formation is a fining upward sequence with cessation of terrigenous sedimentation at the top. The initiation of fine-grained carbonate deposition in the upper subfacies suggests a transgression. The presence of stromatolites and charophytes indicates a shallow photic zone nearshore environment.

4.5.4.1 Higher energy nearshore subfacies

This higher energy nearshore facies consists of two units: a lower laminated bioclastic silty sandy limestone unit and a bioclastic calcareous sandstone unit.

4.5.4.1.1 Laminated bioclastic silty sandy limestone unit:

This laminated bioclastic silty sandy limestone is moderately to well-sorted and fine- to medium-grained. It contains peloids, lithoclasts, goethitic grains, and silicified fossil fragments while its framework grains are mainly composed of quartz and feldspar. Burrowing is absent. Ostracodes and calcareous algae occur in this facies, particularly at East Broad Cove. Phosphatic clasts also have been observed in thin section from Lime Cove which are probably from fish bones and teeth.

The horizontal laminations have a wavy pattern. There are two possible ways that the laminations formed: 1) due to seasonal changes or 2) due to variation in currents. In general terms, the rainy season is a flood time for lakes. On the other hand, dry seasons are times of low water level when lakes receive no sediments or thin deposits of fine materials. A change in current direction or velocity could bring in and cause the deposition of different sediments.

These calcareous laminae may have been deposited on a lake floor with a very shallow, as indicated by some lime mud. This may have occurred during the summer season when shallow and warm waters provided appropriate conditions for algal blooms to increase the pH and to precipitate limestone. Inorganic carbonate precipitation may have occurred in this warm water or have resulted from mixing with Ca-rich inflow. The clastic laminae were possibly generated during periods of high water discharge, such as rainy seasons, when stream velocities were higher. Deposition of sand laminae in this unit may have occurred under these conditions.

4.5.4.1.2 Bioclastic calcareous sandstone unit:

Calcareous silty fine- to medium-grained sandstones with grainstone texture, sparry cement, burrows occur in this unit, especially at East Broad Cove. In thin section, they contain peloids, replacement chert and evidence of local recrystallization from micrite to microspar (Fig. 4-14). Desiccation cracks are found in Woodworth Cove and Davidson Cove as well as silicified wood fragments. Fragmented ostracodes are common.

This unit may represent a shallow environment over which a slight transgression may have caused relatively deeper conditions to develop in comparison to the laminated unit below.

The distribution of the peloids seems to be related to the stromatolites and calcareous algae in that they occur within and below the stromatolitic unit. The peloids, by virtue of occurring in stromatolitic crusts, are interpreted as probable microbial products (Sun and Wright, 1989).

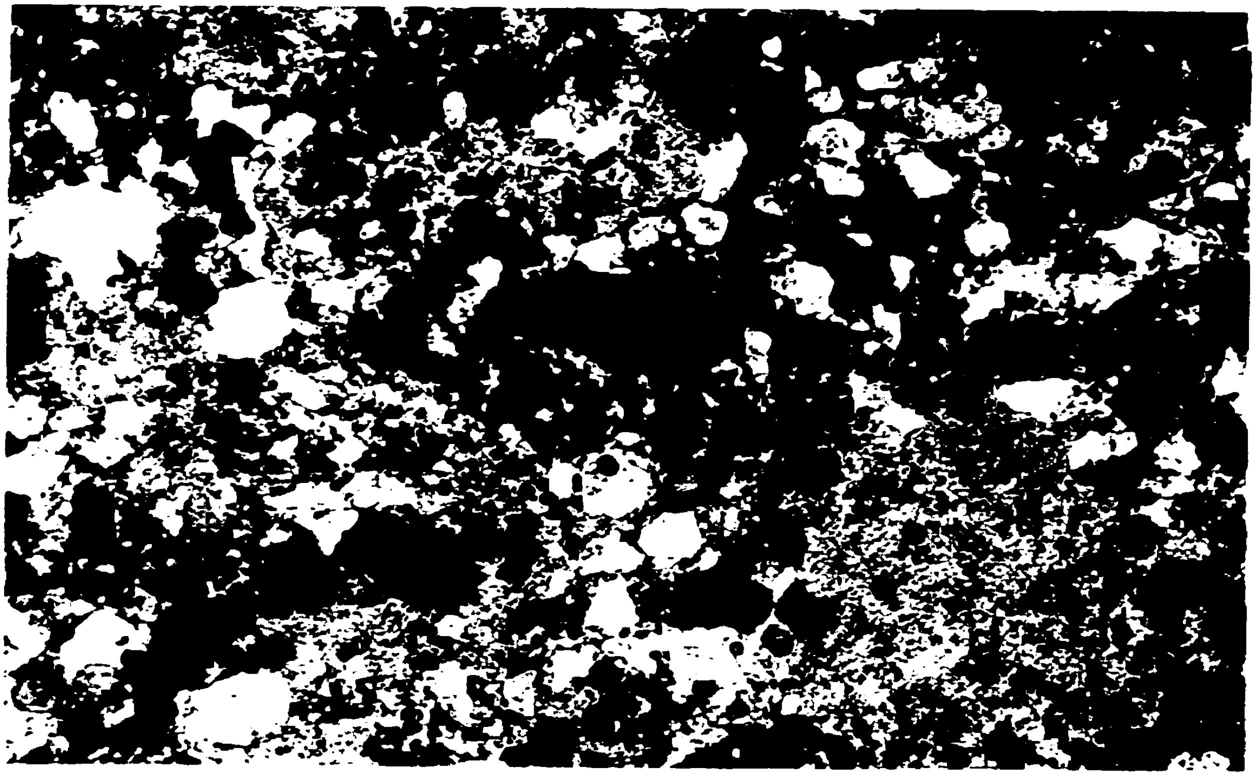


Figure 4-14. Calcareous sandstone from the higher energy nearshore subfacies at Lime Cove. Crossed polars, width of field is 4 mm.

Similar horizontal laminations and lithologies have been reported from the Pliocene Edge Basin Group (Martin and Robert, 1978) and from recent Lake Tanganyika (Cohen and Thuin, 1987) where they occur in lacustrine nearshore environments. The presence of silicified wood fragments and desiccation cracks in Davidson Cove along with appropriate lithologies suggests subaerial exposure and shallow nearshore environments.

4.5.4.2 Lower energy nearshore subfacies

The lower energy nearshore subfacies of the Scots Bay Formation occurs where the nearshore grain-supported carbonates and siliciclastic units grade into nearshore mud-supported carbonate units with decreasing clastic content. This subfacies consists of a lower calcareous stromatolitic silty sandstone unit and an upper fine-grained carbonate unit. A local conglomeratic sandstone unit separates these two units at Lime Cove.

4.5.4.2.1 Stromatolitic unit:

The laterally-linked hemispheroidal (LLH of Logan, and others, 1964) stromatolitic fine calcareous sandstone zone in the Scots Bay Formation ranges from 30 to 60 cm thick. It occurs above the bioclastic calcareous silty sandstone unit and is overlain by the carbonates of the wackestone-packstone unit. The Scots Bay stromatolites are highly silicified and characterized by alternating light and dark fine laminae (Fig. 4-15). They may have been formed by the trapping and binding of fine sediments by filamentous

Figure 4-15. Hand specimen of stromatolites (LLH) characterized by alternating light and dark fine laminae from the lower bed at West Broad Cove.

cyanobacteria. They are composed of a series of small domes or hemispheroids (Fig. 4-16) stacked upon each other. Dark, very fine, argillaceous sediments occur in the darker laminae. The calcareous sandstones are well sorted, very fine to medium-grained, and contain peloids and biotite.

The fine grain size and fine laminations suggest a relatively quiet environment. Logan and others (1964) also suggested a relatively quiet depositional environment for LLH stromatolites. There are no stromatolites in the upper unit of this facies, suggesting a relatively deeper environment for the overlying fine-grained limestone unit. A transgression may have occurred which would have deepened the lake waters.

The assumptions that stromatolites are restricted in modern marine environments to zones of hypersalinity and are associated in many ancient lake deposits with evaporites, marking periods or marginal zones of high salinity, needs to be carefully re-examined in the light of discoveries of modern stromatolites in low-salinity lakes (Reading, 1971). Demicco and Hardie (1994) described unlithified freshwater stromatolites in lakes immediately landward of the tidal flats of Andros Island (Monty, 1978; Monty and Hardie, 1976). In these very shallow lakes, fed entirely by rainwater, mats drape mudcrack polygons in underlying layers to produce laterally-linked, hemispherical stromatolites.

The Scots Bay stromatolites have some environmental and morphological similarities with the recent freshwater stromatolites of Green Lake, New York. On the other hand,

Figure 4-16. Typical stromatolites of laterally linked hemispheroidal variety in West Broad Cove.

they are also similar in some respects to those described from lakes in the East African Rift system where stromatolites are formed from low-Mg calcite precipitated by green algae and bacteria. Stromatolites are common in lacustrine nearshore facies of the Pliocene Ridge Basin Group and are commonly associated with mollusks, ostracodes and plant remains (Martin and Robert, 1978). This association resembles that observed in the Scots Bay Formation.

4.5.4.2.2 Conglomeratic sandstone unit:

A green, coarse-grained conglomeratic sandstone about 25 cm thick occurs above the bioclastic calcareous sandstone unit (Fig. 4-10) in the low-energy subfacies of Lime Cove. About 20 percent of its volume is composed of subangular calcitic rock fragments and chert fragments. The framework is mainly composed of subrounded quartz grains and feldspar grains with small amounts of mica and chlorite. The coarse grained sands and the lack of fine-grained sediments suggest high energy conditions during deposition of this unit. The large fragments of limestone and chert may indicate a nearshore location close to a siliciclastic source area. This unusual bed is probably a storm deposit that transported coarse sediments and winnowed away the fines.

4.5.4.2.3 Wackestone-packstone unit:

The wackestone-packstone unit is thinly bedded, indistinctly horizontally laminated and consists of finely crystalline carbonate with a mudstone-wackestone texture (Fig. 4-17) that is partly recrystallized. It contains little terrigenous clastic material, such as quartz sand and silt. Red and brown chertified logs are present at Lime Cove (Fig. 4-8). The log sizes range from 3 cm to 35 cm in diameter. The dominant matrix material is micrite and no dolomite has been observed. This limestone is of uniform white color. Fossils include ostracodes, gastropods, and fish scales. Eastward from East Broad Cove (toward Davidson Cove) this unit is absent. Stratigraphically, the unit does not exhibit any gradational relationship with the overlying sandstone (Fig. 4-18).

Irregular patches of lighter sparry calcite cement occur in some samples. Silica replaces spar within micronodules that could have been former peloids in the wackestone at East Broad Cove.

The high proportion of fine matrix to grains in this unit and the absence of detrital minerals and rock fragments suggest either deeper, quieter water associated with a transgression or a paleogeographically protected coastal area, such as a bay.

4.5.5 SHORELINE FACIES

Up to 150 cm of thick, brown, massive, pebbly, medium to coarse-grained sandstones occur above the limestone unit at the top of the sections at Lime Cove, East Broad Cove, Central Broad Cove, West Broad Cove and Davidson Cove. This feldspathic, litharenitic sandstone contains truncated ripple marks associated with low-angle cross-

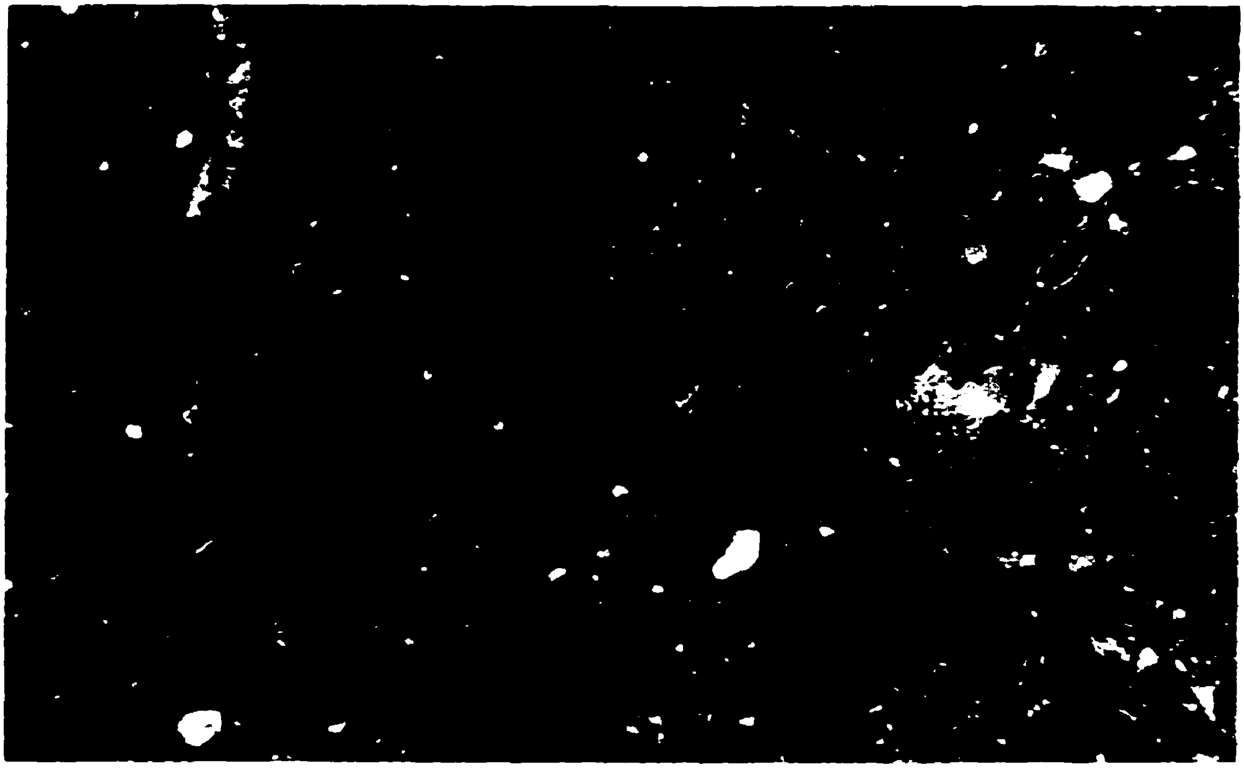


Figure 4-17. Photomicrograph of silicified wackestone which shows the mud supported texture associated with deposition in a nearshore, low-energy environment. Note the few patches being replaced by microcrystalline quartz. Crossed polars, width of field is 4 mm.

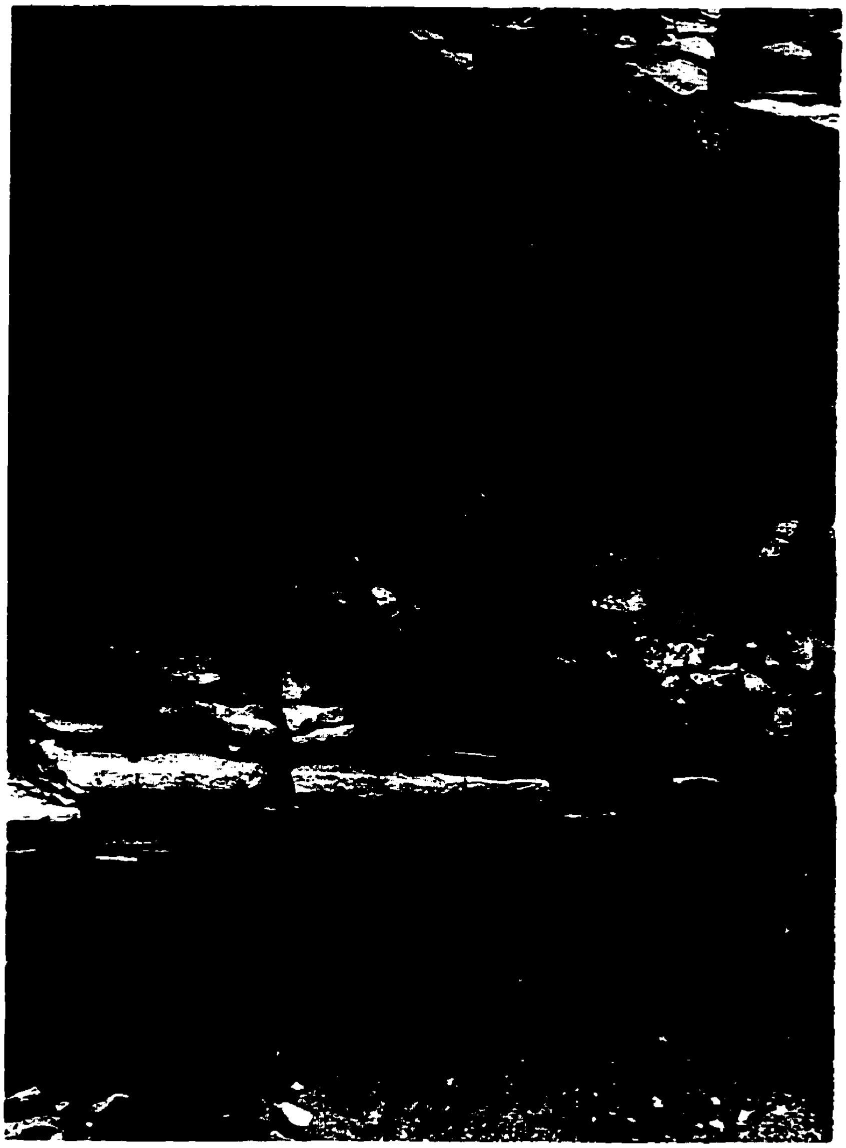


Figure 4-18. The diastem-like sharp contact between the shoreline sandstone (above) and nearshore limestone (below), suggesting a regressive sequence at the top of the Scots Bay Formation. Knife is scale.

stratification and horizontal laminations. Its grains are moderately to poorly-sorted, well rounded and not well packed. The common feldspars are mainly plagioclase and some microcline, while the rock fragments include limestone, chert and basalt. In thin section, it contains mica, unidentified dark grains, calcite lithoclasts in the lower part, quartz and some clay matrix. This hard, massively bedded sandstone exhibits a grain size decrease upward. Weathered, eroded blocks at the base of cliffs are characteristically cubic and huge. Fossil lacustrine snail shells were found in this unit by Cameron (pers. comm., 1998). The calcite lithoclasts are not found in the upper part because they are probably derived from the erosion of underlying limestones, indicating reworking processes.

High energy depositional conditions are suggested by the current structures in this facies. Its generally medium to coarse-grained and conglomeratic nature also suggests a high-energy environment. The contact between this sandstone and the underlying limestone is sharp (Fig. 4-18). Lacking evidence for an unconformity, a diastem is suggested for this sharp, lithologically contrasting contact between two parallel strata. Desiccation cracks and dinosaur footprints at the base of these sandstones (Cameron and Jones, 1988) suggest that subaerial exposure was routine during their deposition.

Similar features have been reported in beach-shoreface subenvironments of the Parachute Creek Member of the Green River Formation (Martin & Robert, 1978). The Parachute Creek contains sublitharenites, subarkoses, erosional surfaces, horizontal stratification and chert pebble conglomerates. Picard and High (1972) also suggested a beach-shoreface subenvironment for part of the Green River Formation where a cyclic sequence of nearshore deposits are separated by an indistinct boundary. Thompson (1974) considered this sandstone at Davidson Cove to represent a paleobeach environment. His interpretation was based on sieve analyses of disaggregated sediment.

The lower sharp contact, coarse sandstones, ripple marks, horizontal and low angle cross-stratifications, few fossils and abundance of lithoclasts indicate vigorous wave and/or current agitation and reworking processes within a high energy environment. These sedimentary structures along with the lithology may record longshore bar and beach sedimentation. Therefore, the author interprets this facies as a shoreline lacustrine beach environment.

4.5.6 LACUSTRINE DEPOSITIONAL MODEL

Studies of the depositional environments of the Scots Bay Formation are not common and detailed. For example, Thompson (1974) focused more on its stratigraphy and geochemistry, while Birney and Hubert (1989) were concerned mainly with the carbonate environments. The rocks of the Scots Bay Formation are thinly bedded, mixed siliciclastic and carbonate rocks that are essentially fine-grained in the lower parts and coarse-grained at the top. Their fossil content, sedimentary structures, and stratigraphic sequence provide adequate information to interpret their depositional environments .

Several lines of evidence indicate that the Scots Bay Formation formed in a freshwater and lacustrine environment; some are more compelling than others: 1) Freshwater fauna, such as ostracodes (e.g., *Darwinula*), charophytes, microgastropods and fish scale. 2) Facies pattern suggested by the deposition of offshore fine materials over almost the entire lake floor. 3) Regressive stratigraphic sequence which is indicated by the three main facies: lower offshore facies, nearshore facies and top shoreline facies (Fig. 4-10). 4) The association of an alluvial channel facies. 5) The lack of evaporites.

Figure 4-19 illustrates the three environmental facies and their depositional settings within Scots Bay Lake. Generally, the lacustrine environment of the Scots Bay Formation was composed of a core of offshore facies that grade shoreward into marginal- lacustrine facies (nearshore and shoreline facies) and alluvial channel facies.

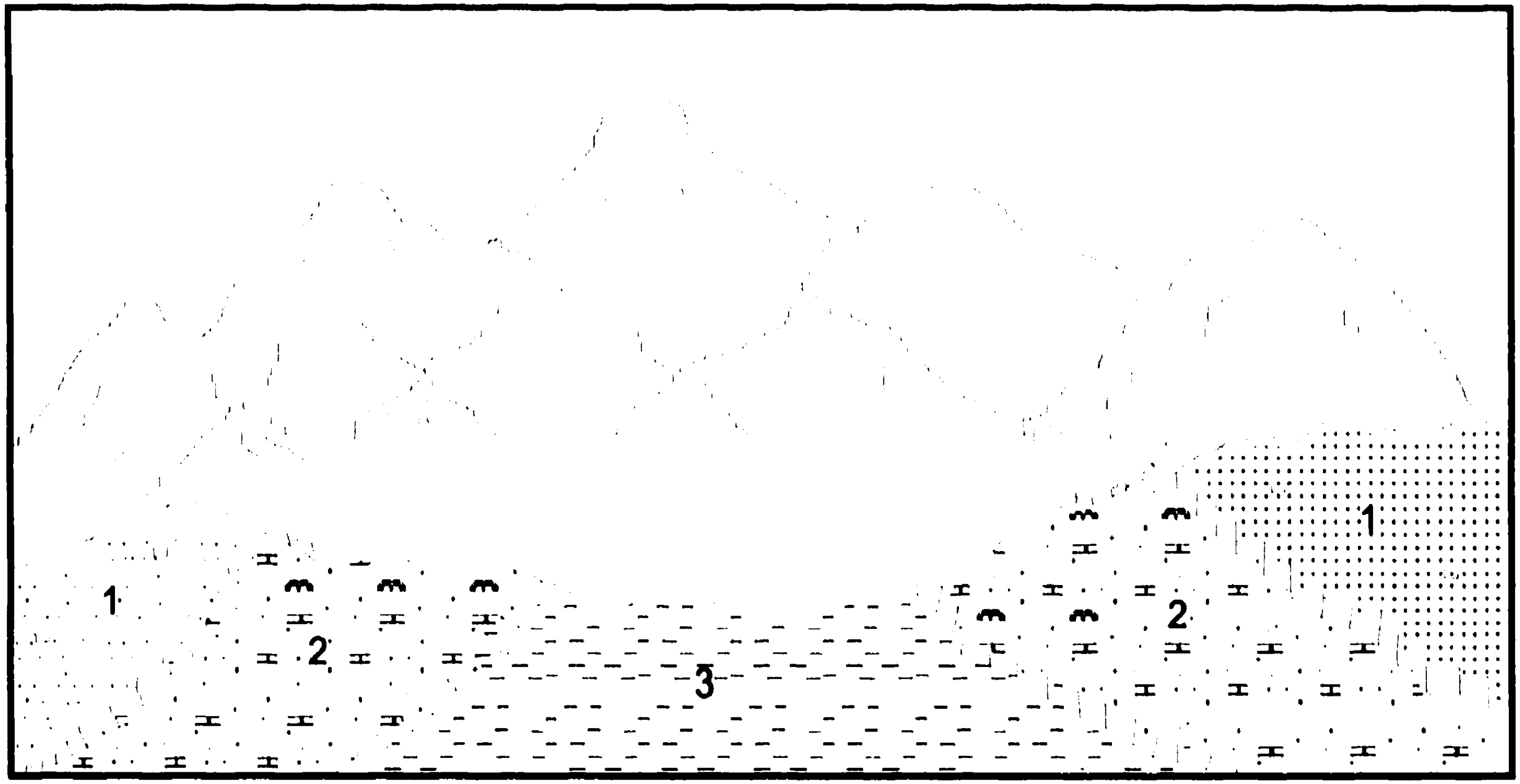


Figure 4-19. Depositional model of Scots Bay Formation shows the three main environmental facies: 1) shoreline feldspathic litharenitic sandstone, 2)nearshore carbonate and siliciclastics, and 3) offshore silt and silty sandstone

The lowest facies represents an offshore environment where the lithology is characterized by very fine-grained silty sandstone. The fine grain size with thin laminations may reflect relatively deep lacustrine conditions where there was a lack of agitation below wave base to winnow away fines and transport in coarse sediments.

Mixed terrigenous and carbonate units of the nearshore facies overlie this silty sandstone. The offshore facies grades into a bioclastic silty sandy limestone of the lower unit of the nearshore facies. The lower nearshore subfacies contains desiccation cracks, rock fragments, algae, scattered oolite grains and an abundance of ostracode valves. These features imply a shallower and higher energy nearshore environment than the offshore facies. The low-energy nearshore subfices consists of a lower stromatolitic unit and an upper wackestone unit, which may represent shallow nearshore environments such as can be found in a bay, as indicated by lime muds and the absence of rock fragments.

The shoreline facies occurs at the top of most Scots Bay outcrops where it is represented by brown feldspathic litharenitic arkose. There has been uncertainty as to whether this sandstone is eolian or fluvial in origin. The presence of calcitic fragments from the underlying limestone, the lacustrine snails, desiccation cracks and the coarse grain size in the lower part of this sandstone indicate subaerial exposure and reworking aqueous processes, probably during wave action in a shoreline environment.

The fluvial channel facies is composed of subarkosic sandstone that filled a small channel at the base of the section in Lime Cove. It displays a fining upward sequence which suggests that a small meandering type stream deposited this facies.

In general, the stratigraphic sequence of these facies records the regressive nature of the Scots Bay Formation with grain size generally increasing upward. The nearshore facies which occurs in the middle of this sequence exhibits a fining upward, carbonate-rich trend or cycle.

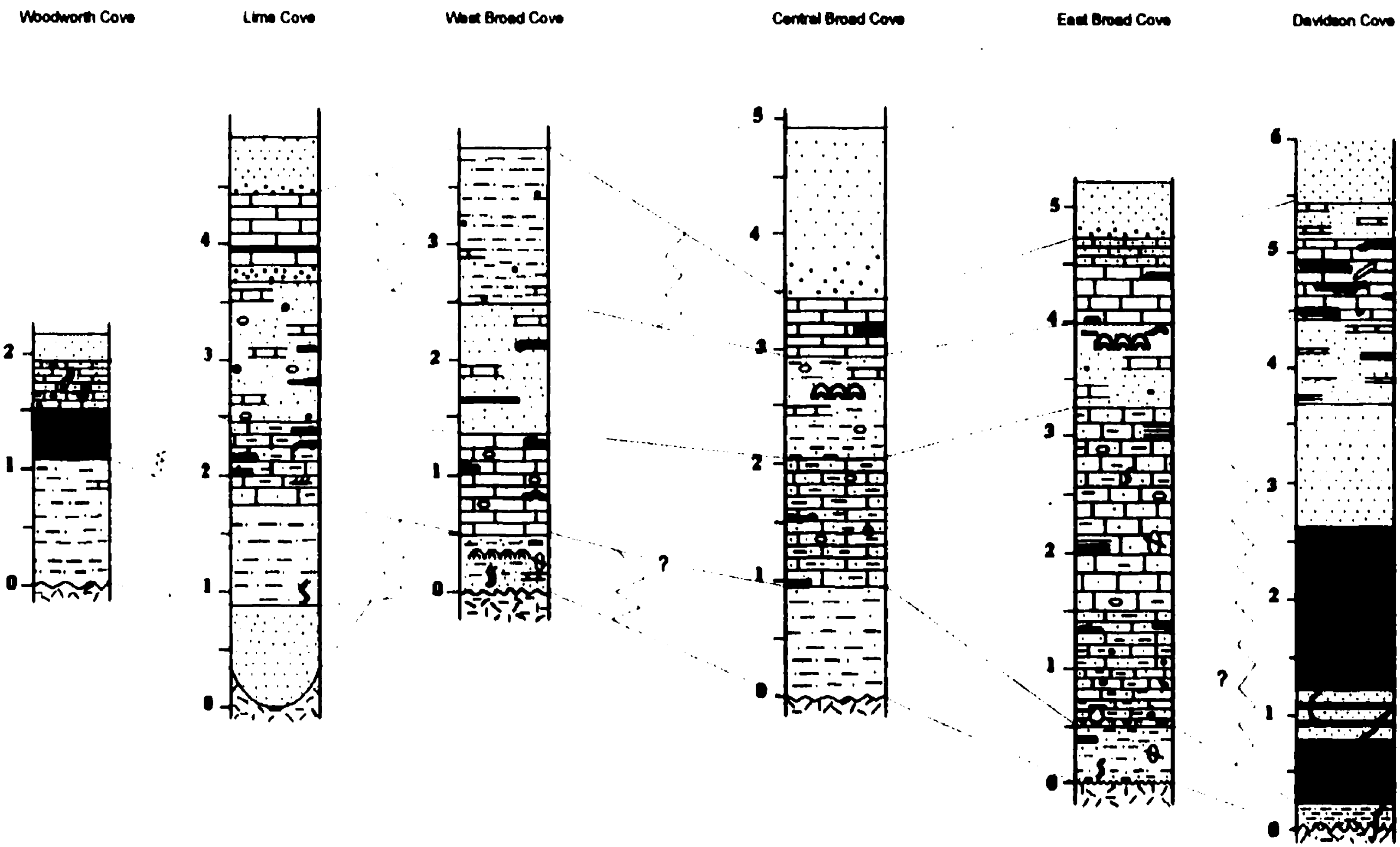
4.5.7 FACIES CORRELATIONS

Despite the closeness of the sections, the lateral correlation of some units in the Scots Bay Formation can be difficult because of the absence, in some sections, of distinctive marker horizons or units, such as stromatolitic calcareous sandstone. Chert nodules occur somewhat scattered throughout every outcrop. Fossils are also not present in the same kinds of beds at different sections. However, there appears to be lateral continuity of some units. For example, the feldspathic litharenitic sandstone at the top is present in all sections except at West Broad Cove where it could be covered by soil and at Woodworth Cove (Fig. 4-20).

The facies at Davidson Cove differ from those at other coves because the main lithologic type at Davidson Cove is sandstone. Klein (1960) reported that in eastern outcrops, sand-sized material dominate; in central outcrops limestone dominates, and in the western outcrops, clayey limestone and claystone dominates.

The basal offshore facies, which is composed of fine silty sandstone, was deposited on the top of the lava flows of the North Mountain Basalt. It is found in all sections except West Broad Cove where it may have been eroded or covered by recent slumping.

The higher energy nearshore subfacies, which is limestone-dominated, occurs throughout all sections but is replaced by siliciclastic rocks at Davidson Cove. These limestones grade eastwards towards Davidson Cove into siliciclastic units, containing chert



(Figure 4-20) Correlation of the main outcrops of the Scots Bay Formation. (No horizontal scale) nodules and chert beds. The lower energy nearshore subfacies is thickest and purest in Lime Cove where it occurs directly below the brown sandstone of the shoreline facies.

The fluvial channel sandstone occurs only at Lime Cove where it was deposited directly on the top of the North Mountain Basalt.

4.6 Conclusion

The Scots Bay Formation was deposited by a shallow, nearshore, somewhat heterogeneous lake system in a generally lacustrine littoral environment. These lacustrine sediments were associated with fluvial channel sandstones in Lime Cove. Lake levels probably varied and some cyclicity is indicated.

Four sedimentary facies are recognized: 1) marginal channel facies; 2) shoreline facies; 3) nearshore facies; 4) offshore facies.

The marginal channel facies represented by subarkosic sandstone displays a fining upward sequence which is coarse-grained in the lower part. These features suggest that a meandering stream may have deposited these sandstones. The offshore facies above contains siliciclastic sediments decreasing in grain size and a low carbonate content. Two nearshore subfacies are recognized higher in the section, one with mixed carbonate and clastic content which represents a shallow relatively higher-energy nearshore environment and the other with increasing carbonate content which represents a quieter nearshore environment. The shoreline sandstone facies at the top is characterized by calcitic fragments derived from underlying limestones which indicate reworking processes. Dinosaur footprints and desiccation cracks indicate subaerial exposure.

The Scots Bay Formation contains a gradational sequence from a lower offshore fine-grained facies through coarser shallow carbonate nearshore environments to a shoreline sandstone facies. This gradational sequence appears to have resulted from a regression or infilling of the paleolacustrine environment. A minor two-step regressive process may be suggested by the lower energy nearshore carbonate facies. The rate of carbonate precipitation was higher in the nearshore environment than in other offshore and shoreline environments. Thompson (1974) stated that the source of the sediments for the Scots Bay Formation was probably to the south. Quartz, as sedimentary grains, is the predominant mineral in the Scots Bay Formation which may suggest a granitic source rock. Klein (1954) suggested that the source rocks for the "Annapolis Formation" in this area were Devonian granite as well as Horton Group and Windsor Group sediments from the south. During the Early Jurassic the North Mountain Basalt would have extended southward to South Mountain, so that streams could have transported quartz detritus northward to the present outcrop location.

Multiple sources are suggested for the lime mud in the Scots Bay Formation, such as disintegration of calcareous algae, passive algae precipitation, and disintegration of mollusks and ostracode skeletons.

CHAPTER FIVE

DIAGENESIS

5.1 Introduction

Understanding of diagenesis and its processes is a crucial pre-requisite to interpretation of lithofacies characteristics and depositional environments. Diagenetic processes affect both pre- and post-lithification sediment characteristics, as they produce changes in textures, structures, and mineral composition. With time, as carbonates are deposited, precipitated, buried, eroded, exposed and reburied, they interact with surficial and interstitial fluids, each of which affects the sediments or rocks in a special ways and leaves a unique diagenetic signature (James and Choquette, 1990). Freshwater diagenesis is characterized by rapid and extensive changes in (a) CO_2 concentration and isotope composition, (b) degree of $CaCO_3$ supersaturation, and (c) flow rates and intermixing of waters (Flugel, 1982).

As work on ancient lacustrine rocks is scarce, the study and interpretation of the diagenetic history of these rocks is not an easy task. Birney-De Wet (1985) studied the petrology of Scots Bay as part of a Masters thesis, whereas a few other studies tended to concentrate on paleontology and sedimentology.

5.2 DIAGENETIC FRAMEWORK

In general, carbonate diagenetic processes encompass dissolution, compaction, cementation, replacement, and recrystallization. Most of these processes have been active in the Scots Bay Formation in addition to some post-lithification processes such as calcite fracture filling. Compositionally, the carbonate-siliciclastic rocks of the Scots Bay Formation consist of a mixture of carbonates and siliciclastic material. The carbonates consist of bioclastics, peloids, and stromatolites, whereas the siliciclastic material consists mostly of quartz, feldspar and chert.

The most common unit in the Scots Bay Formation is a bioclastic silty sandy limestone. One rock sample from this unit at West Broad Cove (e.g., WCS3C) shows a framework of quartz, mica, feldspar, chert, rock-fragments (some of which are volcanic), and clay clasts. The matrix/pseudomatrix is made up of partially chloritized clay. In other samples, there is a local occurrence of patchy, sparry diagenetic calcitic cement. In the Scots Bay Formation, the most abundant fossils are ostracodes whose shells are commonly thin and silicified. Drusy quartz infills the articulated valves (Fig. 5-1). In most cases, the matrix between allochems is generally a mixture of both micrite and recrystallized microspar.

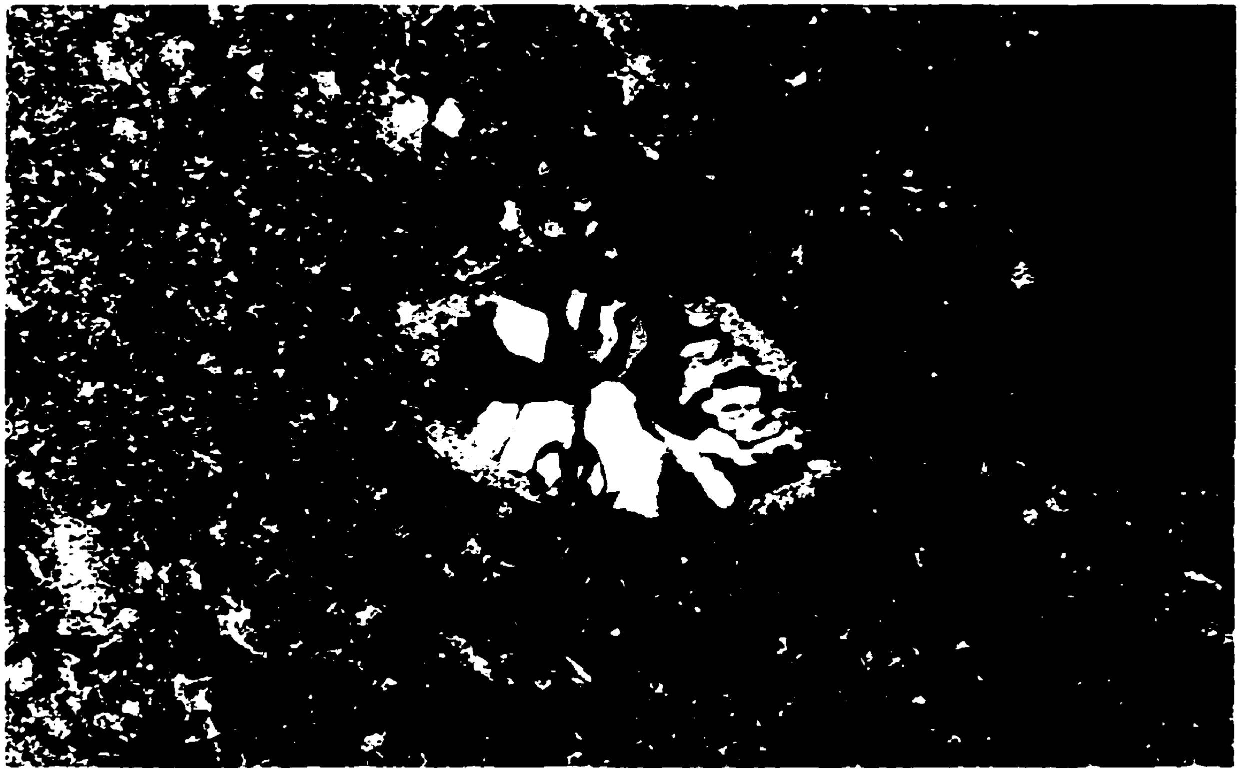


Figure 5-1. Photomicrograph of silty sandy limestone at East Broad Cove showing ostracode shell filled with drusy quartz cement. (sample ESS1C). Crossed polars; width of view is 2.5 mm.

The second most common unit within the formation is composed of bioclastic calcareous sandstone that locally grades into sandy peloidal limestone. In this unit, in which chert and partly silicified stromatolitic limestone are the most distinctive features, minor ostracodes and algal stems are locally present. Recrystallization from micrite to microspar is evident in sample LCS1C from Lime Cove (Fig. 5-2). The presence of patches of peloid-like grains that are nearly replaced by recrystallized micrite suggests that some peloids have been recrystallized. It is difficult, however, to distinguish a sparry cement, which is present as void filling, from recrystallized calcite. Both, however, will be discussed in the next section. Folk (1959) suggested that peloids showing indistinct boundaries might appear so partly as an optical effect due to the small size of the near-spherical pellets and minuscule thickness of the petrographic thin section. In other rocks, however, recrystallization of pellets, matrix or both produce microspar that obscures their boundaries. The presence of uncrushed peloids indicates early lithification, as this is a common process in recent pellets (Tucker, 1990).

5.2.1 Cementation

Cementation of limestone requires an enormous input of $CaCO_3$ and an efficient fluid flow mechanism for complete lithification (Tucker, 1992). Sparry and microsparry cement can be clearly distinguished from micrite by coarser grain size (more than 10 microns) (Folk, 1959; Flugel, 1982). Cementation plays a very significant part in rock

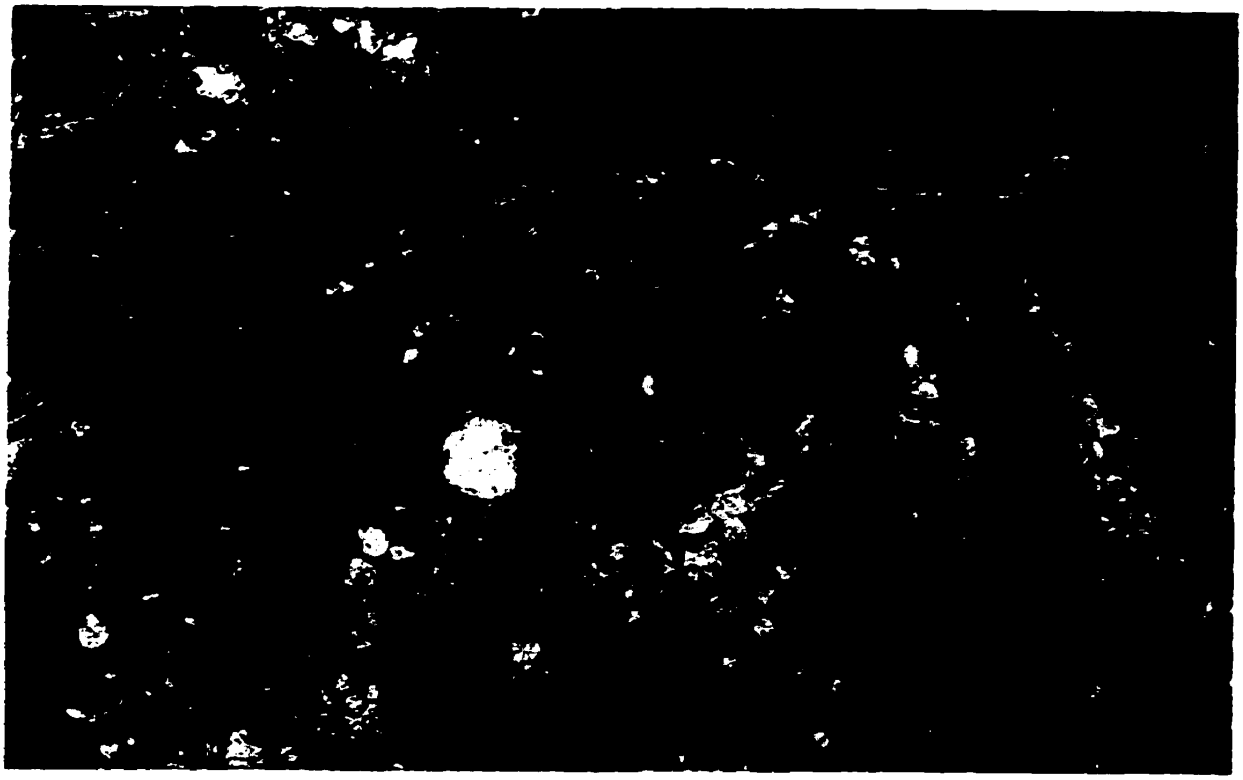


Figure 5-2. Photomicrograph of wackestone-packstone from Lime Cove (sample LCS1E) showing an inter-allochems matrix made up of a mixture of micrite (dark brown) and recrystallized micrite (light). Uncrossed polars; width of view is 4 mm.

forming by joining and holding the grains together.

Cements in the Scots Bay Formation include calcite, silica, iron oxide, and chlorophaeite. Three types of calcitic cement are found. These are: (1) drusy mosaic cement (sparry and microsparry cement), (2) blocky cement and (3) meniscus cement. The original carbonate was probably low-Mg calcite. This is indicated by microprobe analysis showing only 0.23 wt% Mg^{2+} (Birney-De Wet and Hubert, 1989). Alizarin red staining was used to identify dolomite, but it failed to reveal any dolomite mineralization in the Scots Bay Formation

Silica cement fabrics consist of three types: (1) chalcedonic quartz (spherulites), (2) microcrystalline quartz, and (3) drusy quartz. These types will be discussed in more detail in the next chapter which is devoted to cherts. Iron oxide and chlorophaeite occur locally as rim cements. Hematite-stained chalcedonic quartz and shreds of goethite are locally present.

Interlocking of quartz grains is common in the Scots Bay rocks. The degree of grain interlocking is low, indicating a low compaction pressure process. Quartz cementation was probably an early diagenetic event, as indicated by well-preserved wood fossils in the core of chert nodules.

Drusy and blocky calcite cements are the most common cements in the Scots Bay Formation and are clearly distinguishable from recrystallized micrite as they occur along fractures or in cavities formed after fossils dissolved. Drusy calcite is usually found as pore-filling in which crystal size increases progressively towards the pore center (Fig. 5-3). In cavity filling, crystal size of drusy mosaic cement increases away from cavity wall, forming one of the fabric criteria for cement (Bathurst, 1976, p. 418). Drusy mosaic and blocky calcite is relatively coarsely crystalline (0.1 to 0.8 mm) due to slow growth. Their formation indicates that, at times, the pores and fractures must have been filled with water; thus pointing to a phreatic zone environment. Differentiating meteoric phreatic cements from burial cements is difficult if not impossible without thermometry from fluid inclusions or oxygen isotopes (Tucker, 1992). In contrast to neomorphic spars, sparry cements have a high frequency of plane intercrystalline boundaries (Bathurst, 1971). Calcite cement crystals in the Scots Bay Formation, particularly within spherical voids, show this tendency (Birney-De Wet, 1985). The blocky cement is usually found as fracture filling (Fig. 5-4). The blocky calcite crystals often exhibit some well- developed cleavage where the boundaries between the sparry crystals are made up of plane interfaces (Fig. 5-5).

Some microspar cement occurs locally in fractures, dissolved shells and other cavities, as such, it is post-micrite, but not necessarily a recrystallized product of it. The boundary between micrite and this micro-sparry cement is sharp (Fig. 5-3).

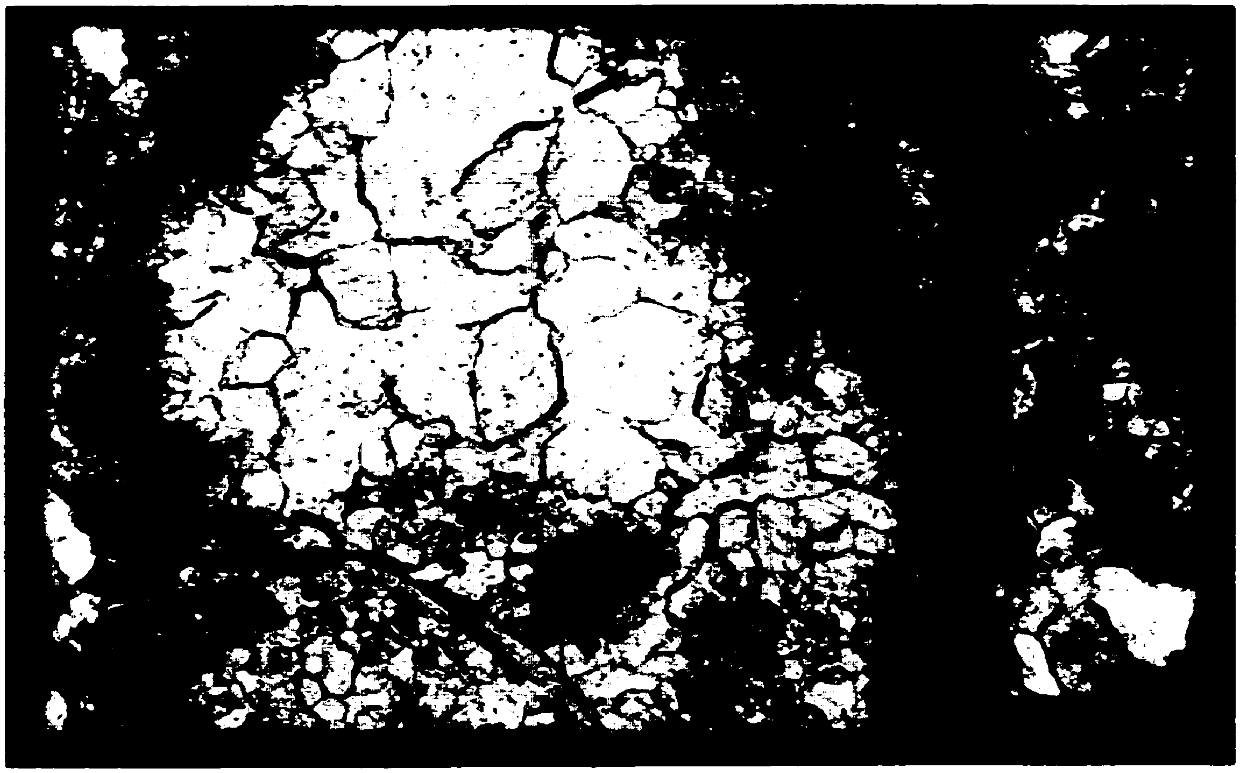


Figure 5-3. Photomicrograph of peloidal limestone showing plane interface boundaries between crystals of the drusy mosaic cement. It also shows crystal size increasing away from the cavity wall. East Broad Cove (sample ESS1V). Crossed polars; width of view is 2.5 mm.

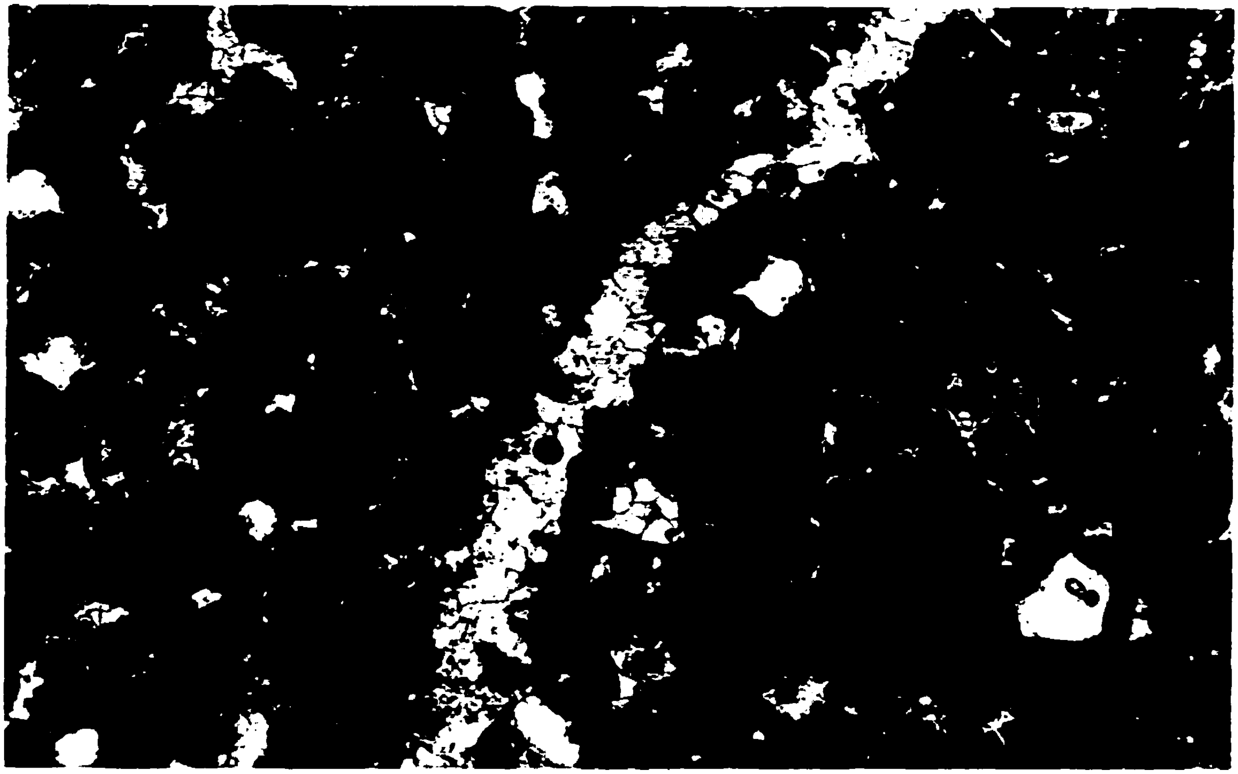


Figure 5-4. Photomicrograph of wackestone-packestone showing the blocky calcite (cement) as fracture filling (sample LCS1E). Crossed polars, width of view is 4 mm.

Figure 5-5. Photomicrograph of wackestone-packstone showing sharp boundary between micrite and blocky calcite. Note that some crystals exhibit well-developed cleavage and the boundaries between the sparry crystals are made up of plane interfaces (sample LCS1E). Crossed polars; width of view is 2.5 mm.

Meniscus cement is of minor, sporadic occurrence in the Scots Bay Formation (Birney-De Wet and Hubert, 1989). Meniscus and pendant cements are excellent indicators of the vadose environment, but if cementation is prolonged and the pores were to be filled, their characteristic shapes would usually be lost (James and Choquette, 1990). Crystals of meniscus cement were found to be usually finely crystalline.

5.2.2 Replacement

Silicification or silica replacement is the most extensive diagenetic phenomenon observed in the Scots Bay Formation. Dolomite, which is the most common replacement mineral in carbonate rocks, was not found in the Scots Bay Formation. Silicification occurs in many forms, as chert nodules, chert beds and as silicified fossils. In some rock samples of the Scots Bay Formation microcrystalline quartz replaces calcite. On the other hand, chalcedonic spherulites and drusy quartz occur as cement in cavity fillings. The latter shows increasing crystal size away from the cavity wall (Fig. 5-6). In sample ESS1S from East Broad Cove, silica replaces spar within micronodules prior to any replacement of the framework's microspar and micrite (Fig. 5-7). Silica replacement is discussed in detail in chapter 6.

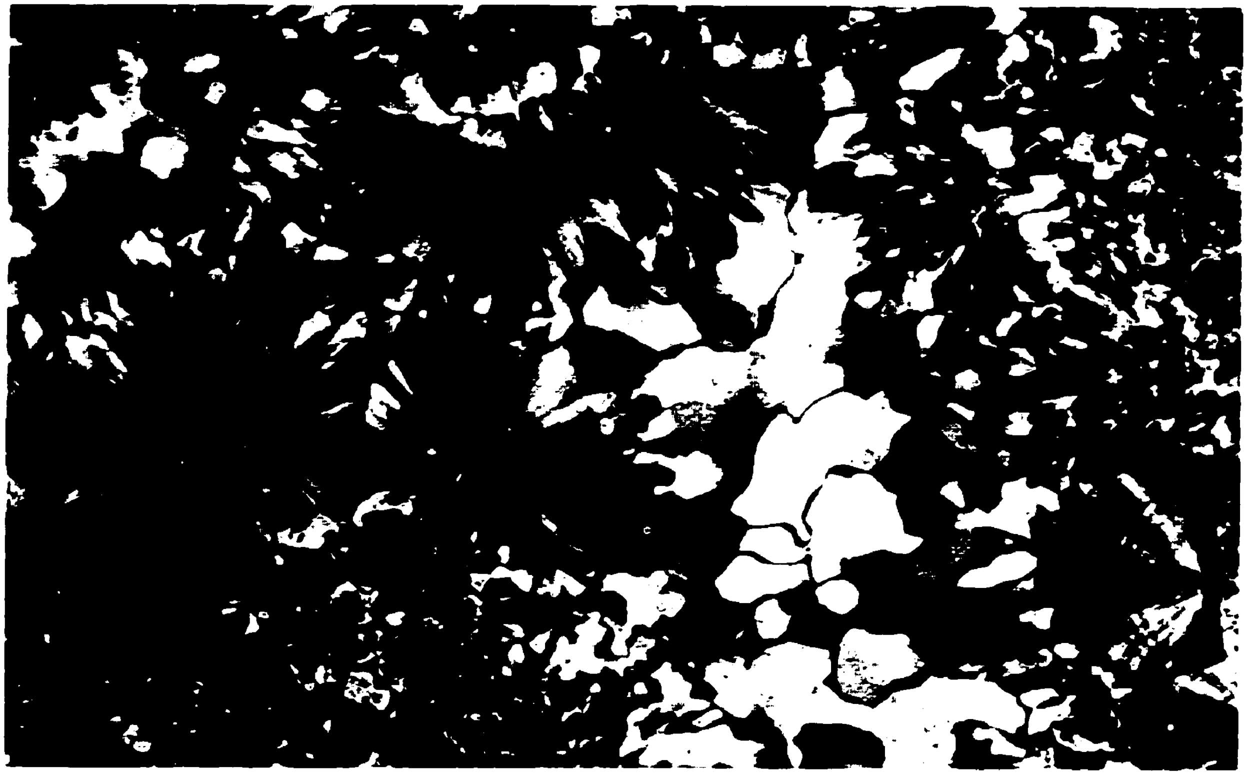


Figure 5-6. Photomicrograph of chertified limestone showing chalcedonic spherulites and drusy cement as cavity filling. The latter shows crystal size increasing away from the cavity wall. East Broad Cove (sample ESS1R). Crossed polars; width of view is 2.5 mm.

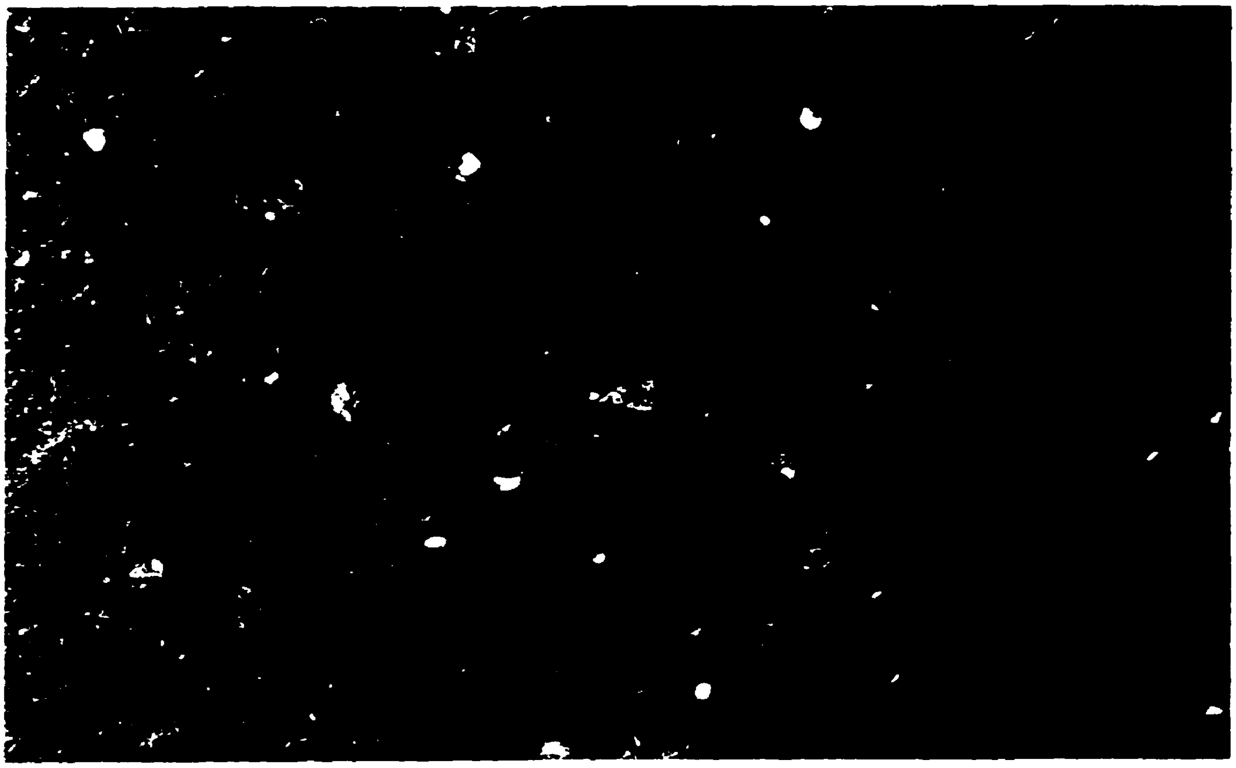


Figure 5-7. Photomicrograph of peloidal wackestone showing silica replacing spar within micronodules prior to any replacement of the framework's microspar and micrite. The angular to subangular outline of some micronodules suggests pseudomorphic structure after evaporites. East Broad Cove (sample ESS1S). Crossed polars; width of view is 4 mm.

5.2.3 Dissolution and Porosity

Dissolution is facilitated when limestones are exposed to fresh water. It is more effective near the air/rock interface because it is controlled by the flux of CO_2 in meteoric water (James and Choquette, 1990). Well-developed solution porosity occurs at Woodworth Cove where it is locally lined with sparry calcite (Fig. 5-8). The interparticle and intraparticle porosity that is probably produced by dissolution of parts of the matrix negates significant compaction and suggests that such dissolution may have occurred in vadose or phreatic zones preceding deep burial. The types of cement, whether drusy to blocky (phreatic) or meniscus (vadose), described in the previous section, also indicate near-surface meteoric diagenesis.

Meteoric water first encountering carbonate sediments is normally undersaturated with respect to $CaCO_3$, so dissolution takes place and yields a vuggy porosity (Tucker and Bathurst, 1990). The presence of space-filling cement in Scots Bay rocks and fossils is the most important petrographic evidence for dissolution. Porosity in the Scots Bay Formation is low. The maximum porosity estimates range between 15 and 20% in fossiliferous limestone at Central Broad Cove. The average total porosity in the Scots Bay Formation is 2 to 3 %, as determined by point-counting. Primary porosities appear to have been reduced by precipitation of sparry calcite cement and early diagenetic silica such as chalcedony and drusy quartz. In some samples porosity reduction may be as high as 20% according to point-count data.

Although moldic porosity is not common, it has been observed in fossiliferous limestones at Central Broad Cove. It occurs as a result of leaching out of fossils early in the history of this formation. The development of open fracture porosity in some samples suggests a tectonic origin. Fractures are mainly filled with blocky and drusy calcite cement (Figs. 5-4 and 5-5). In general, it is doubtful that the total porosity contribution from open fractures exceeds 1%, as also noted by Murray (1981).

5.2.4 Recrystallization

Recrystallization embraces any change in the fabric of a mineral or monomineralic sediments. Fine-grained microcrystalline matrix can be partly recrystallized to coarse-grained calcite spar, as can be found in the Scots Bay Formation. The term grain-growth was introduced into carbonate petrology by Bathurst (1958) to describe the familiar alteration of micritic calcite to sparry calcite. Recrystallized calcite can be seen in Figure 5-9, which shows patches of the original micrite with fuzzy boundaries that have not undergone recrystallization yet. This textural aspect helps to differentiate neomorphic sparry calcite from sparry void-filling cement. When sharp boundaries can be seen between sparry cement and original matrix, cavity-filling cementation is clearly the dominant process. In some samples, the lack of

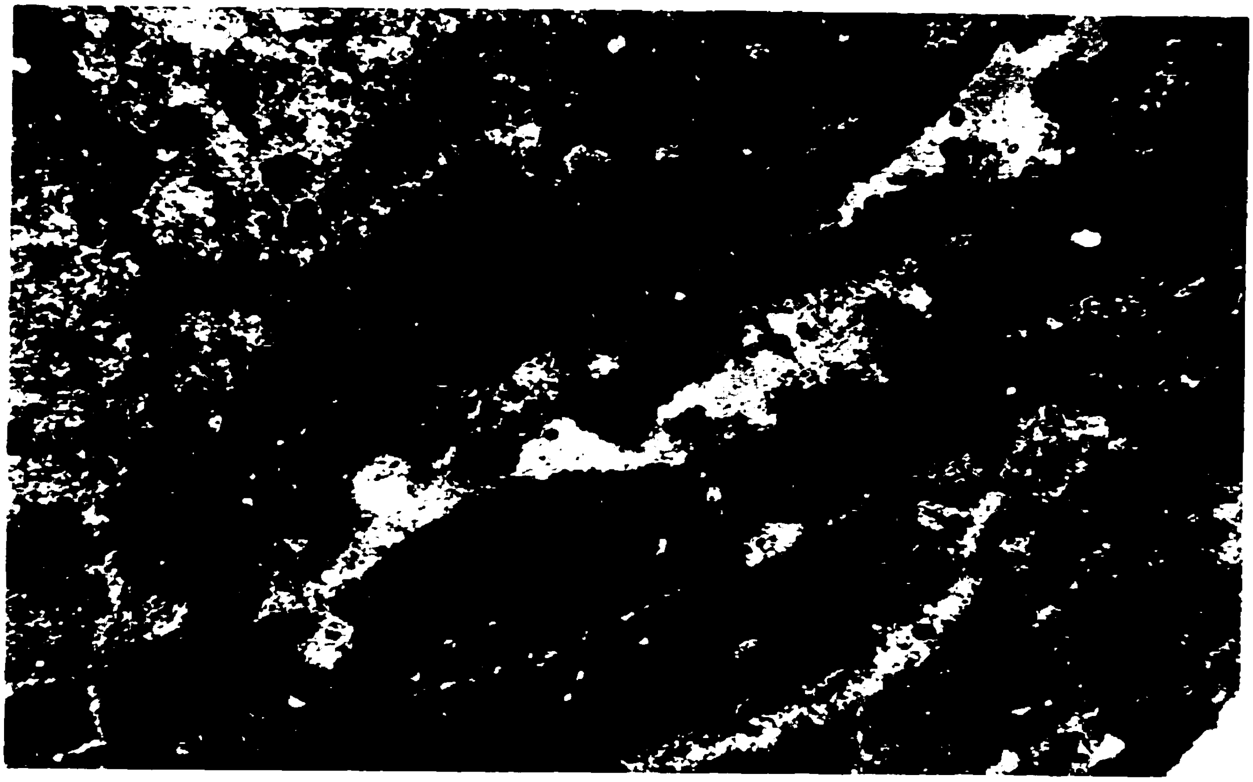


Figure 5-8. Photomicrograph of wackestone showing solution porosity that is locally lined with neomorphic and sparry calcite cement (upper left). (Woodworth Cove, sample WCS1B). Uncrossed polars, width of field is 4 mm.

allochems and presence of microspar indicate that the latter did not form as a cement, but rather as a recrystallized micrite. Another way of identifying recrystallized micrite is to find some terrigenous grains suspended in microspar, such as those in samples LCCS1D and CCS1C2 from Lime Cove and Central Broad Cove. In some specimens, such as in East Broad Cove sample ESS1S, clusters of clots of microcrystalline matrix are surrounded by a recrystallized material with fuzzy boundaries (Fig. 5-9). This pattern is called grumose structure. Grumose structure appears as many little clots of an extremely finely crystalline, dark gray calcite standing out in a matrix of colorless granular calcite (Cayeux 1935, *in* Bathurst 1976, p. 511).

5.2.5 Paragenetic sequence

Lithification processes probably began during early diagenesis, as indicated by the presence of uncrushed peloids and the lack of other compaction phenomena. Dissolution of calcareous unstable minerals (e.g., aragonitic gastropod shells), possibly in the vadose and phreatic zones, appears to have occurred prior to the first cementation phase (Table 5-1). Thus, some cavities including dissolved fossils, formed in the meteoric environment. Once cavities became filled with $CaCO_3$-saturated water, cementation processes ensued. Recrystallized microspar and meniscus cement may have formed prior to the drusy and blocky cement. The latter did not evolve until after

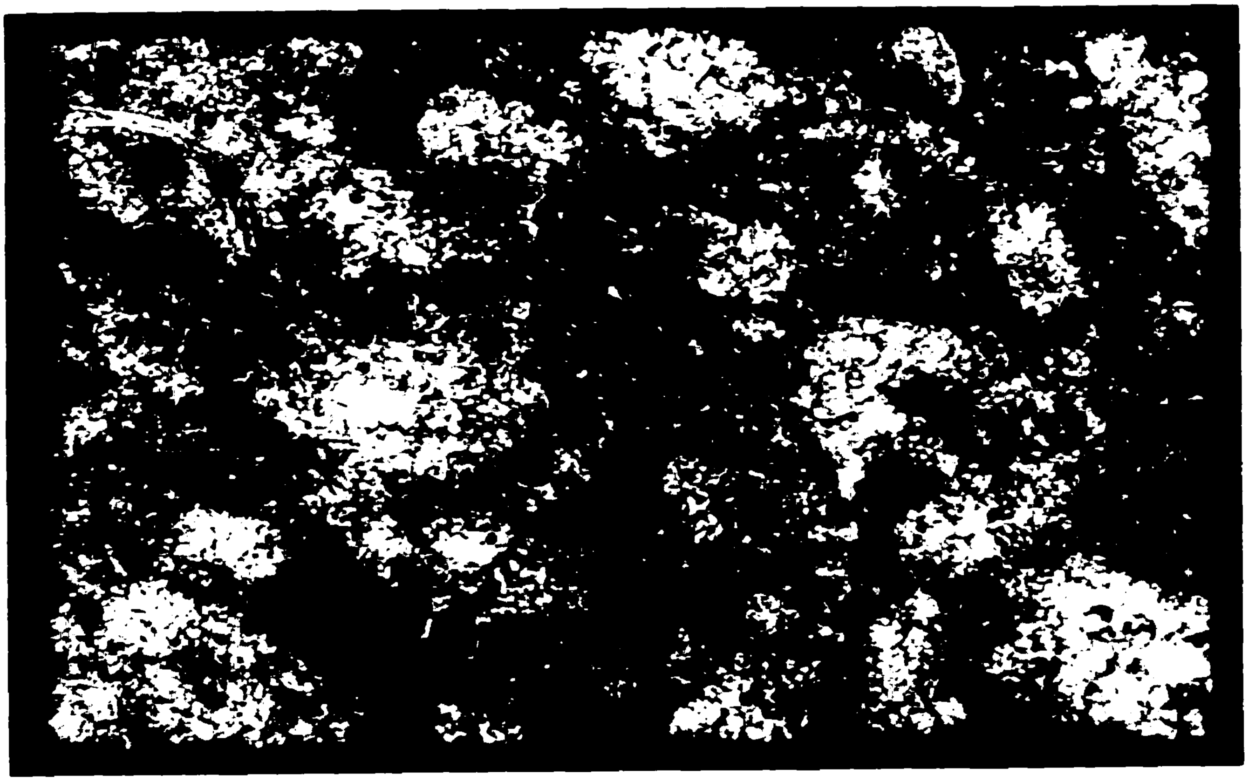


Figure 5-9. Photomicrograph of wackestone showing fine-grained microcrystalline matrix that has been partly recrystallized to microspar. It shows grumose structure (patches of micrite standing out as dark gray in a matrix of colorless microspar). East Broad Cove (sample ESS1S). Crossed polars; width of view is 4 mm.

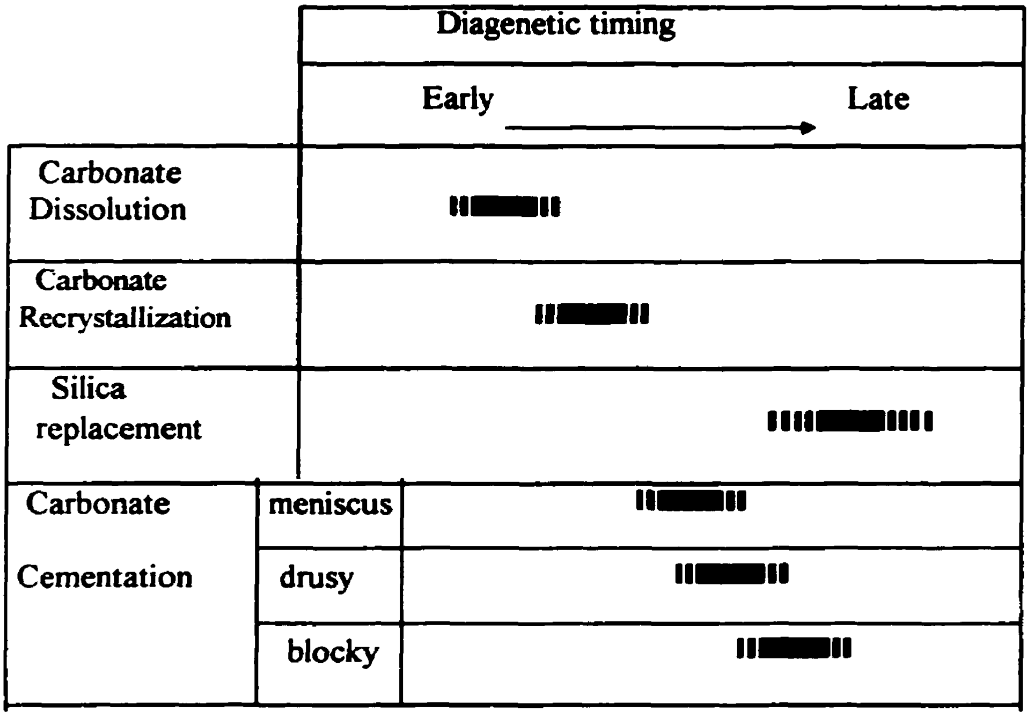


Table 5-1. Paragenetic sequence showing progression of the main diagenetic processes that affected the Scots Bay Formation in relative time.

the development of micro-fractures. Drusy and blocky calcite cements are probably the manifestation of the last carbonate cementation events. Then, the silica mosaic was precipitated as indicated paragentic sequence in Figuure 5-1.

5.3 Conclusions

During early diagenesis, some calcite dissolution took place in shallow burial environments or near the surface before cementation. Three types of calcite cements occur in the Scots Bay Formation: drusy mosaic, blocky, and meniscus cement. Phreatic and vadose meteoric cements make up most of the cements of Scots Bay limestones. On the other hand, meniscus cement probably formed very early during lithification and prior to formation of the drusy and blocky sparry cements. Porosity in the Scots Bay Formation averages about 2-3%, is mainly secondary, and appears to have been generated by solution.

Evidence of recrystallization of micrite into microspar are: 1) fuzzy contacts between the recrystallized microspar and relict micrite, 2) micrite inclusions within the microspar, and 3) replacement of some micritic allochems (pellets) by microspar.

Silica occurrence in the Scots Bay Formation is exhibited mainly by the occurrence of nodular and bedded chert, both being replacement products and by silicification of fossils. Detrital quartz and pore-filling silica cement are subordinate.

CHAPTER SIX
CHERTS

6.1 Introduction

Chert is a very general term for fine-grained siliceous sedimentary rocks of chemical or biological origin; it is dense and a very hard rock. Based on impurities, chert has many variety names. The most common varieties are jasper which is red because of hematite inclusions and flint which is gray to black on account of inclusions of organic matter. Cherts in carbonate rocks are common throughout the stratigraphic record. Cherts in limestones are abundant in strata as old as early Paleozoic, such as those of the Appalachian region (Twenhofel, 1932). The origin of nodular chert in carbonate strata has been the subject of voluminous literature dating back to at least the latter part of the nineteenth century (Meyers, 1977).

In the field, cherts in the Scots Bay Formation can be broadly divided into nodular and bedded types, both present as replacements and possibly some primary precipitated silica (Birney-De Wet and Hubert 1989), but detrital chert grains and pore-filling cements also occur in these limestones and sandstones. The nodules in the Scots Bay Formation are red, reddish-brown and brown, cylindrical in shape, and have their long axes usually parallel to bedding. Some nodules are isolated and irregularly distributed within beds.

The contact between the cherts and the surrounding limestone is usually sharp. Cherts may contain patches of limestone as well as wood fragments.

6.2 REPLACEMENT AND AGE

Much of the chert in the Scots Bay Formation occurs as partial replacement of the limestone and silty sandy limestone beds. It also replaces calcareous fossils, wood fragments, and tree trunks within the limestones. The degree of selectivity of the replacement process is apparently a function of a number of variables including pH, dissolved silica activity, porosity and permeability (Hesse, 1990).

Evidence of replacement includes: 1) occurrence of chert along fissures in limestone indicating some post-depositional origin, 2) presence of some patches of limestone in chert masses, 3) association of silicified fossils in limestone, and 4) preservation of precursor sedimentary and biological structures and textures in some chert nodules such as woody structure (Fig. 6-1).

The presence of silicified fossils (that were once woody and calcareous) in the Scots Bay Formation in association with chert lends strong evidence to replacement origin for this chert. Such an association has been observed in many other formations such as the Illinois Limestone and dolomite formations (Biggs, 1957). Fossils in the Scots Bay Formation are well preserved due to being incorporated in chert before they

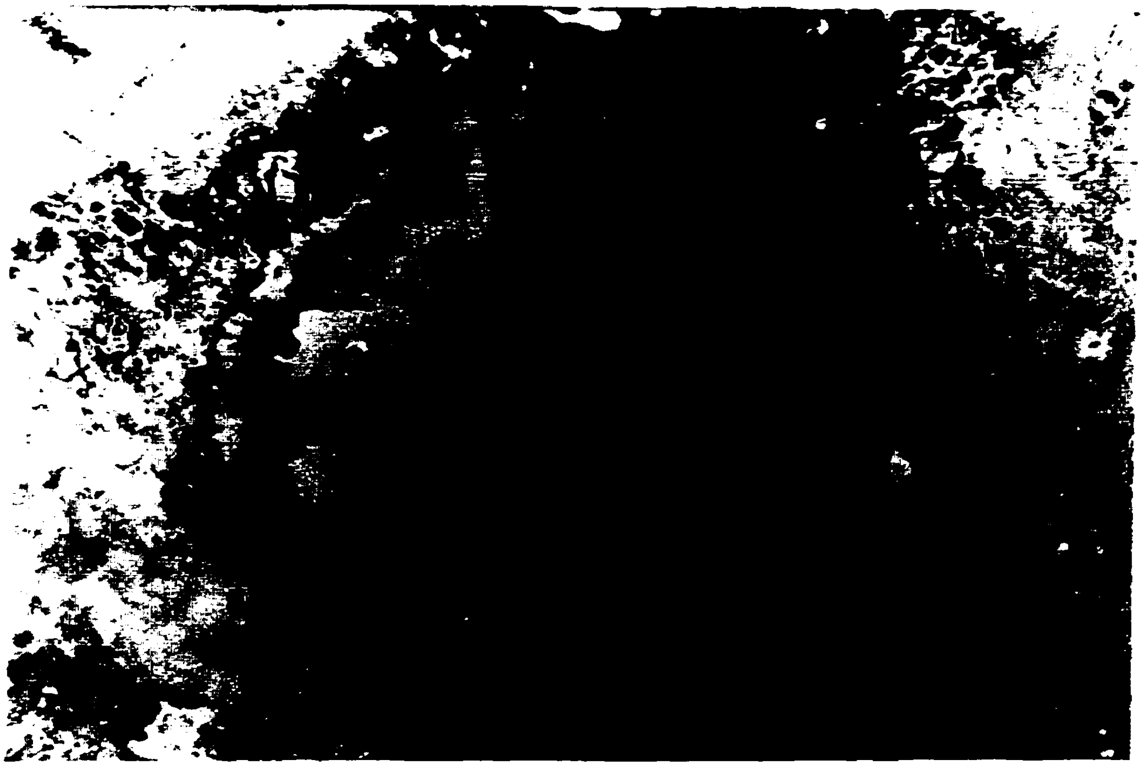


Figure 6-1. Photomicrograph of the center of a chert nodule in transverse section, showing woody structure typical of the cores of chert nodules. Sample is float from Lime Cove. Width of view is 1 mm.

could have been crushed by overburden pressure. In some cases, there is primary carbonate cement around the margin of dissolved ostracodes followed by drusy quartz precipitated in the cavity centers. These phenomena indicate that chertification preceded or at least was associated with the lithification of these limestones.

Chert nodules are found within limestone beds where the limestone is compacted around the chert nodules (Fig. 6-2). The calcareous limestone laminae often warp around or drape over the chert nodules, indicating an early diagenetic origin. Birney-De Wet (1985) observed that nodules commonly depress the sedimentary layers beneath them whereas overlying beds may drape over them, suggesting little lithification prior to chert formation. The presence of detrital chert fragments in the bottom of the sequence, as well as in most beds above, indicates that chert formed early in the history of the Scots Bay Formation. The nodules and bedded cherts do not seem to be facies dependent, except for their absence from the shoreline facies.

6.3 CHERT PETROLOGY

In the Scots Bay Formation, chert microfabrics consist of three major types (Fig. 6-3): 1) chalcedonic quartz, forming bundles of microfibrous crusts and spherulites; 2) microcrystalline quartz composed of equant grains; and 3) drusy quartz cement forming crystals of increasing size towards cavity centers.

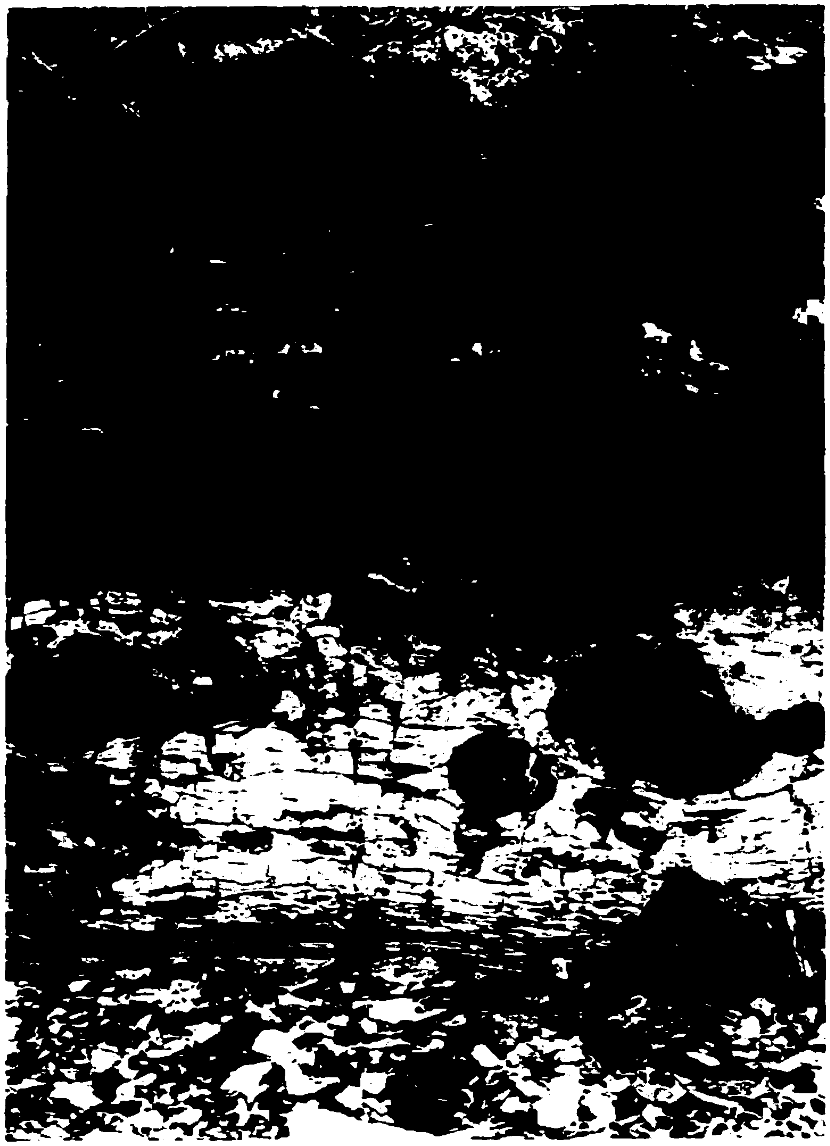


Figure 6-2. Limestone strata of the nearshore facies at Lime Cove appear compacted around chert nodules, indicating development of chert prior to complete lithification. Hammer for scale.

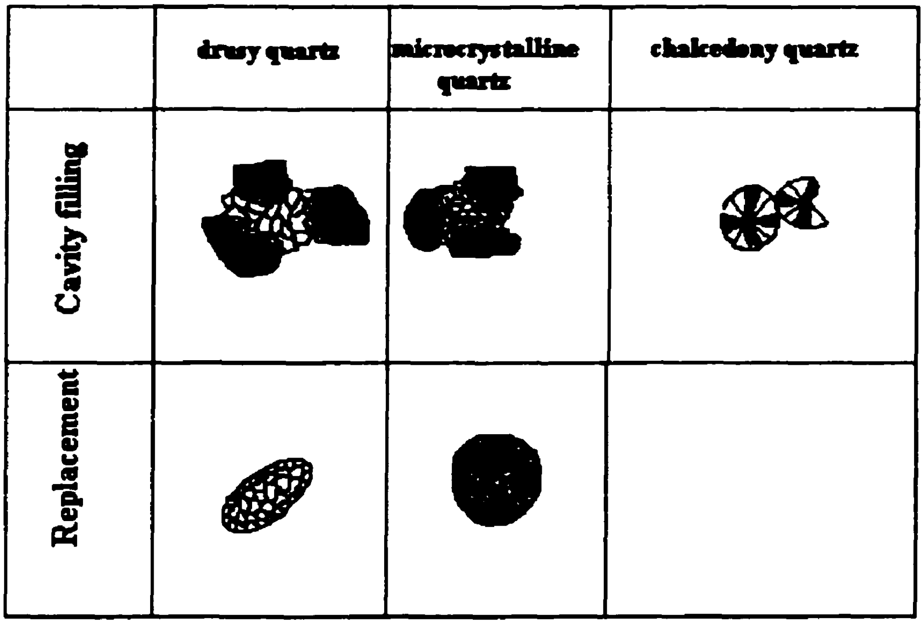


Figure 6- 3. Chert fabrics in the Scots Bay Formation. Drusy quartz occurs as calcite replacement in ostracode shell (lower left), and as pore filling with increasing size toward the center (upper left). Microcrystalline quartz occurs in dense, tiny interlocking grains as replacement and cement. Chalcedony quartz, forming bundles of radiating microfibrous crusts and spherulites, occurs as cavity filling.

The dominant siliceous constituent is microcrystalline or cryptocrystalline quartz, defined as chalcedony (Smith, 1960). Locally, goethitic shreds and spheres with hematite staining occur as cavity fillings that are usually associated with chalcedony. In this study, of precipitation, as indicated by the fiber-like crystals, while the relatively coarse-grained microcrystalline quartz appears to have formed slowly.

Microcrystalline quartz is very abundant in the Scots Bay cherts. It occurs as dense interlocking grains with random orientations (Fig. 6-4). The average size of each individual grain is 4-6 microns in diameter. Wightman's (1970) study of silica veins in the Early Jurassic North Mountain Basalt Formation also indicated that the major mineral of these veins is microcrystalline and chalcedonic quartz. Under the polarizing microscope, individual grains appear to have undulose extinction which may be caused by impurities and can also be related to the properties of precursor grains where a replacement origin is apparent (Cameron, pers. comm., 1999). The drusy quartz probably represents a final stage of silica deposition as cavity fillings.

Chalcedonic microfibrous silica occurs as cavity fillings, as indicated by aggregates of spherulites showing a polygonal outline (Fig. 6-5). Under crossed polars, chalcedony usually shows straight extinction (although some undulose extinction was observed). Under uncrossed polars, chalcedony of the Scots Bay Formation is brownish in color. Chester (1956) stated that chalcedony often appears brown under the microscope because light is scattered by submicroscopic pores. The spherulites consist of radiating

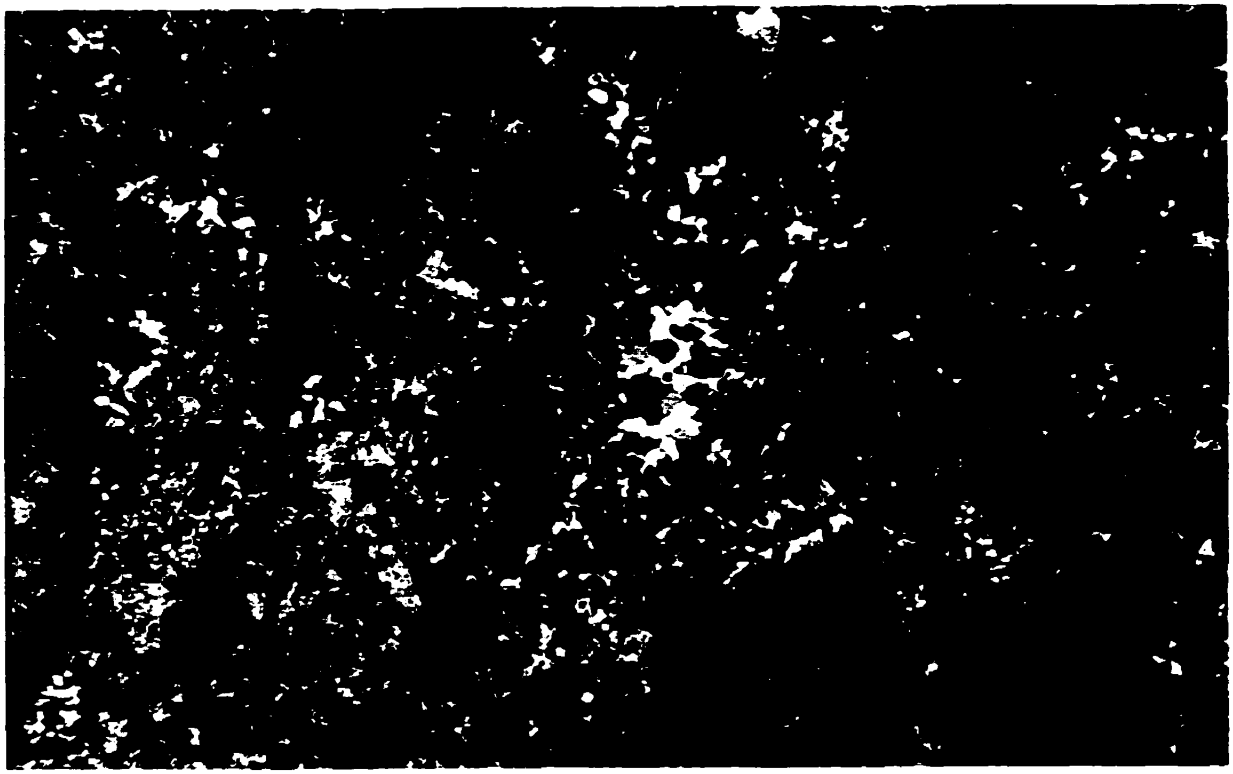


Figure 6-4. Photomicrograph showing drusy quartz and chalcedonic spherulites filling cavities. Note the fine quartz with dense, interlocking crystals with random orientations. East Broad Cove (sample ESS1R). Crossed polars; width of view is 4 mm.

Figure 6-5. Photomicrograph of silicified peloidal limestone showing the polygonal boundaries of chalcedonic spherulites and radial fibrous silica that suggests formation as a pore-filling. East Broad Cove (sample ESS1T). Crossed polars; width of view is 2.5 mm.

arrays of fibrous-chalcedony. Each individual fiber of a spherulite may extend from the center outward and end against fibers of adjacent spherulites. No nuclei were observed in these spherulites. The silica fabrics in some thin sections show some transformation from chalcedonic spherulites into drusy mosaics (Fig. 6-6). Length-slow and length-fast spherulitic chalcedony are both present in the Scots Bay Formation, usually as cavity fillings (Fig. 6-7). Mineralogically, in length-slow chalcedony the elongation of the fibers is parallel with the crystallographic c-axis, whereas in length-fast chalcedony the elongation of the fibers is perpendicular to the crystallographic c-axis. Length-slow means that the slower polarized light component produced in double refraction is the component vibrating parallel to crystal light; length-fast can be defined similarly for the faster component (Chesworth, 1970).

Length-slow chalcedony, having c-axis parallel to length of the fibers is unusual in nature. It occurs almost exclusively in association with sulphates and other evaporites (Folk & Pittman, 1971). The Scots Bay Formation cherts seem to have no gypsum or sulphate mineral precursors and, furthermore, there is no evidence of replacement of evaporites by length-slow chalcedony. It would seem, therefore, that the hypothesis of Folk and Pittman (1971) may not apply well to cherts of the Scots Bay Formation. However, despite the lack of evidence for abundant evaporites, scattered gypsum grains do occur in some thin sections such as in sample LCS1C at Lime Cove and some possible evaporite pseudomorphs may be present (fig. 5-7). At this location, however, gypsum

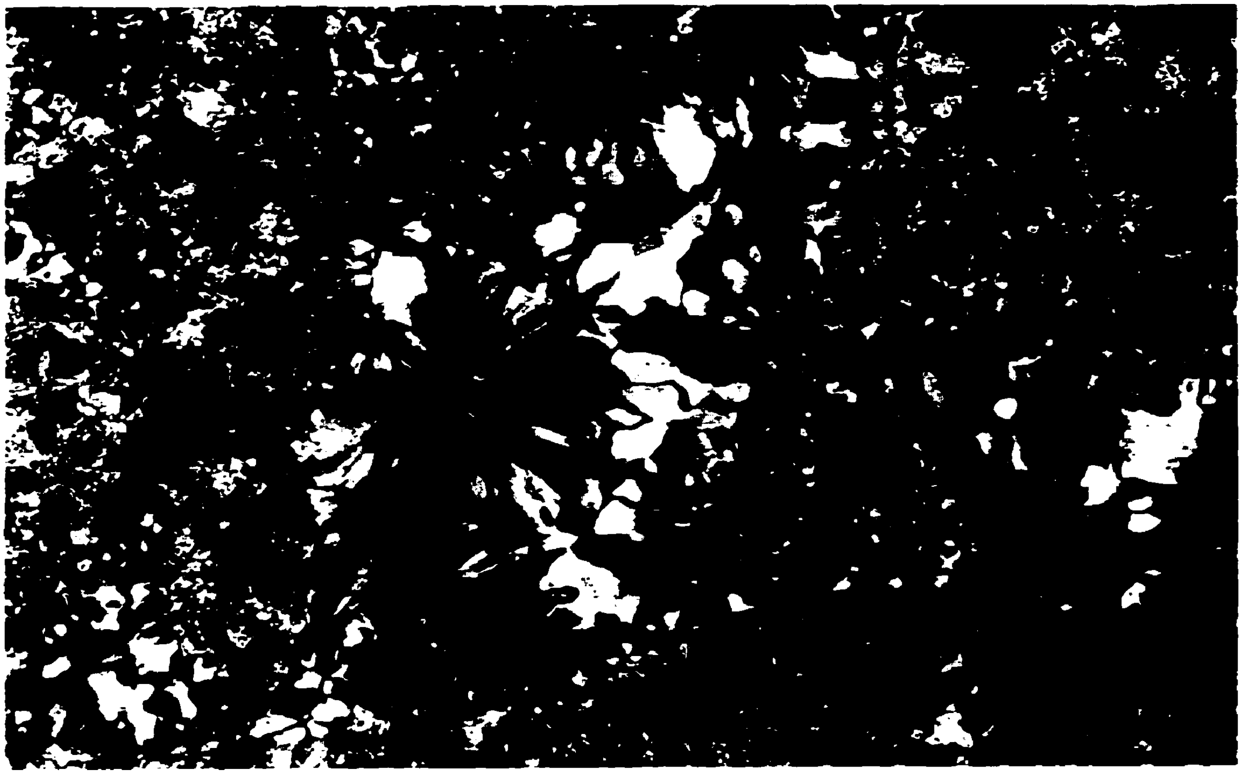


Figure 6-6. Photomicrograph of silicified limestone showing chalcedonic spherulites in process of recrystallization to grain-growth quartz mosaics. East Broad Cove (sample ESS1R). Crossed polars; width of view is 4 mm.

Figure 6-7. Photomicrograph of chertified limestone showing two types of cavity fillings: 1) precipitation at the pore's boundaries of length-slow chalcedony (yellow) and length-fast chalcedony (brown), and 2) precipitation at the cavity center of drusy quartz that increases in grain size towards the center. Lime Cove (sample CH1). Crossed polars; width of view is 2.5 mm.

may have been derived from the underlying Blomidon Formation and carried through the hot spring system of the Scots Bay lacustrine palaeoenvironment where it may have had considerable chemical and crystallographic control over the development of chalcedony.

6.4 SOURCE AND CONDITIONS FAVOURING SILICA PRECIPITATION

Silica solubility increases with increasing temperature, pH, and pressure. Most silica precipitation at hot springs and geysers takes place when fluids equilibrated with respect to quartz, chalcedony, or volcanic glass at elevated temperature in the subsurface rise rapidly to the surface where they attain high levels of supersaturation at lower temperature and pressure (Renault and others, 1998). Chert in the Scots Bay Formation could have formed from hydrothermal solutions associated with the Early Jurassic volcanism that created the North Mountain Basalt Formation below.

Generally, chert precipitates initially as amorphous silica (Pettijohn, 1975) that later crystallizes to microcrystalline quartz and chalcedony under certain circumstances. Spherulitic chalcedony of the Scots Bay Formation may have formed as a result of rapid cooling of hydrothermal solutions. Experimentally, Oehler (1976) found that freshly solidified silica gel crystallized to chalcedonic spherulites under hydrothermal conditions of pressure reaching up to 3 kb and at temperatures between 100° to 300° C for periods ranging from 25 to 2500 hours. The spherulitic chalcedony produced was either length-slow, length-fast or a combination thereof. White and Corwin (1961) pointed out that chalcedony develops by transformation of silica under near surface conditions at moderate temperatures and pressures. These conditions are restricted to sedimentary and low-temperature hydrothermal environments.

Silica transported to sites of deposition by fluids issuing from hot springs or other magmatic sources might arrive in sufficient quantities to form entire layers (Twenhofel, 1932). Cameron (1985) first suggested hot-spring waters as the source of silica in the Scots Bay Formation and Birney-De Wet and Hubert (1989) confirmed the interpretation of silica-rich hydrothermal springs that seeps around and on the floor of the Scots Bay Lake. The latter interpreted most of the Scots Bay silica as siliceous tufa deposited by hydrothermal solution.

Birney-De Wet and Hubert (1989) deduced that the chalcedonic spherulites in the Scots Bay cherts were formed as gels in association with hot springs. The hot water may have been brought upwards through cracks and joints in the underlying formations and would have subsequently spilled out on the floor of the lake. This hydrothermal, silica-saturated water would have moved upwards due to heat from a magmatic source below. Other evidence that supports a hot-spring origin is the presence of pipes (or channelways) serving as conduits for the hot water to move upwards to the surface. These are present at Davidson, Lime and Central Broad coves, as well as in the underlying basalt, where they are now filled or partly filled by mudstone, amethyst or smoky quartz.

Silica could have also been a component of volcanic springs supplying hydrothermal water to the Scots Bay Lake. This is also indicated by the silicified pipes and fractures that lead down to older magmatic rocks, such as the North Mountain Basalt. These waters may have contained considerable amounts of dissolved ferrous iron, thus explaining the presence of iron oxide in the jaspers of the Scots Bay cherts. Biggs (1957) stated that in general, silica deposited from volcanic springs would be localized around the vents and that silicified pipes should be found leading downward into older rocks.

Finally, it should be mentioned that an organic origin for silica in the Scots Bay Formation is ruled out. Scanning electron microscopy and polarizing petrographic microscopy failed to reveal any presence of siliceous fossils such as radiolaria, diatoms or sponge spicules. These are commonly associated with organic cherts. The possibility of their occurrence is further negated on two grounds; the first is the marine environment required for radiolaria, and the second is that diatoms are not expected to occur in Early Jurassic lake deposits. Diatoms did not evolve until the onset of Cretaceous times. As such, the absence of organic siliceous material and evidence for contemporaneous hot springs indicates that the Scots Bay cherts were penecontemporaneous with deposition and are inorganic in origin.

CHAPTER SEVEN
PALEONTOLOGY AND AGE

7.1 Introduction

The occurrence of invertebrate fossils in the Fundy Group has been known for about a century, but these fossil assemblages have not yet been well studied, described and documented. There is a variety of fossils and some are well preserved in the Scots Bay Formation.

Because there is a paucity of studies of Late Triassic-Early Jurassic nonmarine fossils available worldwide, there is insufficient knowledge about their biostratigraphy, paleoecology and evolution. This information is necessary to understand and interpret the depositional environments, age and paleoecology of the Scots Bay Formation as well as other Fundy Group formations along eastern North America.

The Scots Bay Formation contains microgastropods, ostracodes, vascular plants, stromatolites, dinosaur footprints, and vertebrate bones, and fish teeth and scales (Cameron & Jones 1990). In the study of the molluscan fauna of the Scots Bay Formation, some progress was made by Cameron (1986) and Cameron and Jones (1988).

In this study, 139 specimens of small bivalves and microgastropods were collected and prepared for study. Sixty-three specimens are snails. Silicified miscellaneous vascular plant materials, such as unidentified wood fragments and stems, were collected but not studied. Freshwater ostracodes are the most common faunal element in the Scots Bay Formation. Silicified ostracode specimens are common in bioclastic limestones at Woodworth Cove, Central Broad Cove and East Broad Cove. Nearly 800 specimens were prepared and studied.

The Scots Bay Formation is at a crucial age just above the Triassic-Jurassic boundary over which there is currently a debate regarding the kind and number of late Triassic extinction event(s) (Olsen and others, 1987). Because there are very few well preserved early Jurassic freshwater fossil assemblages known worldwide, a thorough study of the fossils of the Scots Bay Formation should be significant regionally along the eastern North America continent and possibly more broadly to correlations with northwest Africa (Sues and Olsen, 1990) and elsewhere.

7.2 PREVIOUS WORK

Previous studies of the Scots Bay Formation began earlier this century with Haycock (1900), who examined the Scots Bay rocks and suggested a Cretaceous age based on his fossil collection which included fish scales and teeth and fucoids. The name

Scots Bay Formation was proposed by Powers (1916), who reported plant remains, "worm" burrows, and fish scales and bones from these beds. Klein (1962) reported finding Isaura ovata (Lea) from the Scots Bay Formation. Thompson (1974) described and identified in thin section the freshwater gastropod genus *Hydrobia* from the Scots Bay Formation.

Cameron (1985, 1986), Cameron and Jones (1988, 1990) and Cameron and others (1990) identified freshwater ostracodes, microgastropod species, plant fossils, vertebrates, and calcareous algae which could be used as age determiners for the Scots Bay Formation. They identified the microgastropod genera *Hydrobia*, *Valvata*, and *Gyraulus* (=*Planorbis*) and the ostracode genera *Metacypris* and *Darwinula*, indicating post-Triassic, possibly a Jurassic age.

7.3 METHODS

Field work involved describing and measuring several sections in each cove. Samples were taken from each outcrop for paleontological and sedimentological laboratory descriptions and analyses. Seventy-five thin sections were studied with a petrographic microscope. In this present study, approximately 800 specimens of ostracodes, 53 small bivalves, and 63 microgastropods (Fig. 7-1) were prepared and studied from collections taken from different localities in the study area during the summers of 1997 and 1998. Although silicification has enhanced preservation of some fossils, details, such as ostracode muscle scars and other internal features, are difficult to observe. Physical and chemical methods were used to release the silicified ostracode and micromollusk shells from their matrices. Some ostracodes were prepared with low concentrations of acetic acid or formic acid, while others were released from matrix by boiling the weathered and crushed rocks only in water. Light and SEM microscopes were employed for study and photomicrography of these microfossils.

7.4 FOSSIL ASSEMBLAGES

Fossils in the Jurassic Scots Bay Formation are rare and mostly silicified. They include a relatively low diversity of ostracodes, small gastropods, small clams, invertebrate burrows, fragments of charophyte stems, freshwater stromatolites, log and wood fragments, rare ferns, and very rare fish, vertebrate bones, and dinosaur footprints. In this study, ostracodes and mollusks were studied most and the plants and trace fossils least.

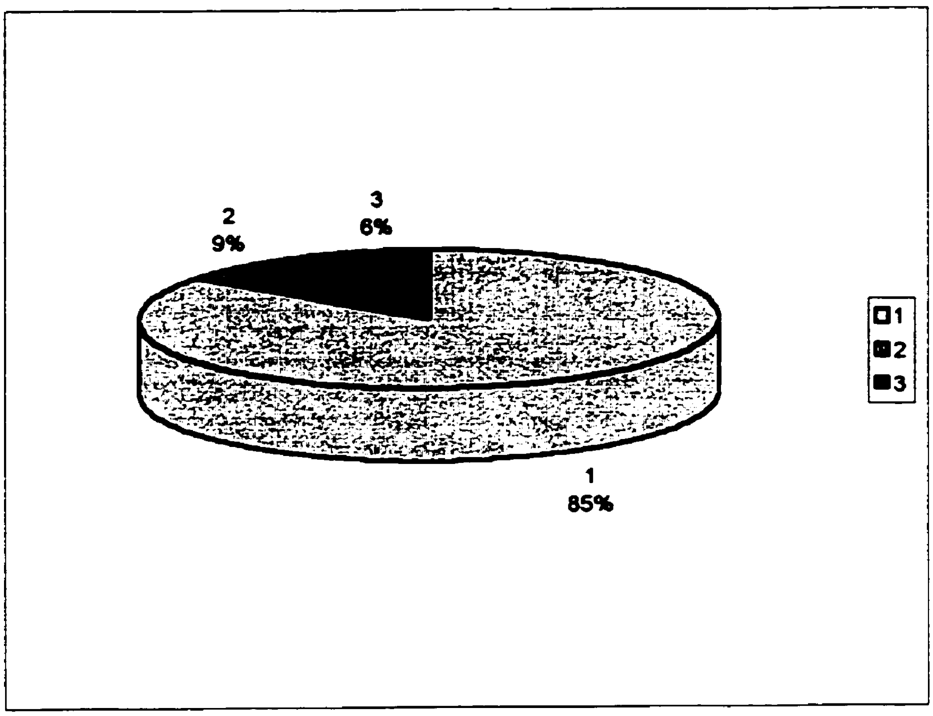


Figure 7-1. The main faunal percentages (by number of specimens) in the Scots Bay Formation: 1) ostracodes, 2) microgastropoda, and 3) small bivalves.

7.4.1 Chlorophyta

Green algae (chlorophyta) are represented by charophyte "stems" (Charophyta) which range from late Silurian to Recent. In the Scots Bay Formation, these are silicified algal "stems" that have been observed under the microscope, particularly in samples from West Broad Cove and East Broad Cove. These fossils are silicified tubes measuring about 0.4 to 0.6 mm in diameter and about 1.4 mm between nodes (Plate 1). The nodes are interpreted to be the base of tiny branchlets characteristic of charophytes from lacustrine environments. No well-preserved gyrogonites were recovered. Probably, they grew in a nearshore alkaline littoral environment of the Scots Bay Lake.

7.4.2 Vertebrata

The vertebrate fossils identified by Cameron and Jones (1988) include dinosaur footprints *Anchisauripus* and *Eubrontes*, sphenodontid bones (?*Clevosaurus*), osteichthyan remains of *Semionotus* (Jurassic), and spiral coprolites from freshwater sharks. The composite age range for these fossils is late Triassic to Early Jurassic.

Explanation of plate 1

Plate 1. SEM photomicrographs of silicified "stem" fragments of charophytic algae. Note the bases of "branchlets" clustered (swellings) at the nodes (X24).

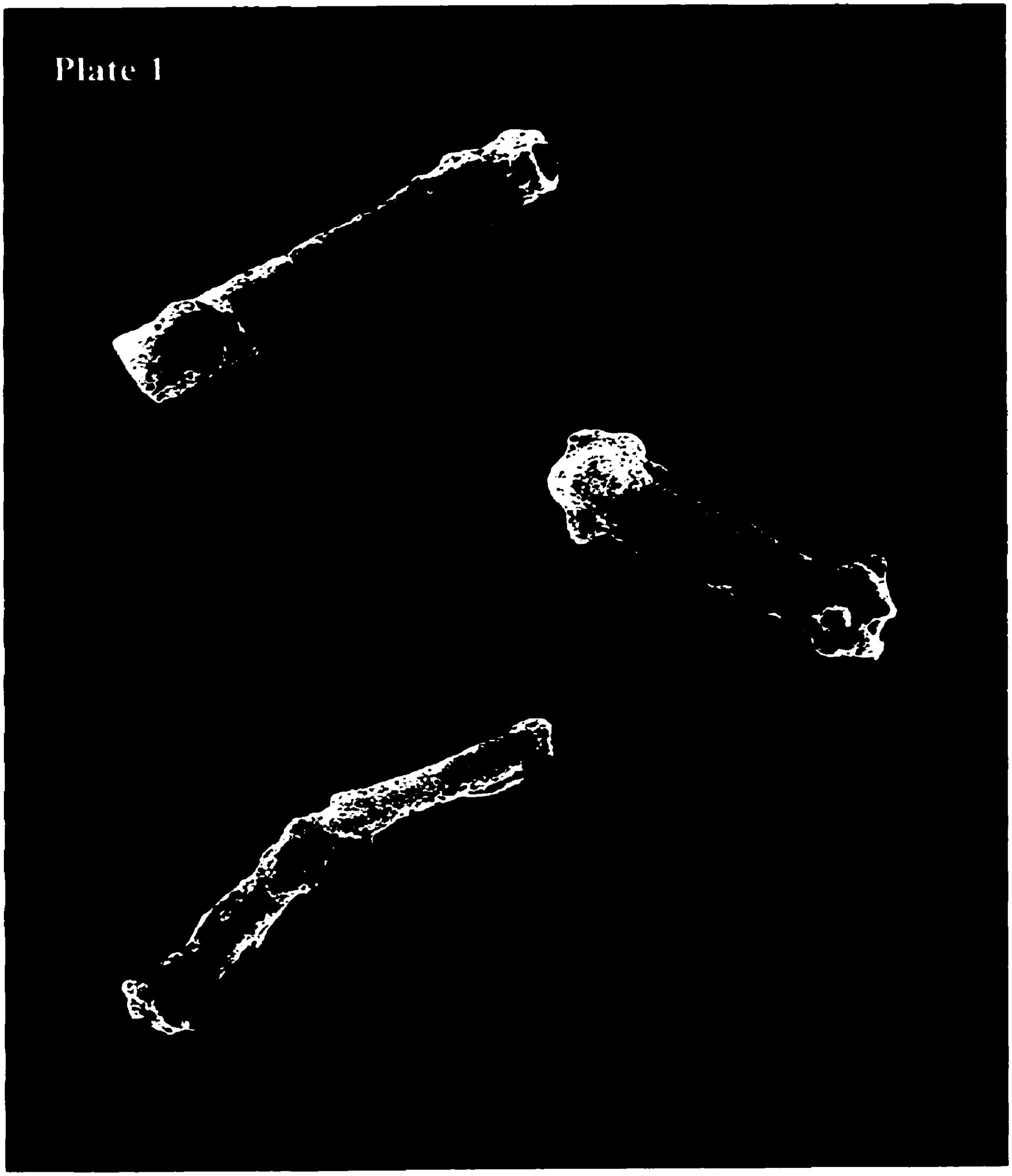


Plate 1

7.4.3 Mollusca

Small clams and gastropods characterize the fossil mollusks of the Scots Bay Formation. Microgastropods have been found in Woodworth Cove, Central Broad Cove and East Broad Cove. They are most common in association with ostracodes in bioclastic limestone beds, e.g., at Central Broad Cove. The gastropod genera identified so far include *Gyraulus*, *Valvata*, and *Hydrobia*. A new small bivalve identified as *Naiadites scotsbayensis* n. sp. has been found in the Scots Bay Formation. It is rare and occurs in a bioclastic limestone bed 55 cm above the base of the section at East Broad Cove and in the basal beds at Woodworth Cove. This fossil may be what Klein (1962) identified as Isaura ovata (Lea), as they have not been recognized by any other workers.

7.4.4 Small Ostracodes

Since their first appearance in the Devonian, freshwater ostracodes have increased considerably in diversity. During much of the Mesozoic, cytherids and cypridids shared dominance, while darwinulids, which are relatively minor components in most Mesozoic-Cenozoic deposits, were predominant during the Permo-Carboniferous (Mckenzie, 1971). In the Scots Bay Formation, darwinulids dominate the ostracode assemblage.

Little, however, is known about Early to Middle Jurassic freshwater ostracodes in the world and particularly in North America. Besides the Scots Bay Formation, they have been reported from only a few other places, such as the Fastnet Basin of Southwest Ireland, coal-bearing strata of South China, the Ardon Formation of Israel, and other Triassic-Jurassic "Newark" basins of eastern North America. Those reported from the Newark basins have rarely been thoroughly studied or identified. Therefore, comparative morphological and taxonomic problems were encountered in this study due to the lack of information on comparable Early Jurassic nonmarine microfaunas.

Three genera of silicified small freshwater ostracode species occur in the Scots Bay Formation: *Darwinula, Timiriasevia* and *Metacypris.* They were mostly thin-shelled forms that are now moderately to well preserved. However, extensive silicification obscures the morphology of some specimens. Despite the large number of specimens, the diversity of species is low, as is typical of freshwater ecology (Van Morkhoven; 1963, Moore, 1961). *Darwinula* is, however, more abundant than both *Metacypris* and *Timiriasevia* counted together. *Darwinula* is represented by at least three species. All of these species are now reported as new occurrences in the Scots Bay Formation. *Timiriasevia* is reported for the first time from the Scots Bay Formation, and it is represented by one species. *Metacypris* was also found and identified by Cameron (1986).

There is some confusion in the literature over the identification of the genera *Timiriasevia* and *Metacypris* because of their morphological similarities with the genera

Gomphocythere, *Bisulcocypris* and *Cytheridella*, (Table 7-1). Internal features and muscle scars were not observed for these specimens from the Scots Bay Formation which makes their positive identification difficult. It is also not easy to differentiate between *Bisulcocypris*, *Metacypris* and *Timiriasevia*, as they resemble each other so closely externally that they could be considered one genus (Honigstein, pers. comm., 1998). Pinto and Sanguinetti (1958) also found great confusion among authors about the genera *Metacypris*, *Gomphocythere*, and *Cytheridella*.

Some representatives of *Timiriasevia* and *Metacypris* in this assemblage are characterized by a prominent ridge developed along the mid-ventral region of the carapace.

7.4.5 Giant Ostracodes

A new species of a unique "giant" ostracode occurs only in a calcareous sandstone bed at Woodworth Cove. It is associated with species of *Darwinula* and is found as whole carapaces and single silicified valves. Such ostracodes have not reported, and it has not been possible to see the hinge line clearly nor internal muscle scars, so identification is difficult. Its phylogenetic relationships, therefore, remain obscure. This thin-walled ostracode may not otherwise have been preserved were it not for the silicification of the valves and their permineralization with silica. Thus, perhaps this kind of ostracode should be expected to be rarely preserved and difficult to identify.

	METACYPRIS	GOMPHOCYTHERE	CYTHERIDELLA	BISULCOCYPRIS	TIMIRIASEVIA
Outline in dorsal view	Female cordate; male ovate, no depression or sulcus. Constricted, no sulcus.	Female piriform; male ovate elongate; in front of the anterior middle portion becomes	Female cordate; male ovate with a strong sulcus in the anterior middle portion.	Female piriform; male ovate elongate, with two sulci in the anterior portion.	Both female and male have heart shape.
Outline in lateral view	Oblong, with convex dorsal margin rounded in front and obscurely angular behind.	Rhomboidal, with straight dorsal margin.	Rhomboidal, with straight dorsal margin, inclined forward in the anterior third.	Rhomboidal to oblong with a sinuose to an almost straight dorsal margin.	Oval, slightly constricted anterior of mid-point.
Ventral view	Flat and deeply impressed along the central and posterior portions of median line.	Flat, defined at the sides by the velate ridges. No marginal ridges.	Flat and slightly impressed along the central and posterior portion of the median line. No marginal ridges.	Flat and slightly impressed along the central portion of median line. No marginal ridges.	Ventral margin weakly convex in anterior third. Ventral side of the carapace is flattened to produce a broad surface.
Ornamentation	Without or with nodes; no velate ridge or carina.	Without nodes; presents ventrally a strong longitudinal velate ridge.	Unisulcate in front of midlength and without other ornamentation as nodes, velate ridge or carina.	Bisulcate anteriorly without or with nodes; no velate ridge.	Fine pits, small ribs, individual longitudinal ridges bifurcate and unite.
Hingement	RV with laminated angular projection anteriorly, posteriorly by a strong rectangularly produced flange, which projects a single sharply cut tooth. LV formed by a deep sulcus behind and shallower one in front.	Lophodont	One valve has a well developed selvage forming a hinge-bar that fits in a sulcus (flange groove) in the opposite valve.	One valve has a flat anterior tooth which is smooth and semicircular and a more triangular smooth and sharp posterior tooth. Between the teeth a narrow and straight sulcus to receive the hinge-bar from the opposite valve.	RV hinge provided with smooth median furrow and elongate terminal tooth plates (Treatise, 1961). Median bar long, smooth, and strongly developed (Bate, 1965).

Table 7-1. Comparative table of five ostracode genera, (Modified after Pinto and Sanguinetti, 1958).

7.5 SYSTEMATIC PALEONTOLOGY

Phylum Mollusca

Class Bivalvia

Order Pterioida Newell, 1965

Family Myalinidae Frech, 1891

***Naiadites* Dawson 1894**

Type species: *Naiadites carbonarius* Dawson, Supp. Acad. Geol. (1860); Rev. Biv. Moll. Coal Form. Nova Scotia (1894) p. 6, figs. 1-3.

Description: Like *Myalina* internally, apart from minor differences of anterior musculature resulting from relatively greater length of anterior end in *Naiadites;* modioliform, umbones not terminal. LV usually more inflated than RV; wide and shallow byssal sinus present in some; carina (umbonal ridge) of variable curvature, inflation and prominence runs from umbo of one or both valves toward posteroventral margin (Moore, 1960).

Naiadites scotsbayensis n. sp.

Plate 2

Derivation of specific name. **With reference to the Scots Bay Formation.**

Description: Silicified shell ovate, modioliform, unequivalve, elongate marked with

growth lines, umbones terminal, with pointed anterior end. Hinge and musculature unknown, inner surface smooth. Length averages 6.6 mm (range = 2.5-16.2 mm), thickness averages 2.6 mm (range = 1.1-5.5 mm), and width averages 3.6 mm (range = 1.6-7.2 mm) (Table 7-2, Fig. 7-2).

Remarks: Although the majority of freshwater bivalves occurring in the Mesozoic belong to the Family Unionidae, these bivalve shells have no affinity with any recognized genus found in Jurassic nonmarine rocks. Therefore, identification was difficult and is to be considered tentative at this stage of study. *Naiadites scotsbayensis* n sp. does not belong to the well-known freshwater family Unionidae because of differences in morphology, such as shell outlines. Its elongate shell outline reveals a resemblance to the nonmarine Myalinidae, particularly the genus *Naiadites*, which is represented particularly in the Early Pennsylvanian coal-bearing deposits of western Europe and Nova Scotia (Newell, 1940).

The relatively thick shell resembles macrofossil marine species of *Inocermaus* but its size is smaller. These differences in size and habitat preclude the possibility of *Inocermaus*.

Based on the shell outlines and shape (Plate 2) these bivalves reveal characteristics very similar to the genus *Naiadites*, espically *N. carbonarius* Dawson from the Carboniferous "Coal Formation" of Nova Scotia (Newell, 1940). *N. carbonarius*, however, is larger in size than *Naiadites scotsbayensis* n. sp.

These similarities may raise the possibility of erosional reworking processes during the Early Jurassic that cannot be easily addressed. Otherwise, the range of this freshwater bivalve genus must be extended to the Early Jurassic.

Location: These small bivalves have been found in East Broad Cove, 55 cm above the base, and in the basal beds exposed at mid-tide at Woodworth Cove.

Types: Holotype NSEBC1, paratypes NSEBC2 and NSEBC3.

Sample No.	Length (mm)	Width (mm)	Thickness (mm)
1	16.2	7.2	5.5
2	10.7	6.8	4.2
3	11.7	4.9	4.2
4	10.1	6.4	5.0
5	9.4	5.1	3.4
6	6.5	3.5	2.6
7	7.0	3.7	2.8
8	7.9	3.8	3.1
9	7.5	4.7	3.5
10	6.8	3.3	2.1
11	7.2	4.5	2.8
12	6.2	2.8	2.7
13	6.9	3.7	1.7
14	5.8	3.2	2.2
15	7.0	4.6	2.5
16	8.8	4.3	3.0
17	7.0	4.4	3.3
18	4.6	2.4	2.7
19	9.2	4.0	3.3
20	5.1	3.8	2.2
21	6.3	3.7	2.5
22	6.9	3.1	2.4
23	4.2	2.5	2.3
24	6.1	3.0	2.8
25	4.3	2.5	2.4
26	4.1	2.8	2.0
27	3.7	2.1	1.9
28	5.6	3.1	2.4
29	4.3	2.5	2.0
30	3.7	2.4	1.7
31	5.3	3.0	2.3
32	2.7	1.9	1.3
33	7.7	4.3	2.5
34	7.9	4.8	2.6
35	4.6	3.0	2.3
36	3.9	1.6	1.7
37	2.5	1.8	1.1
Means	6.6	3.6	2.6

Table 7-2. Measurements (mm) of 37 specimens of *Naiadites scotsbayensis* n. sp.

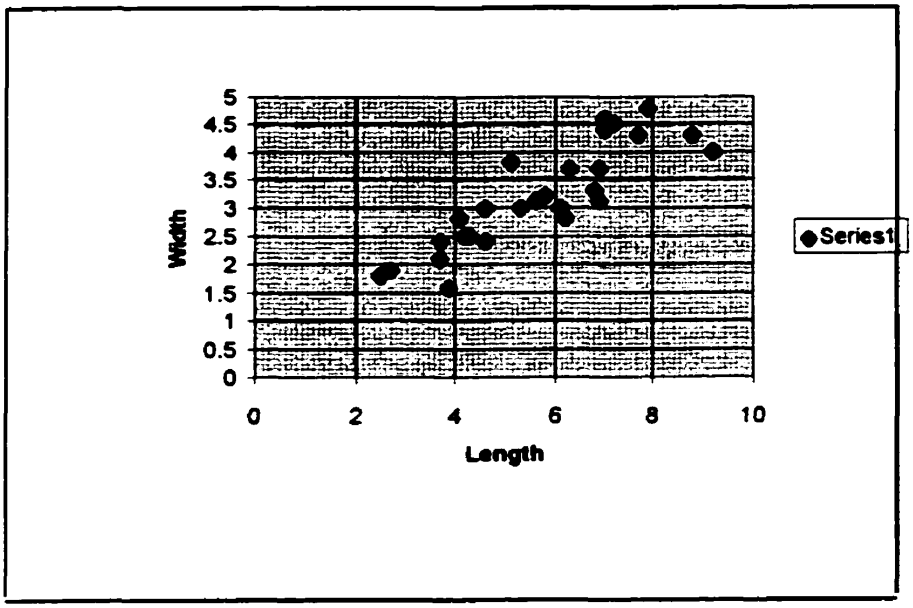


Figure 7-2. Growth series for *Naiadites scotsbayensis* n. sp.

Explanation of plate 2

Plate 2. New small bivalve (?*Naiadites scotsbayensis* n sp.) found at East Broad Cove. (X 6).

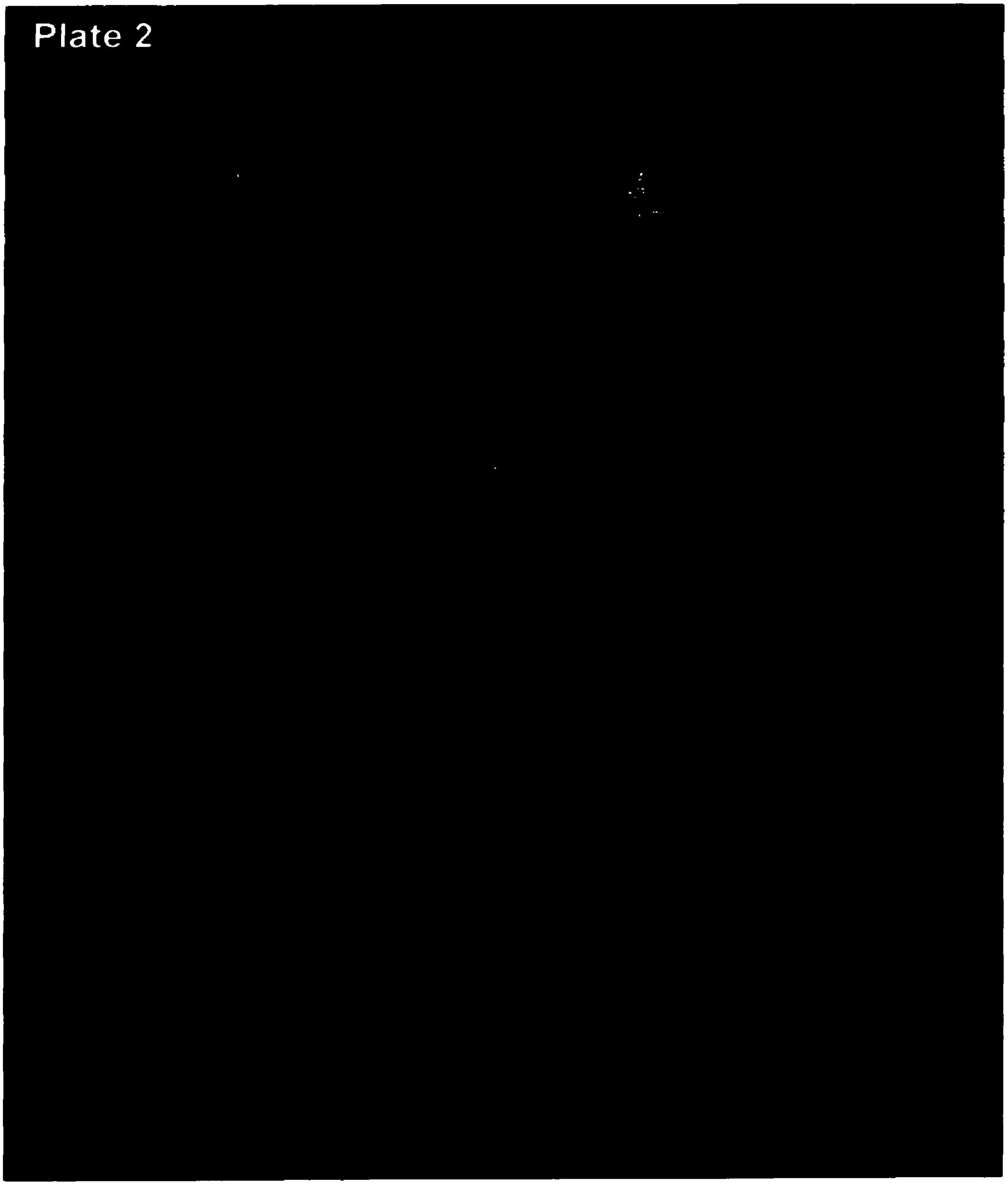


Plate 2

Class Gastropoda

Order Caenogasrotpoda Cox, 1959

Family Hydrobiidae Stimpson, 1865

Hydrobia Hartmann, 1821

Genus: *Hydrobia* Hartmann, 1821 (*Paludestrina* Orbigny, 1840) Pilsbry, Philadelphia Acad. Nat. Sci., Pr., 86 (1934) p. 559-560.

Description: Entire shell, or early whorls only, acute; whorls convex, smooth or with collabral threads; apertural margin uninterrupted, not thickened (Moore, 1960).

Hydrobia sp.

Plate 3, Fig. 1, 2

Description: Silicified, thin-shelled, high-spired, acute, heavily costate axially, apex blunt. Consisting of five whorls separated by well-impressed sutures. Aperture ovate and uninterrupted. The height of the last whorl is about third of total length.

Dimensions: Average measurement of specimens: height 1.90 mm and width 0.90 mm.

Family Valvatidae

Valvata Muller 1774

Type species: *Valvata bicincta* WHITEAVES, Contr. Can. Pal., 1, pt. 1 (1885) p. 25, pl. 3, fig. 8; Cret., Mouth of Blind River, Canada; Can. Geol. and Nat. Surv., ann. Rept., n. s., 2-E (1886) p. 166.

Description: Shell small, spiral, turbinate or subdiscoidal; whorls rounded or carinated; aperture entire, circular; lip simple, sharp; operculum orbicular, multispiral; whorls with a thin elevated edge (Walker, 1918).

Valvata sp.

Plate 3, Fig. 3, 4

Description: Silicified shell, umbilicate, smooth, without lamella, with 3 to 3 1/2 whorls. Spire slightly elevated, suture impressed, aperture circular. No carina.

Dimensions: Average measurement of specimens: height 1.5 mm, width 1.2 mm.

Family Planorbidae

Gyraulus (=*Planorbis*) Geoffroy 1767

<u>Genus</u>: *Planorbis* n. sp. Jepsen, Am. Phil. Soc., Pr., 69 (1930) p. 495; Gray Bull Eocene, Park County, Wyo.

<u>Description</u>: Shell small to moderately large, flatly coiled in most species or with a very low spire in a few; umbilicus present. Operculum absent. (Clarke, 1981).

Gyraulus sp.

Plate 3, Fig. 5

<u>Description</u>: Smooth, small silicified shell with no growth lines preserved; with three whorls and impressed suture lines. Body whorl flat and slightly rounded, aperture ovate to elliptical. Shelf developed, especially on outer whorls and a spiral carina forming a slight keel at distal edge of shelf. Umbilicus wide and moderately deep, bordered by rounded rim.

<u>Dimensions</u>: Average measurement of specimens: wide 2.2 mm, height 0.25 mm.

Explanation of plate 3

Hydrobia sp.

Fig. 1- Apertural view (X 30)

Fig. 2- Abapertural view (X 33)

Valvata sp.

Fig. 3- Apertural view (X 30)

Fig. 4- Side (apical ?) view (X 38)

Gyraulus sp.

Fig. 5- Apical view (X 42)

Fig. 6- Umbilical view (X 35)

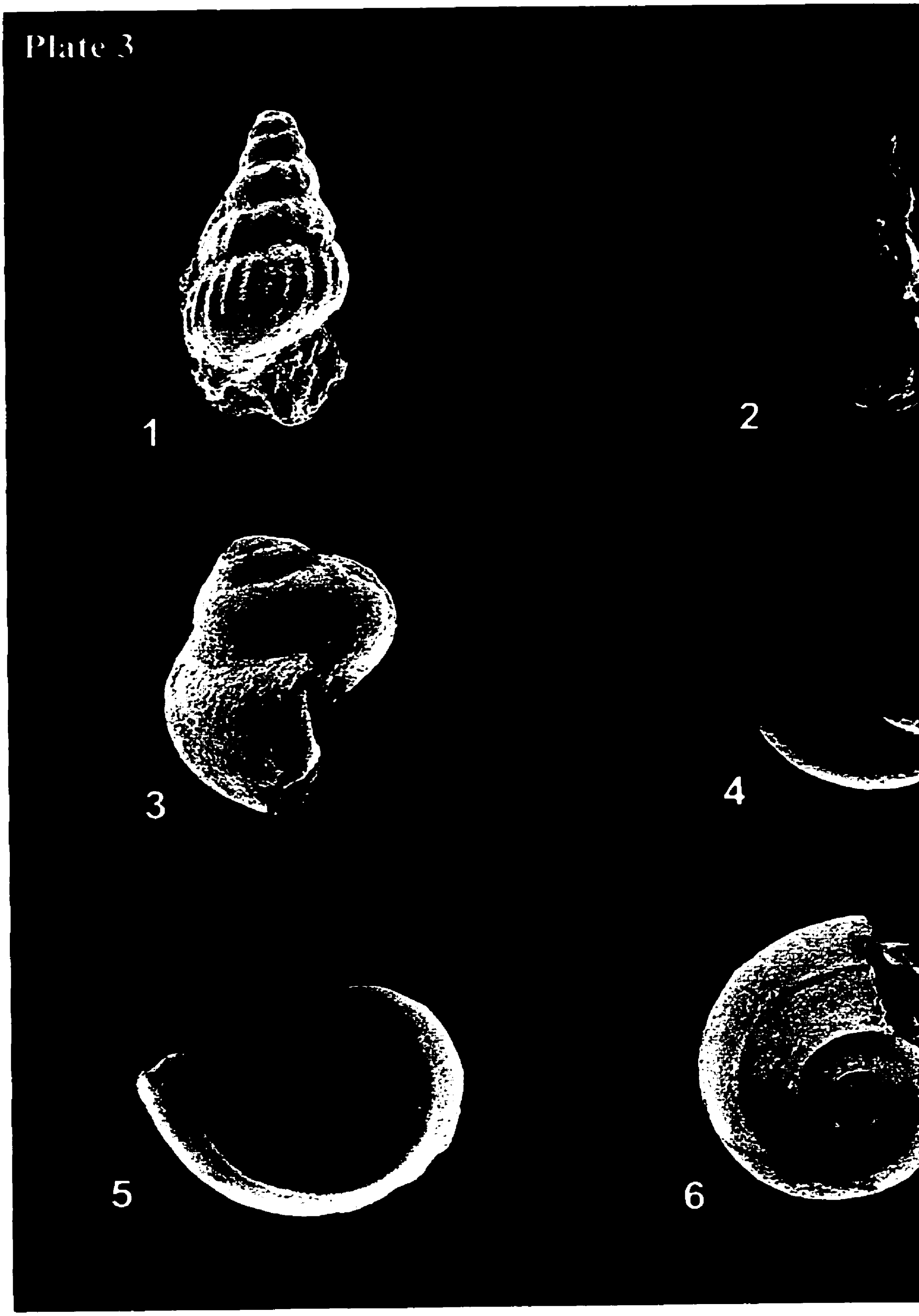


Plate 3
1
2
3
4
5
6

Phylum Arthropoda

Class Crustacea Pennant, 1777

Subclass OSTRACODA Latreille, 1806

Order Palaeocopida Henningsmoen, 1953

Suborder Podocopina Sars, 1866

Superfamily Darwinulacea Brady and Norman, 1889

Family Darwinulidae Brady and Norman, 1889

Darwinula Brady and Robertson, 1885

1870 *Argilloecia* (part.) plus *Polycheles*, Brady and Robertson in: Ann. Mag. Nat. Hist., ser. 4, v. 6, p. 10, 25.

1872 *Darwinella,* Brady & Robertson in: Ann. Mag. Nat. Hist., ser. 4, v. 9, p. 50.

1889 *Darwinula,* Brady & Norman in: Sci. Tr. Royal. Dublin Soc., ser., 2, v. 4, p. 121.

Description: Elongate, oblong or ovate, thin-shelled calcitic carapace; surface is smooth; height less than one-half the length, usually highest in the posterior quarter; anterior is usually narrower than posterior. Margins are rounded with posterior margin broader and well-rounded; ventral margin straight. Adont hinge forms as a result of right valve overlapping the left valve.

Dimensions : The length ranges from 0.35 to 1.2 mm, height 0.20 to 0.55 mm.

Occurrence: This genus is well known for its worldwide distribution in fresh- water deposits, particularly in Mesozoic rocks. They have been found, for example, in the Middle Jurassic rocks of China, Wealden Formation of Germany, and Early Jurassic Kota Limestone of India. In the Scots Bay Formation, this genus has been found in most outcrops where it is most abundant in bioclastic silty sandy limestones.

Darwinula sarytirmenensis Sharapova, 1947

Plate 4 , figs. 3, 4, 7

1947 *Darwinula sarytirmenensis,* Sharapova, Mandelstam, Atlas of the leading form fossils, fauna U.S.S.R. pl. 2, fig. 8.

1975 *Darwinula sarytirmenensis*, Govindan, Paleontology, v. 18, part 1, p. 215, text-fig. 2a-h.

Description: Carapace is irregularly oval, kidney shaped, large, smooth; both ends rounded in lateral view, anterior end broadly rounded; greatest height slightly posterior to midlength. Left valve larger and overlaps right valve throughout entire length of ventral margin. Dorsal margin slightly convex; ventral margin moderately concave.

Dimensions: Average measurement of specimens: length 0.95 mm, height 0.48 mm (Table 7- 3).

Materials: Six whole specimens and single valves.

Remarks: Shell is thinly silicified. Muscle scars and internal features were not observed. Although similar to *Darwinula magna* (Jiang, 1963), the height/length ratio is much higher. It is distinguishable from the other species in the Scots Bay Formation by its slightly convex dorsal margin and concave ventral margin, and more evenly rounded posterior region.

Location: Central Broad Cove, 190 cm above base; only single valves at Woodworth Cove, 110 cm above base.

Samples	Length (mm)	Height (mm)
1	1.10	0.55
2	0.80	0.42
3	1.00	0.50
4	0.82	0.40
5	0.95	0.45
6	1.00	0.53
Mean	0.95	0.48

Table 7- 3. Measurements (mm) of 6 specimens of *Darwinula sarytirmenensis.*

Darwinula aff. *liassica*

Plate 4 , figs. 1, 2

1894 *Darwinula liassica* (Brodie), Jones, , pl. 9, figs. 1a, b, c, p. 162.

1964 *Darwinula liassica,* Anderson, pl. XIII, figs. 81, 82.

Description: Carapace small, elongate, valve surfaces smooth. Dorsal margin nearly straight or weakly convex, ventral margin straight. Left valve larger than right valve which it overlaps. Both ends rounded in side view, anterior end slightly narrower than posterior end. Greatest length passes through slightly below mid-point.

Dimensions: Average measurement of specimens: length 0.56 mm, height 0.25 mm (Table 7- 4).

Materials: Ten whole specimens

Remarks: Shell is silicified. Dimensions are precisely the same as *Darwinula liassica* as given by Wilson (1964) from the Bristol Horizon (Rhaetic assemblage). It can be distinguished from the *Darwinula oblonga* (Roemer, 1939) and Darwinula *major* (Jones, 1894) by a slightly arched dorsal margin near the anterior end and by its smaller size. This species has been reported from Rhaetic strata of England and Germany and also from Mesozoic coal-bearing strata of South China (late early Jurassic assemblage).

Location: East Broad Cove and Central Broad Cove from 190 cm above the base.

Samples	Length (mm)	Height (mm)
1	0.52	0.23
2	0.60	0.29
3	0.61	0.26
4	0.57	0.26
5	0.60	0.27
6	0.55	0.27
7	0.50	0.21
8	0.52	0.22
9	0.58	0.27
10	0.55	0.25
Mean	0.56	0.25

Table 7- 4. Measurements (mm) of 10 specimens of *Darwinula aff. liassica*

Darwinula acadiaensis n. sp.

Plate 4, figs. 5, 6

Derivation of name. With reference to Acadia University.

Description: Carapace oblong, valve surface smooth. Both ends rounded in lateral view, anterior end narrower than posterior end; greatest height anteromedian. Ventral margin nearly straight, dorsal margin slightly convex and strongly arched near the anterior end. Muscle scar pattern consists of a rosette of radially elongated attachment sites; the number of individual scars varies from 9 to 12.

Dimensions: Average measurement of specimens: length 0.82 mm, height 0.40 mm (Table 7-5).

Materials: 93 carapace and 8 single valves.

Remarks: Shell is silicified; mostly internal molds available for study. This species is somewhat similar to *D. sarytirmenensis* Sharapova (1947), but its dorsal margin is more strongly arched near the anterior end. Also, the ventral margin is nearly straight whereas in *D. sarytirmenensis* it is slightly concave.

D. acadiaensis is represented by both juveniles and adults (Fig. 7-3).

Location: East Broad Cove from 190 cm above the base.

Types: Holotype is specimen DAEBC1; paratypes are DAEBC2 and DAEBC 3

Samples	Length (mm)	Height (mm)
1	0.82	0.40
2	0.83	0.40
3	0.90	0.49
4	0.83	0.40
5	0.80	0.40
6	0.85	0.41
7	0.88	0.40
8	0.90	0.46
9	0.80	0.38
10	0.97	0.50
11	0.80	0.40
12	0.80	0.41
13	0.81	0.40
14	0.75	0.31
15	0.60	0.27
Mean	0.82	0.40

Table 7-5. Measurements (mm) of 15 specimens of *Darwinula acadiaensis* n. sp.

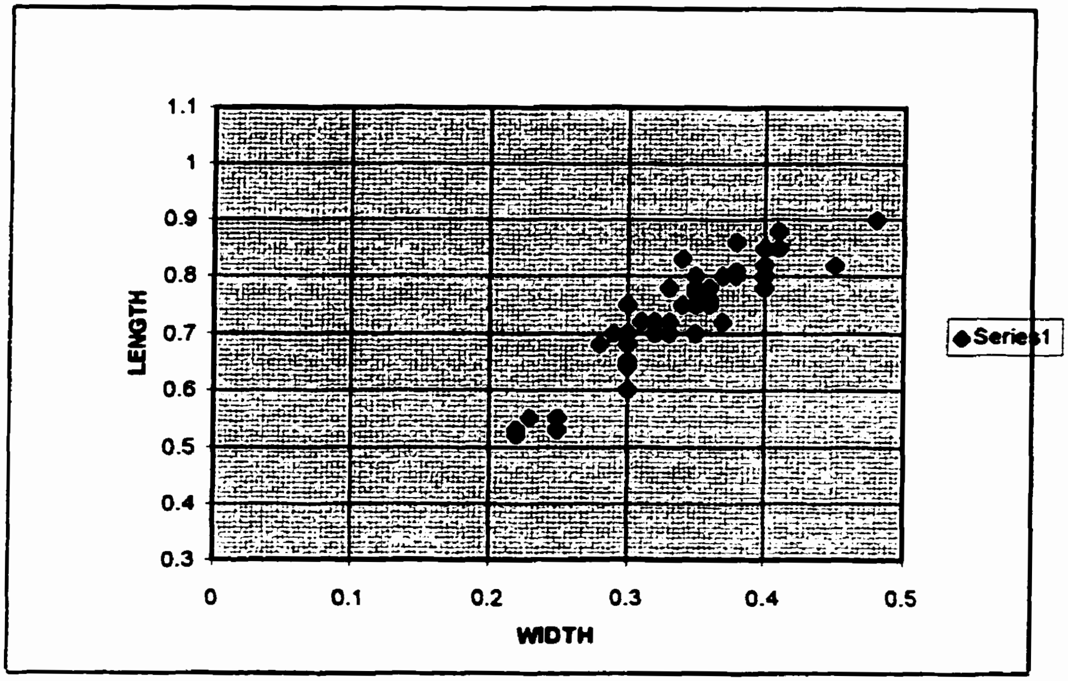


Figure 7-3. Growth series for *Darwinula acadiaensis* n. sp.

Darwinula sp. 1

Plate 4, fig. 8

Description: Elongate, oblong, thin-shelled carapace; surface smooth. Height less than one-half the length, greatest height at midlength. Maximum length at mid-height. Both anterior and posterior ends are usually narrow but anterior end narrower. Ventral margin straight, dorsal margin very weakly arched at mid-height.

Dimensions: Average: length is 0.45 mm, average height 0.20 mm

Materials: One whole specimen and four poorly preserved carapaces.

Remarks: *Darwinula* sp. 1 can be distinguished from the other species by its more narrowly rounded posterior and anterior ends. This species is similar to *Darwinula hettangiana* Ainsworth but its size is quite smaller.

Location: East Broad Cove from 190 cm above the base.

Explanation of plate 4

Darwinula aff. *liassica*

Fig. 1- Oblique view (X 77)

Fig. 2- Ventral view (X 66)

Darwinula sarytirmenensis

Fig. 3- Oblique view (X 43)

Fig. 4- Oblique view (X 60)

Fig. 7- Dorsal view (X 56)

Darwinula n. *acadiaensis*

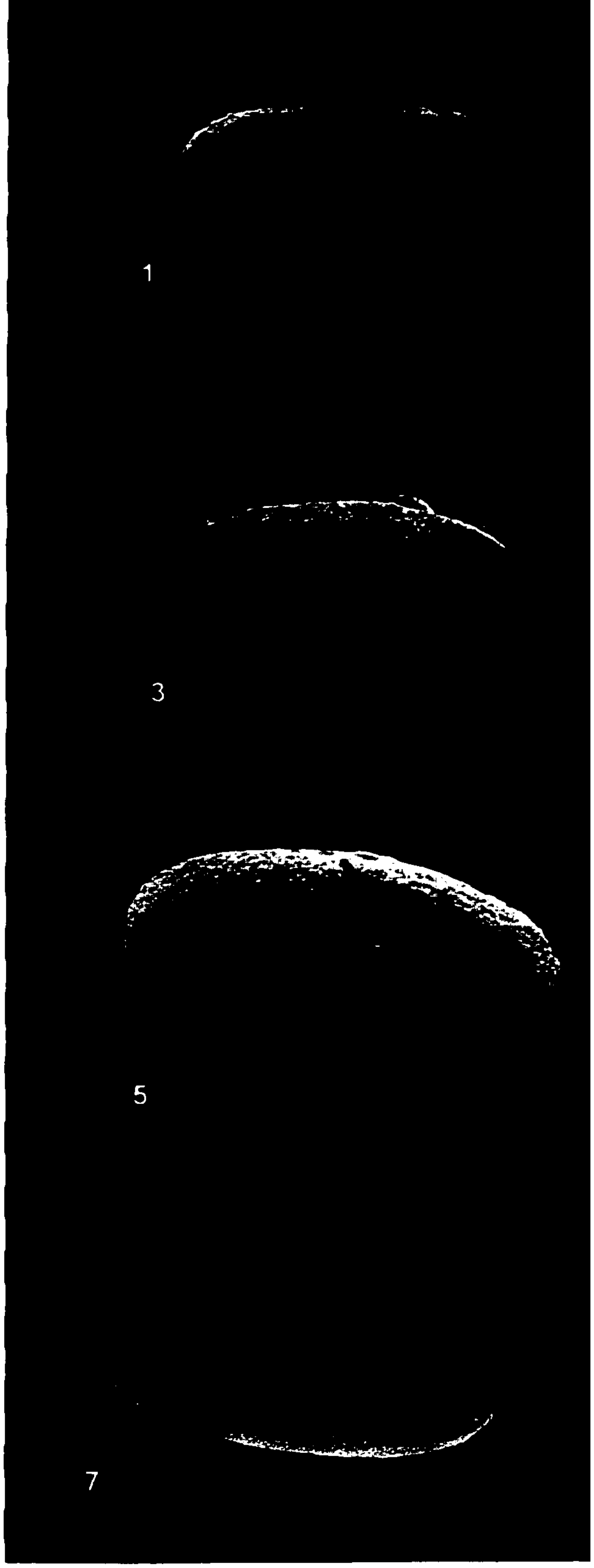
Fig. 5- Lateral view, arrow indicates adductor muscle scar on internal silica mold (X 77)

Fig. 6- Lateral view of juvenile carapace (X 60)

Darwinula n. sp.

Fig. 8- Lateral view (X 105)

Plate 4



Superfamily Cytheracea Baird, 1850

Family Limnocytheridae Klie, 1938

Metacypris Brady & Robertson, 1870

1870 *Metacypris cordata*, Brady & Robertson, in: Ann. and Mag. Nat. Hist., ser. 4, v. 6, p. 1-33, pls. 4-10.

Description: Carapace subrhombic from side, female heart-shaped from above, no sulcus, valve margins incurved except in anterior. Hinge of RV with laminated angular anterior projection and rectangular strongly produced posterior flange bearing a single sharply cut tooth (Moore, 1960).

Metacypris ridgensis n. sp.

Plate 5, Figs. 1 to 4

Derivation of name. With reference to a short ridge developed along the sides.

Description: Suboblong or subrhombic in lateral outline with tapering carapace margin, convex, unequal valved. Dorsal and ventral margins are nearly straight and parallel, but ventral margin may be slightly convex. Anterior end is narrowly rounded, but posterior end evenly thick and almost circular. Greatest length occurs at approximately mid-height. Small short longitudinal ridge developed parallel to the outer margin and centered posterior to mid-line.

Dimensions: Average measurement of specimens: length 0.51 mm, height 0.29 mm (Table 7-6).

Materials: More than 45 internal molds and 4 carapaces.

Remarks: Shell is silicified; mostly internal molds available for study. This genus resembles *Timiriasevia* in outline and surface ornamentation, but *Timiriasevia* is heart-shaped in dorsal view.

Location: East Broad Cove from 190 cm above the base.

Samples	Length (mm)	Height (mm)
1	0.45	0.22
2	0.46	0.30
3	0.45	0.35
4	0.57	0.36
5	0.52	0.30
6	0.65	0.38
7	0.40	0.19
8	0.58	0.32
9	0.57	0.31
10	0.47	0.28
11	0.40	0.22
12	0.60	0.30
Mean	0.51	0.29

Table 7-6. Measurements (mm) of 12 specimens of *Metacypris ridgensis* n. sp.

Family Uncertain

Genus Timiriasevia Mandelstam, 1947

1947 *Timiriasevia epidermiformis,* Mandelstam, in: *Vses. Neft. Nauchno-issled. Geol.-razy Inst.* 239-259, pls. 1-2.

Description: Carapace roughly kidney-shaped, LV larger than RV, anterior end always more broadly rounded than posterior end, dorsal margin almost straight to convex, ventral margin weakly convex in anterior third; surface with fine pits, small ribs, or irregular spines. Very like *Metacypris* (*syn. Gomphocythere*) in general features but with different hinge (Moore, 1960).

Timiriasevia aff. *digitalis*

Plate 5, figs. 4 to 8

1975 *Timiriasevia digitalis*, Govindan, Paleontology, v. 18, part 1, plate 37, fig. 7-11, p. 214.

Description: Carapace bean-shaped in lateral view, female is heart-shaped in dorsal view. Both valves are similar in size with greatest height one third of the distance from posterior to anterior. Anterior end tapers and is narrower than posterior end, while posterior end is more broadly rounded and almost spherical in dorsal view. Dorsal margin is straight to slightly convex; ventral margin is almost straight. In some specimens, a small short longitudinal ridge is developed parallel to the outer margin and centered posterior to mid-line. Valve surface reticulate with fine pits. Some male carapaces have poorly developed sulci on the anterior half. Muscle scars not seen. Strong sexual dimorphism; female much more swollen in posterior region than male.

Dimensions: Average measurement of specimens: length 0.49 mm, height 0.27 mm (Table 7-7).

Materials: 23 carapaces and 4 single valves.

Remarks: Size and general morphology resembles *Timiriasevia digitalis* Govindan (1975) of Kota limestone of India (Middle Jurassic). These specimens also resemble some species of *Bisulcocypris* and *Metacypris*, however they have only one poorly developed sulci on the anterior half of some male carapaces, not two. Some specimens are characterized by the presence of unique prominent short longitudinal ridge in the mid to posterior half, which makes them different from any other Mesozoic freshwater ostracode species assemblage. Furthermore, they are smaller than species of *Metacypris*. The assignment to *T. aff. Digitalis* is tentative due to the lack of muscle scars and preserved internal features.

Location: East Broad Cove from 190 cm above the base.

Samples	Length (mm)	Height (mm)
1	0.45	0.30
2	0.55	0.31
3	0.40	0.22
4	0.52	0.30
5	0.44	0.20
6	0.46	0.21
7	0.65	0.38
8	0.40	0.22
9	0.52	0.30
10	0.50	0.30
Mean	0.49	0.27

Table 7-7. Measurements (mm) of 10 specimens of *Timiriasevia aff. digitalis.*

Explanation of plate 5

Metacypris ridgensis n. sp.

Fig. 1- Oblique view (X 100)

Fig. 2- Dorsal view (X 51)

Fig. 3- Internal view of single valve (X 74)

Fig. 4- Oblique view of juvenile internal mold (X 74)

Timiriasevia aff. *digitalis.*

Fig. 5- Dorsal view of male carapace (X 74)

Fig. 6- Ventral view of male carapace (X 63)

Fig. 7- Dorsal view of female carapace (X 70)

Fig. 8- Ventral view of female carapace of internal mold (X 102)

Pla

1

3

Family Uncertain

Megawoodworthia n. gen.

Megawoodworthia salemi n. sp.

Derivation of name: The genus name with reference to its size and Woodworth Cove, where they have been found; species name with reference to author's father.

Description : Ovate to oblong shape with rounded ends (Fig. 7-4), ranging from 2.5 to 4.5 mm in length and 1.6 to 3.4 mm in height. The specimens appear to exhibit bilateral shell symmetry, where a line from the mid point on the dorsal margin drawn to the ventral margin roughly divides the better specimens into two equal halves with smooth surfaces. The ventral margin is slightly convex, rather than straight. The dorsal margin is straight to slightly convex and the more complete specimens are relatively wide thus creating a bulbous appearance. The hinge line is not often observable.

Dimensions: Average measurement of specimen: length 3.3 mm, height 2.6 mm (Table 7-8).

Materials: Twenty four carapaces and 86 valves.

Remarks: The original valve appears to have been very thin, as indicated by cleaned single valves and thin-section analysis of them. Because the valves are mainly nested and silicification coats many valves, the original valves may appear to be falsely much thicker. This early silicification may be the reason for the well preserved state of these thin-shelled giant ostracodes in the Scots Bay Formation and why they have not been reported elsewhere in the world.

Consulting fossil ostracode specialists about these large forms has led to some confusion. There have been contrasting suggestions about whether these fossils are giant ostracodes or bivalves. They are large enough to superficially resemble some freshwater bivalved micromolluscs, such as *Pisidium*. However, the morphological features described above, the thin shell that does not thicken dorsally, and the absence of growth lines all support an ostracode interpretation for these specimens.

Robin Whatley (personal communication, 1998, University of Wales) considered them to be ostracodes after examining photographs and suggested that they may have been reworked from an older marine formation. The possibility of reworked materials is rejected because they are so thin-shelled, they are preserved by silicification, and no such occurrence has been reported anywhere in Nova Scotia.

Rick Forester (personal communication, 1998, U. S. Geological Survey) examined single valves of these large specimens and suggested a bivalve affinity because the hinge area is poorly preserved, an umbonal area is present, their relatively large height/length ratio, and the absence of a bulbous posterior. He also believed that the height of most ostracodes is small relative to the length because ostracodes crawl around on the substrate and that would be hard to do if they were high relative to their length as in these specimens.

Samples	Length (mm)	Height (mm)
1	2.8	2.2
2	3.6	3.0
3	3.1	2.5
4	3.9	3.0
5	3.7	2.5
6	3.8	2.8
7	4.5	3.4
8	4.0	3.0
9	2.7	2.3
10	4.1	2.9
11	2.6	2.3
12	2.5	2.0
13	4.0	3.3
14	3.1	2.2
15	2.9	2.3
16	2.5	1.6
17	3.7	2.6
18	4.0	3.0
19	3.5	3.0
20	4.0	3.3
21	3.0	2.5
22	3.7	2.7
23	3.7	2.9
24	3.4	2.7
Mean	3.5	2.6

Table 7-8. Measurements (mm) of 24 specimens of *Megawoodworthia salemi* n. sp.

A "giant" ostracode interpretation for this fossil is supported by the following arguments: 1) The height-length ratio in whole specimens is not too abnormal and is similar to the ratio in other ostracode genera, such as *Cytherella*. 2) An umbo-like shell region is present on some ostracodes, such as in the Cypridinidae. 3) The absence of a bulbous shape in the posterior of these specimens is common in many groups of ostracodes. 4) These valves do not have a pronounced thickening of the shell toward the hinge area, as in clams. The latter is typical of growing bivalves because they calcify continuously and add extra shell material in the hinge area which is the oldest part of the shell. An ostracode calcifies a new thin valve after each moult, so it does not thicken the shell excessively in the hinge area. A pseudothickening is apparent on some of these specimens because of secondary silica cement over the silicified valves.

Type species: Holotype, MSWC1; paratypes MSWC2 and MSWC3.

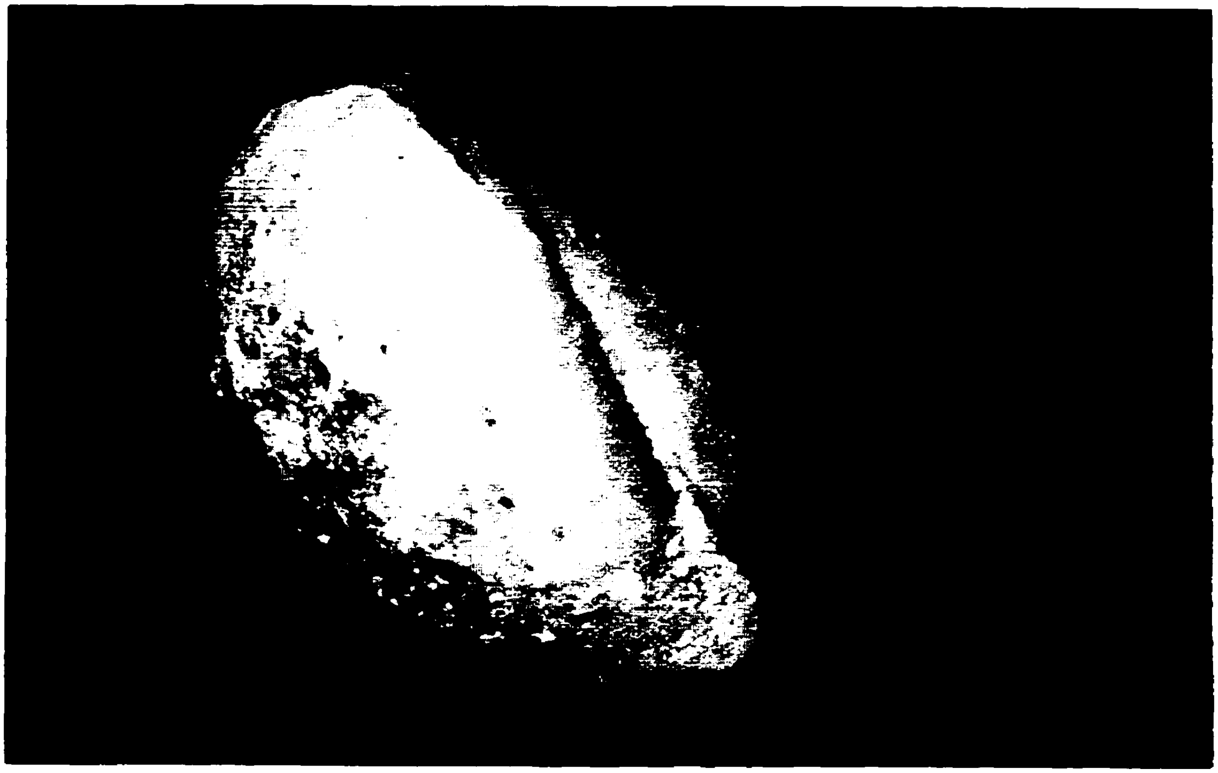


Figure 7-4. Dorsal view of *Megawoodworthia Salemi* n. sp., holotype MSWC1, X38.

7.6 PALEOECOLOGY OF SCOTS BAY

The study of the environmental requirements and water chemistry of ostracodes began early this century, so that paleoenvironmental reconstruction can be made from fossil ostracode assemblages. Ostracodes have been found in almost all environments: oceans, rivers, lakes, springs, estuaries and brackish lagoons. Carbonel (1988) reported that the abundance and diversity of ostracodes can reflect a good food supply, low energy levels and an adequate oxygen supply. The earliest known freshwater ostracodes inhabited shallow ponds, coal-forming swamps, and streams of Devonian time. Some ostracodes are well known as freshwater living organisms such as Darwinulidae, most of the Cypridae and a few Cytheridae.

During the early to mid Mesozoic, the process of sedimentation around the Bay of Fundy took place in mostly continental environments. No marine fauna were found in these sediments to indicate probable mixed marine and freshwater environments, such as in estuaries or lagoons.

Based on geochemical studies, Thompson (1974) concluded that the climate during the deposition of Scots Bay Formation was warm and humid with seasonal variation in precipitation. In this warm subtropical environment, ostracodes, microgastropoda and algae thrived in shallow well-oxygenated waters of Scots Bay Lake.

The ostracode assemblages in the Scots Bay Formation have are more numerous in carbonate rocks, rather than in the siliciclastic rocks. Limestones and carbonate deposits are well-known in slightly alkaline environments which are more appropriate for ostracode faunas. Today, and probably since the Jurassic, cyprid, darwinulid, and limnocytherid ostracodes occur in all fresh aqueous environments except those of low pH and very high alkalinity (Whatley, 1983). They are found from deepest lakes to the shallowest temporary puddles. According to Van Morkhoven (1963), *Darwinula* is essentially a freshwater form and occasionally is also encountered in oligomesohaline waters. *Darwinula* represents the largest component of the Scots Bay assemblage.

The salinity and temperature of the Scots Bay Lake evidently did not reach extreme values even when lake levels fell as evidenced by the horizons with mudcracks (Birney-De Wet and Hubert, 1989). On the evidence obtained from the occurrences of genera like *Darwinula*, *Timiriasevia* and *Metacypris* in ancient environments and the absence of significant amounts of evaporite minerals, it is thought that the Scots Bay Formation was deposited under oxygenated, freshwater conditions. This lake was shallow, as suggested by the presence of charophyte and other vegetation. It existed in a humid climate, according to Thompson (1974).

7.7 AGE OF THE SCOTS BAY FORMATION

The age interpretation of Scots Bay Formation has fluctuated from Cretaceous to Triassic to Early Jurassic during this century. It has been a matter of minor controversy to determine the precise age of this formation. Haycock (1900) suggested a Cretaceous age, but in 1913 he found a head of a fish that was identified as a Triassic genus. Power (1916) suggested a Triassic age for the Scots Bay Formation based on the supposed Triassic fish found by Haycock. Cameron (1986), Cameron and Jones (1990), and Cameron and others (1990) suggested an Early Jurassic age. Cameron (1986) noted that the Scots Bay fauna resembles, at the generic level, the freshwater invertebrate faunas of the Late Jurassic Morrison Formation of North America and Purbeck Beds of Europe.

The occurrence of the Scots Bay Formation on the top of the stratigraphic sequence in the Bay of Fundy makes its age determination problematical. Knowing the age of the underlying North Mountain Basalt just provides a lower age limit. Greenough (1995) stated that a U-Pb zircon date of 202 ± 1 Ma for the underlying North Mountain Basalt supports other conclusions that dated all the related igneous activities at 201 ± 2 Ma (Sutter, 1988; Dunning and Hodych, 1990). Palynological studies of Cornet (see Olsen and Baird, 1982) indicate that the Triassic-Jurassic boundary is near the top of the Blomidon Formation which underlies the North Mountain

Basalt Formation. The North Mountain Basalt probably extruded over a period of time less than one million years (Colwell pers. comm. to Cameron, 1986). Only a minor paleosol developed on the basalts. Deposition of the Scots Bay Formation occurred soon after extrusion. The silicification of Scots Bay Formation from hot springs suggests an age very soon after the lava flows of the North Mountain Basalt (Cameron and Colwell, pers. comm., 1999).

Ostracodes may hold the greatest promise for pinning down the exact age biostratigraphically of the Scots Bay Formation. However, the high proportion of new species (*Metacypris, Timiriasevia,* the new "giant" ostracode, and *Darwinula* n. sp.) in this low-diversity fossil assemblage do make precise age determination of the Scots Bay Formation by ostracode correlation difficult. The genus *Timiriasevia* was originally reported from the Middle Jurassic of the former U.S.S.R. and from Bathonian (Middle Jurassic) beds of the Paris Basin (Oertli, 1958).

The darwinulid ostracodes, however, support an Early Jurassic age for the Scots Bay Formation. *Darwinula liassica* is known from Early Jurassic freshwater deposits, such as the coal-bearing strata of south China (Mao-yu, 1983). *Darwinula sarytirmenensis* has been reported from the Late Early Jurassic of South China (Xu, 1983) and from the Middle Jurassic Kota Limestone of India (Govindan, 1975).

An Early Jurassic age is supported by the stratigraphic position of the Scots Bay Formation and the rare Early Jurassic dinosaur footprints at its top (Cameron and others, 1990). This age is consistent with its correlation with the Early Jurassic McCoy Brook Formation along the north shore of the Bay of Fundy (Olsen and Baird, 1982).

It seems that the following indications may suggest that the age of the Scots Bay Formation could be extended to Middle Jurassic: many of the ostracodes of Scots Bay Formation appear to be very similar to the ostracode assemblage of the Kota Limestone in India which is Middle Jurassic age (Govindan, 1975). The genera *Metacypris* and *Timiriasevia* are Middle & Late Jurassic ostracodes. The evidence of weathering, soil formation, and erosion of the irregular upper surface (nonconformity) of North Mountain Basalt on which the sediments of the Scots Bay Formation were deposited may suggest a time gap (hiatus) between the two formations.

The Early to Middle Jurassic age uncertainty using biostratigraphic techniques may be resolved by further work on other elements of the Scots Bay fauna. The time range of several of these ostracode genera may extend back to Early Jurassic, but there are very few well-studied Early Jurassic freshwater microfossil assemblages known throughout the world for comparisons with the Scots Bay fauna at this time.

CHAPTER EIGHT

CONCLUSION

The Early Jurassic Scots Bay Formation records the deposition of lacustrine strata composed of mixed carbonate and siliciclastic rocks. In this study, four sedimentary facies are recognized: 1) marginal channel facies, 2) offshore facies, 3) nearshore facies (basal high energy and upper low energy units), and 4) shoreline facies. The calcareous sediments suggest alkaline waters while the nonmarine fossil assemblage indicate a freshwater lake(s). The fossil algae in nearshore facies indicate shallow water or littoral depths. The invertebrates, woody debris, sedimentary structures, sedimentary textures, and dinosaur tracks suggest that shoreline and nearshore conditions dominated.

The marginal channel facies is represented by moderately sorted, mixed coarse to fine subarkosic sandstone with clasts mainly composed of basalt fragments and sand-sized quartz grains. The fining upward nature of this unit may indicate that a meandering stream deposited this sandstone.

The offshore facies is represented by a silty sandstone unit characterized by fine grains and low carbonate materials. Bioturbation may indicate that the bottom waters and sediments were well oxygenated.

The nearshore facies is represented by two subfacies: a lower higher energy nearshore subfacies which is characterized by mixed carbonate and siliciclastic content and an upper lower energy nearshore subfacies which is characterized by fine-grained limestone. The higher energy nearshore subfacies consists of bioclastic laminated silty sandy limestone and peloidal calcareous sandstone. It contains desiccation cracks, horizontal laminations, rock fragments and chert. Scattered oolite grains occur in this facies, but they are not common. The lower energy nearshore subfacies is micrite dominated and consists of a wackestone-packstone unit and a silicified stromatolitic (LLH) unit. These stromatolites are a series of small domes or hemispheroids stacked upon each other and composed of dark argillaceous and calcareous sandstone.

At the top of the sequence, a shoreline facies is represented by a pebbly feldspathic litharenitic coarse sandstone that contains truncated ripple marks associated with low-angle cross-stratification and horizontal current laminations. Desiccation cracks and dinosaur footprints suggest subaerial exposure was routine during the deposition of these sandstones.

In the central outcrops, for example, at Lime Cove, limestone and calcareous sandstone are the dominant rock types, while in the eastern outcrops (e.g., Davidson Cove) sandstones dominate. In general, the Scots Bay Formation shows a vertical environmental gradation from offshore fine-grained sediments up through coarser, shallower nearshore sediments. This gradation repeats again from upper quiet nearshore fine-grained sediments into the coarse shoreline sandstones at the top, suggesting the possibility of some cyclicity. The rate of carbonate accumulation in the nearshore environments was higher than in the offshore and shoreline environments. The vertical stratigraphic sequence of these facies records an overall regressive phase during most of the history of "Scots Bay Lake."

The Scots Bay Formation was deposited by a littoral lake system that was generally shallow. More than one small freshwater lake may have existed. These lacustrine sediments followed a basal fluvial channel sandstone at Lime Cove.

The majority of the diagenetic alterations of Scots Bay sediments occurred early in its history. Chert beds and nodules are common. Microspar from recrystallized micrite is common. The chert is principally early diagenetic in origin and consists of chalcedony and microcrystalline quartz that formed as pore filling cement and replacements of carbonate sediments and calcareous fossils. The source of the silica was hot-spring fluids associated with the underlying basaltic lava flow. Drusy and blocky calcitic sparry cement was precipitated last.

Fossils in the Scots Bay Formation are rare and mostly silicified. They include a relatively low diversity of ostracodes, small gastropods, small clams, invertebrate burrows, fragments of charophyte stems, freshwater stromatolites, rare ferns, log and wood fragments, and very rare fish, vertebrate bones, and dinosaur footprints. Ostracodes reported for the first time include *Darwinula sarytirmenensis*, *D.* aff. *liassica*, *D. acadiaensis* n. sp., *Darwinula* n. sp., *Metacypris ridgensis* n. sp., and *Timiriasevia aff. digitalis.* A new giant ostracode that is up to 4.5 mm in length named

Megawoodworthia salemi n. sp. is also reported. Recent studies indicate that the North Mountain Basalt was extruded 201 ± 2 Ma age, and the deposition of Scots Bay took place soon after the flows of basaltic lava. The darwinulid ostracodes and dinosaur footprints also suggest an Early Jurassic age for the Scots Bay Formation. This confirms its age according to its stratigraphic position which suggests its correlation with the Early Jurassic McCoy Brook Formation along the north shore of the Bay of Fundy.

REFERENCES

AAPG Explorer, 1985, American Association of Petroleum Geologists: Editor Kenneth M. Wolgemuth. Published by American Association of Petroleum Geologists (AAPG); Tulsa, OK; USA.

Ackermann, R. V., Schlische, R. W. and Olsen, P. E., 1995, Synsedimentary collapse of portions of the lower Blomidon Formation (Late Triassic), Fundy rift basin, Nova Scotia. Can. J. Earth Sci. Vol. 32, p.1965-1976.

Adams, A. E., Mackenzie, W. S. and Guilford C., 1984, Atlas of sedimentary rocks under the microscope. England, Wiley and Sons, Inc., p. 4 - 83.

Bate, R. H., 1965, 1965, Freshwater ostracodes from the Bathonian of Oxfordshire. Paleontology, vol. 8, part 4, p. 749-759.

Bathurst, R. C., 1958, Diagenetic fabrics in some British Dinantian limestone. Liverpool Mnchester Geol. J., p.87.

Bathurst, R. C., 1976, Carbonate sediments and their diagenesis. New York, Wiley and Sons, Inc., p. 321 - 516.

Benson, R. H., 1961, Ecology of Ostracodes Assemblages. In Treatise on Invertebrate Paleontology. Edited by R. C. Moore, Geological Society of America, and the University of Kansas, p.56-63.

Biggs, D. L., 1957, Petrography and origin of Illinois nodular cherts, Ill. Geol. Surv. Circ., 245, p. 3-18.

Birney-De Wet, C. C., 1985, Sedimentology and petrology of the Scots Bay Formation (Lower Jurassic), Nova Scotia, Canada. Unpublished M.Sc. thesis; University of Massachusetts at Amherst, 325 pp.

Birney-De Wet, C. C., and Hubert, J. F., 1989, The Scots Bay Formation, Nova Scotia, Canada, a Jurassic carbonate lake with silica-rich hydrothermal springs. Sedimentology, 36, p. 857-873.

Blakeney, R., and Thompson, J., 1971, Stratigraphy of the Lime Cove outcrop of the Scots Bay Formation, Triassic Group, N.S. Acadia University research project.

Blatt, H., Middleton, G. And Murray, R., 1972, Origin of sedimentary rocks. Prentice Hall Inc., 634 p.

Boehner, J. H. Calder, Carter, D. C., Donohoe Jr., H. V., Ferguson, L., Pickerill, and Ryan, R. J., 1986, Carboniferous-Jurassic Sedimentation and Tectonics: Minas, Cumberland and Moncton Basins, Nova Scotia and New Brunswick. In Basins of Eastern Canada and Worldwide Analogues. Symposium field trip, Atlantic Geoscience Society Special Publication Number 4, p.1-122.

Bromley, M. H., 1987, Geology of the Melange at Clark Head, Cumberland County, Nova Scotia. Honours thesis, Acadia University, 107 p.

Brown, D. E., 1986a, The Bay of Fundy: Thin-skinned tectonics and resultant Early Mesozoic sedimentation. In Basins of Eastern Canada and Worldwide Analogues, Program with Abstracts, Atlantic Geoscience Society, Halifax, Nova Scotia, p. 28.

________, 1986b, The Bay of Fundy: hydrocarbon potential of an Early Mesozoic basin; Reserves 21-Canada's Hydrocarbon Reserves for the 21st Century, Program and Abstracts. Canadian Society of Petroleum Geologists, Calgary, Alberta, p. 30.

________, and Grantham R. G., 1992, Fundy Basin Rift Tectonics and Sedimentation; Geological Association of Canada, Mineralogical Association of Canada, Joint Annual Meeting, Wolfville '92; Field Trip A-3, Guidebook, 57 p.

Cameron, B., 1985, Discovery of silicified lacustrine microfossils and stromatolites: Triassic-Jurassic Fundy Group, Nova Scotia. Geological Society of America, Programs with Abstracts, v.17, p. 538.

________, 1986, Jurassic fossils from the Scots Bay Formation. Program and Summaries, Tenth Annual Open House and Review of Activities. Nova Scotia Department of Mines and Energy Information Series No. 12, p. 167- 169.

________, and Colwell, J. A., 1983, Origin of chert, Scots Bay Formation (Jurassic), Nova Scotia. In Current Research in the Geological Sciences in Canada, ed. T. E. Bolton; Geological Survey of Canada, paper 83-5, p. 60.

________, and Jones, J. R., 1988, Plant fossils from the early Mesozoic Fundy Group of the Annapolis Valley region of Nova Scotia. In Mines and Minerals Branch, Report of Activities 1988, part A, eds. D. MacDonald and Y. Brown. Nova Scotia Department of Mines and Energy, Report 88-3, p. 173-177.

________, and Jones, J. R.,1990, Non-marine fossils of Late Triassic-Early Jurassic

Fundy Group of the Annapolis Valley, Nova Scotia. Atlantic Geology, vol. 26, no. 2, p. 167.

________, and Jong, W., 1985, Subsurface stratigraphy of the late Triassic Wolfville sandstone and Blomidon shale of the Fundy Basin: Annapolis Valley, Nova Scotia. In Ninth Annual open House and Review of Activities. Nova Scotia Department of Mines and Energy, Information Series No. 9, p. 105-106.

________, Domanski E., and Jones J. R., 1990, Contributions to the vertbrate paleontology of the Late Triassic-Early Jurassic Fundy Group along the Scots Bay-Cape Blomidon coast. In Program and Summaries, Fourteenth Annual Open House and Review of Activities, Nova Scotia. Department of Mines and Energy, Report 90-3, p. 36.

________, Rogers, D., Grantham, R. and Jones, J. R., 1985, Silicification and silicified microfossils and stromatolites from the Scots Bay Formation, Fundy Basin, Nova Scotia a progress report. Maritime Sediments and Atlantic Geology, v. 21, p. 41- 42.

Carbonel, p., Colin, J. P., Danielopol, D. L., Loffler, H., and Neustrueva, I., 1988, Paleoecology of limnic ostracodes: a review of some major topics. Palaeogeography, Palaeoclimatology, Palaeoecology, 62 , p. 413-461.

Cayeux, L., 1935, Les Roches sedimentaires de France; Roches Carbonates. Masson, Paris, p. 463.

Charles, R. W., and M. D. Picard, 1974, Petrology of carbonate rocks of the Green River Formation (Eocene). Jour. Sedi. Petro., v. 44, p. 738-759 .

Chester, R. P., 1956, A study of chalcedony. American Journal of Science, v. 254, p. 32-50.

Chesworth, W., 1970, Length-slow chalcedony after sulphate evaporates minerals in sedimentary rocks. Nature Physical Science, v. 230, p. 64-65.

Clarke, H. A., 1981, The freshwater Molluscs of Canada. Published by National Museum of Natural Sciences/ National Museums of Canada. Catalogue No. NM 95-17/5. 446 p.

Cohen, A. S., and Thuin, C., 1987, Nearshore carbonate deposits in Lake Tanganyika. Geology, v. 15, p. 414-418.

Colwell, J. A., and Cameron, B., 1985, North Mountain Basalt, AUGC field trip. (unpublished).

Cornet, B., 1977, The palynostratigraphy and age of the Newark Supergroup; Ph.D. Thesis, Pennsylvannia State University, University Park, Pennsylvania, p. 171- 181.

Dawson, J. W., 1894, Revision of the Bivalve Mollusks of the Coal Formation of Nova Scotia. Canadian Research Sciences, part 3, v. 5, p.1-18.

De Decker, P., 1983, The limnology and climatic environment of modern halobiont ostracodes in Australia - a basis for paleoenvironmental reconstruction. In Applications of ostracoda. R. F. Maddocks (ed.), University of Houston Geoscience, Houston, p. 250-254.

Demicco, R. V., and Hardie, L. A., 1994, Sedimentary structure and early diagenetic features of shallow marine carbonate deposits. SEPM Atlas series No. 1, Ed. By P. A., Scholle, Special Publication, p. 80-81

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture. In: W. E. Ham editor, Classification of carbonate rocks. Am. Assoc. Petrol. Geologists, Tulsa. Okla., p. 108-121.

Dunning, G., and Hodych, J. P., 1990, U/Pb zircon and baddeleyite ages for the Palisades and Gettysburg sills of the northeastern United States: implications for age of the Triassic/Jurassic boundary; Geology, v. 18, p. 795-798.

Ells, R. W., 1894, Notes on recent sedimentary formation on the Bay of Fundy coast. Proc. And Trans. N.S. Inst. of Sci. Session 1893-4, p. 416 - 419.

Fletcher, H., 1911, Kingsport sheet No. 84, Hants and Kings Counties. Geol. Sur. Can. Map13A.

Flugel, Erik, 1982, Microfacies Analysis of Limestones. Translated by K. Christenson. Springer-Verlag, Berlin and Heidelberg 1978.

Folk, R. L., 1954, The distribution between grain size and mineral composition in sedimentary rock nomenclature. Jour. Geol. v. 62, p. 344-359.

_______, 1959, Practical petrographic classification of limestone. Bulletin of the American Association of Petroleum Geologists, v. 43, pp.1-38.

_______, 1962, Spectral subdivision of limestone types. Classification of carbonate rocks, AAPG. Memoir 1, edited by W. E. Ham, published by p. 62-84.

_______, and Charles, E. W., 1952, A study of the texture and composition of chert. Amer. Journal of Science, v. 250, Pp. 498-510.

_______, and Pittman, J. S., 1971, Length-slow chalcedony: A new testament for vanished evaporites. Jour. Sedi. Petro., v. 41, p. 1045-1058.

Fouch, T. D., and Dean W. E., 1982, Lacustrine and associated clastic depositional environments. In Sandstone Depositional Environments, Edited by P. A. Scholle and D. Spearing. American Association of Petroleum Geologists, P. 87-114.

Gomez, C., and Melendez, N., 1991, Rhythmically laminated lacustrine carbonate in the Lower Cretaceous of la Serrania de Cueneca Basin (Iberian Ranges, Spain), in Lacustrine Facies Analysis, edited by P. Anadon, Ll. Cabrera and K. Kelts. Blackwell Scientific Publications, 1991.

Good, S. C., Yenik, L. A., and Mcdonald, N. G., 1994, Non-marine molluscs from the Scots Bay Formation, Newark Supergroup (Early Jurassic), Nova Scotia: Taxonomic assessment and paleoecologic significance. Abstract with Programs, Geol. Soc. America, v. 26, p. 20.

Govidan, A., 1975, Jurassic freshwater ostracodes from the Kota Limestone of India. Paleontology, v. 18, part 1, p. 207-216.

Greenough J. D., 1995, Mesozoic rocks. In Geology of the Appalachian- Caledonian

Orogen in Canada and Greenland, ed. H. Williams; Geological Survey of Canada, Geology of Canada, no. 6, p. 569-600.

Haycock, E., 1900, Records of post-Triassic changes in Kings County, Nova Scotia. Trans. of the Nova Scotia Inst. of Sci., 1899, V. 10, p. 287-302.

Hesse, R., 1990, Silica diagenesis: origin of inorganic and replacement cherts. In Diagenesis, edited by I. A. McIlreath and D. W. Morrow. Geological Association of Canada. Series 4, p. 253-275.

Hubert, J. F., and Forlenza, M. F., 1988, Sedimentology of braided river deposition in Upper Triassic Wolfville red beds, southern shore of Cobequid Bay, Nova Scotia, Canada. In Triassic-Jurassic Rifting; Continental Breakup and the Origins of the Atlantic Ocean and Passive Margins (Ed. by W. Manspeizer), Elsevier, Amsterdam, p. 231-247.

_______, and Mertz, K. A., 1984, Eolian sandstone in Upper Triassic-Lower Jurassic red beds of the Fundy Basin, Nova Scotia. J. Sedim. Petrol., 54, p 798-810.

Huntec Limited of Toronto (1965), Minas Basin study, part 1: report for the Atlantic Development Board, 66-67.

James, N. P., and Choquette, P. V., 1990, Limestone - Introduction. In Diagenesis, edited by Ian A. McIlreath and David W. Morrow, Geological Association of Canada. Series 4, p. 9-11.

James, N. P., and Choquette, P, V., 1990, Limestone the meteoric diagenetic environment. In Diagenesis, edited by I. A. McIlreath and D. W. Morrow. Geological Association of Canada. Series 4, p. 55-73.

Jiang, X. T., 1963, Carboniferous-Permian, Mesozoic and Cainozoic ostracod fauna from the Djunger Basin. Unpublished manuscript.

Jones, T. R., 1894, On some fossil ostracoda from southwest Wyoming, and from Utah, USA, Geol. Mag., N.S., Decade III, 10(9): 385-391.

Keith, H. D., & Padden, F. J., 1963, A phenomenological theory of spherulitic crystallization. Jour. App. Phys., v. 34, p. 2409- 2421.

Klein, G. de V., 1954, The Geology of the Acadian Triassic. Unpublished M. A. Thesis, University of Kansas, p. 143.

_______, 1957, The Geology of the Acadian Triassic in the Type Area, Northeastern Annapolis-Cornwallis Valley, Kings County, Nova Scotia. Unpublished M.Sc. thesis, University of Kansas, p. 46-49.

_______, 1960, The Acadian Triassic. Unpublished Ph.D. thesis, Yale University, p. 332.

_______, 1962, Triassic sedimentation, Maritime Provinces, Canada. Geol. Soc. Amer. Bull. v. 73, pp. 1127-1146.

_______, 1963, Regional implications of Triassic paleocurrents, Maritime Province, Canada. Journal of Geology. v. 71, p. 801-808.

Koons, E. D., 1942, The origin of the Bay of Fundy and associated submarine scarps.

Jour. Geomorph. v. 4, pp. 237-249.

Liew, Yuk-Choi, 1976, Structure, geochemistry, and stratigraphy of Triassic rocks, North Shore of Minas Basin, Nova Scotia. Unpublished M.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

Lindholm, R. C., 1978, Triassic-Jurassic faulting in eastern North America: A model based on pre-Triassic structures. Geology, v. 6, p. 365-368.

Logan, B. W., Rezak, R., and Ginsburg, R. N., 1964, Classification and environmental significance of algal stromatolites. Jour. Geol., v. 72, p. 68-83.

Manspeizer, W., Puffer, J., and Cousminer, H., 1978, Separation of Morocco and eastern North America: A Triassic-Liassic stratigraphic record. Geol. Soc. of Am. Bull., v.89, p. 901-920.

Martin, H., L., and Osborne R. H., 1978, Lacustrine facies in the Pliocence Ridge Basin Group: Ridge Basin, California. Spec. Publs int. Ass. Sediment. 2, p. 169-187.

McDonald, N. G., 1992, Paleontology of the Early Mesozoic (Newark Supergroup) Rocks of the Connecticut Valley. Northeastern Geology, vol.14, No. 283, 1992, p. 185-200.

Mckenzie, K. G., 1971, Palaeozoogeography of freshwater ostracoda. Bull. Center Rech. Pau-SNPA, 5 suppl. Pp. 179-190.

Meyers, W. J., 1977, Chertification in the Mississippian Lake Valley Formation, Sacramento Mountains, New Mexico. Sedimentology, v. 24, p. 75-105.

Monty, C. L. V., 1972, Recent algal stromatolitic deposits, Andros Island, Bahamas. Preliminary report: Geologische Rundschau, v. 61, p. 742-783.

Monty, C. L. V., and Hardie, L. A., 1976, The geological significance of the freshwater blue green algae calcareous marsh, in Stromatolites. Walter, M. R., ed. Developments in Sedimentology 20, Elsevier, p. 447-477.

Moore, R. C. (ed.). 1961, Treatise on Invertebrate Paleontology, part Q: Ostracoda. Geol. Soc. Amer. and Univ. Kansas Press, p. 56-73, 253- 254, 311-314, 357-158,

Murray, R.C., 1981, Origin of porosity in carbonate rocks. Journal of Sedimentary Petrology, Vol. 30, No. 1, pp. 59-84.

Newell, N. D., 1940, Paleozoic Pelecypods *Myalina* and *Naiadites*. Am. Jour. Sci., v. 238, p. 286-295.

Oehler J. H., 1976, Hydrothermal crystallization of silica gel. Geol. Soc. Amer. Bull., v. 87 , p.1143 to 1252.

Oertli, H. J., 1958, Ostakoden. In:, Neue Helvetien-Faunen aus der Molasse zwischen Aare und Emme (Kt. Bern). R. F. Rutsch, C. W. Drooger and H. J. Oertli. Mitt. Naturforsch. Ges., Bern, N. F., 16: 1-36

Olsen, P. E., 1980, The Latest Triassic and Early Jurassic Formation of the Newark Basin (Eastern North America, Newark Supergroup): Stratigraphy, Structure, and Correlation. Bull.. N. J. Acad. Sci., 25: 25-51.

_______, 1981, Triassic and Jurassic Formations of the Newark Basin. In Field Studies of New Jersey Geology and Guide to Field Trips. W. Manspeizer (editor)52nd Ann. Mg. N. Y. State Geol. Assoc. Newark College of Art sand Sciences, Rutgers University, Newark, New Jersey, p. 2-37.

_______, 1989, part II, Chapter 9, 10, and 11; In: Olsen, P. E., Schlische, R. W., and Gore, P. J. W., (Eds.), Tectonic, Depositional, and Paleoecological History of the Early Mesozoic Rift Basins, eastern North America; Field Trip Guidebook T-351, American Geophysical Union, Washington, D. C.

_______, 1997, Stratigraphic record of the early Mesozoic breakup of Pangea in the Laurasia-Gondwana rift system. Annual Reviews of Earth and Planetary Sciences v. 25, p.337-401.

_______, and Baird, D., 1982, Early Jurassic vertebrate assemblages from the McCoy Brook Formation of the Fundy Group (Newark Supergroup, Nova Scotia, Canada): Abstracts with Programs, Geol. Soc. America, v. 14, p. 70.

_______, Shubin, N. H., and Anders, 1987, New Early Jurassic tetrapod assemblages constrain Triassic-Jurassic tetrapod extinction event. Science, vol. 273, p. 1025-1029.

Pettijohn, F. H., 1957, Sedimentary rocks. Harper and Row, Publishers, Inc., 718 p.

Pettijohn, F. H., 1975, Sedimentary rocks. Harper and Row, Publishers, Inc., p. 549-554.

Picard, M. D., and High, L. R., 1972, Criteria for recognising lacustrine rocks. In: Recognition of Ancient Sedimentary Environments. Ed. By J. K. Rigby & W. K.

Hamblin. Soc. Econ. Paleont. Miner., Spec. Publs. 16, 108-145.

_______,and High, L. R., 1981, Physical stratigraphy of ancient lacustrine deposits. Recent and ancient nonmarine depositional environments: model for exploration, p. 233 - 259.

Pinto, I. D., and Sanguinetti, Y. T., 1958. *Bisulcocypris* a new Mezozoic genus and preliminary note about its relation with *Metacypris* and allied forms. Bol. Soc. Bras. Geol. 7(1):75-90.

Platt, N. H., and Wright, V. P., 1991, Lacustrine carbonate: facies models, facies distribution and hydrocarbon aspects. In Lacustrine Facies Analysis, edited by Anadon P., Cabrera L., and Kelts K. Blackwell Scientific Publications, p. 57-74.

Powers, S. 1916, The Acadian Triassic. Jour. Geology, v. 24, p.1-122.

Reading, H.G., 1971, Sedimentary Environments and Facies. Oxford : Blackwell Scientific, 1986. 467 p.

Renult, Jones, B., R. W., and Rosen, M. R., 1998, Microbial biofacies hot-spring sinters: A model based on Ohaaki Pool, North Island, New Zeland. Jour. Sedi. Rese., v. 68, no. 3, p. 413-433.

Roemer, F. A., 1839, Versteinerungen norddeutschen Oolithengebirges. Vol. II. 1839.

Sargent, H. C., 1929, Further studies in chert. Geol. Mag., v. 66 , p.399-412.

Smith, W. E., 1960, The siliceous constituents of chert. Geol. En Mijnbouw, 39e, NR 1, p.1-8.

Stevens, G. R., 1980, Mesozoic vulcanism and structure-northern Bay of Fundy region, Nova Scotia; field trip guidebook no 8, Geological Association of Canada, Dalhousie University, Halifax, Nova Scotia, p. 3-11

_______, 1985, Wolfville, Blomidon and Scots Bay Formation, in Williams, G., and others (Eds.), Lexicon of Canadian Stratigraphy. Canadian Society of Petroleum Geologists, v. VI, p. 36- 37, 334-335 and 404-405.

_______, 1987, Jurassic basalts of northern Bay of Fundy region, Nova Scotia; Geological Society of America Field Guide, v. 5- Northeastern Section, p. 415-420.

Sues, H. C., and Olsen, P. E., 1990, Triassic Vertbrates of Gondwanan aspects from the Richmond Basin of Virginia. Science, v. 249, p. 1020-1022.

Sun, S. Q., and Wright, V. P., 1989, Peloidal fabrics in upper Jurassic reefal limestone, Weald Basin, southern England. Sedimentary Geology, v. 65, Pp. 165-181.

Surdam, R. C., and Wray, J. L., 1976, Lacustrine stromatolites, Eocene Green River Formation, Wyoming, In Stromatolites, edited by M.R. Walter. New York, Developments in Sedimentology 20. Elsevier, p.535-541.

Sutter, J. F., 1988, Innovative approaches to the dating igneous events in the Early Mesozoic Basins of Eastern United States; in Studies of the Early Mesozoic Basins of the Eastern United States, (ed.) A. J. Froelich and G. R. Robinson; United States Geological Survey Bulletin, V. 1776, p. 194-200.

Swift D. J. P., and Anilk, K. Lyall, 1968, Origin of the Bay of Fundy, An interpretation from sub-bottom profiles. Marine Geology, v.6, p. 331-343.

Tagg, A. R., and Uchupi, E., 1966, Distribution and geological structure of Triassic Rocks in the Bay of Fundy and the northeastern part of the Gulf of Maine. U.S. Geol. Survey Prof. Paper 550- B, pp. 95-98.

Thompson, J. P., 1974, Stratigraphy and geochemistry of the Scots Bay Formation, Nova Scotia. Unpublished M.Sc. thesis, Acadia University, Wolfville, Nova Scotia. 367 p.

Tucker, M. E., 1990, Carbonate background to carbonate sedimentation. Edited by Tucker, M. E., and Wright, V. P. Blackwell Scientific Publications, p.28-67.

_______, 1992, Diagenetic processes, products and environments. Edited by Tucker, M. E., and Wright, V. P. Blackwell Scientific Publications, p.314-336.

_______, and Bathurst, R. G. C., 1990, Meteoric diagenesis. In Carbonate diagenesis. Edited by, Tucker, M. E., and, Bathurst R. G. C. Blackwell Scientific Publication. p. 176-193.

_______, and P. Wright, 1992, Carbonate Sedimentology. Blackwell Scientific Publications, Oxford, p. 81-134.

Twenhofel, W. H., 1932, Treatise on Sedimentation., The Williams & Wilkens Co. Baltimore. p. 520-629.

Van Morkhoven, F. P. C. M., 1963, Post-Paleozoic ostracoda. 1, Amsterdam. Elsevier. p. 29-31.

Van Tuyl, F. M., 1918, The origin of chert. Am. Jour. Sci., ser. 4, v. 45,

p. 449-456.

Wade, J. A., Brown, D. E., Traverse, A., and Fensome, R., 1996, The Triassic-Jurassic Fundy Basin, eastern Canada: regional setting, stratigraphy and hydrocarbon potential. Atlantic Geology, 32, p. 189-213.

Walker, Bryant, 1918, A synopsis of the classification of fresh-water Mollusca of North America. Univ. Mich., Mus. Zool., Miscellaneous Publication 6, p. 1-88. Ann. Arbor, MI.

Whatley, R. C., 1983, The application of ostracoda to paleoenvironmental analysis. In application of ostracoda. Edited by R.F. Maddocks. Houston, Tex: Dept. of Geosciences, University of Houston, University Park, p. 51-77.

White, J. F., and Corwin, J. F., 1961, Synthesis and origin of chalcedony. Amer. Min., v. 46, p. 112-119.

Wightman, J. F., 1970, Vein silica paragenesis in Triassic basalt, Digby Neck, Nova Scotia. Unpublished M.Sc. thesis, Acadia University.

Wilson, R. C., 1966, Silica diagenesis in Upper Jurassic limestone of southern England. Jou. Sedi. Petro., v. 36, pp. 1036-1049.

Withjack, M. O., Schlische, R. W., and Olsen, P. E., 1998, Diachronous rifting, drifting, and inversion on the passive margin of Central Eastern North America: an analog for other passive margins. AAPG Bulletin, v. 82/5A, p. 817-835.

Xu, Mao-yu, , 1983, Ostracods from the Mesozoic Coal-Bearing Strata of South China. Applications of ostracoda (R. F. Maddocks, ed.) Uni. Houston Geosc. 1983: 325-371.