STRATIGRAPHY OF THE BLOW ME DOWN BROOK FORMATION, HUMBER ARM ALLOCHTHON, WESTERN NEWFOUNDLAND, CANADA

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by

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Abstract

The Cambrian age Blow Me Down Brook formation of the Humber Arm Allochthon has been poorly understood since geological study began in the area more than 140 years ago. A detailed study has never been carried out exclusively on the formation, nor a complete stratigraphy designated. The aim of this thesis is to compose a stratigraphy for the Blow Me Down Brook formation based upon sedimentology, petrography and ichnology.

Regional mapping of coastal sedimentary strata from the community of Fox Island River, north to Rope Cove is used to show extensive and continuous sections of Blow Me Down Brook formation. These exposures, paired with a recently documented basal contact between Blow Me Down Brook red shale beds and underlying Fox Island River volcanics, have allowed development of a composite stratigraphy for the Blow Me Down Brook formation. The formation, herein estimated to be about 400 m thick, is formed of six informal, but distinct stratigraphic units: A, B, C, D, E and F. Unit A, massive red shale interbedded with volcanics; Unit B, thick bedded red (hematitic) and greenish coloured micaceous sublithrenite and lithic subarkose; Unit C, quartz and feldspar pebble conglomerate with calcarenite boulders; Unit D, coarse grained greenish coloured quartzarenite and sublitharenite with minor subarkose interbedded with red, green and grey shale; Unit E, massive siliceous red and black shale, and Unit F; a quartzose greenish sandstone interbedded with black shales.

The sandstones of Unit F are commonly petroliferous, and tend to be associated with the calcareous Northern Head Group. One area (near Sluice Brook) shows evidence

for a petroleum system in the Blow Me Down Brook formation. Here, petroliferous Blow Me Down Brook formation overlies the Northern Head Group in an antiformal structure. The shales of the Northern Head Group have a 'greasy' texture and may have acted as a source rock; overlying beds of red shales form a seal.

The Blow Me Down Brook formation is derived from offshore turbidity flows, with little understanding of how the formation relates to the Summerside and Irishtown formations of the same age. With knowledge of the stratigraphy and petrography stronger arguments may be made for correlating the Summerside formation with lower units A and B of the Blow Me Down Brook formation. The more quartzose upper units C, D, E, and F of the Blow Me Down Brook formation may be correlated to the Irishtown formation.

By careful recognition of strata and successions, it may be feasible to effectively map these rocks across the region.

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Chapter 1

Introduction

1.1 Introduction

The Appalachian Orogen extends 3200 km from the state of Alabama along the eastern seaboard of the United States, into Canada's Atlantic provinces and terminates in western Newfoundland. The complex geology shows the Precambrian age evolution of a south facing Laurentian passive margin through a series of rift and drift phases. This was followed by orogenesis in the Paleozoic as the Iapetus Ocean closed and oceanic crust was thrust upon continental crust.

In Atlantic Canada the Appalachian orogen has been divided into the Humber, Dunnage, Gander, Avalon and Meguma zones based on large - scale structure, lithology and paleoenvironments (Figure 1.1) (Williams, 1975). All except the Meguma zone are represented on the island of Newfoundland. The Humber Zone extends from the western limit of Appalachian deformation eastward to the Baie Verte – Brompton line (Williams, 1979). It represents the deformed continental margin of Laurentia, and it is within this zone that a complete Wilson cycle is preserved. In it, rocks and structure can be interpreted to show the rifting of the Laurentian craton and development of a passive margin in the Ediacaran and lower Cambrian characterized by siliciclastic sedimentation. This is followed by slow subsidence and sediment deposition on a shallow carbonate platform and adjacent slope and basin through the Early Paleozoic. The closing of the Iapetus Ocean marks the next stage of the cycle, triggering the collapse and deformation of the ancient Laurentian margin during the Taconic Orogeny (Williams, 1995). The

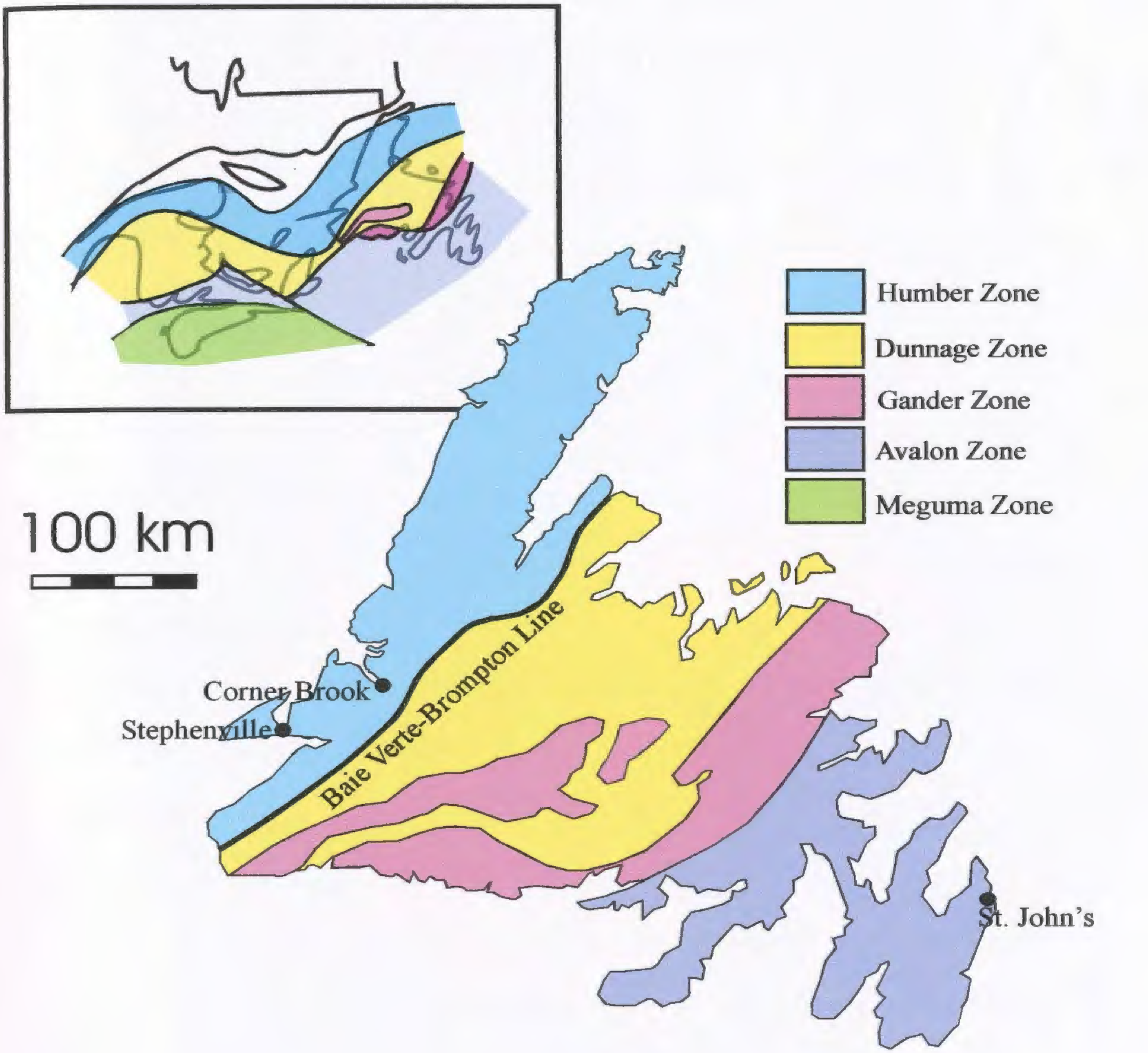

Figure 1.1: Tectonostratigraphic zonation of the Canadian Appalachian region in Newfoundland. (Modified from Williams, 1995)

Wilson Cycle ends with continental collision of the European Baltic and Avalonian terrains during the Acadian Orogeny.

In western Newfoundland, the Appalachian Orogen holds a wealth of geological history that has been studied and interpreted for more than a century. In particular the Humber Arm allochthon has been the focus of numerous studies within the region. The allochthon consists of Precambrian to Ordovician age siliciclastic rocks, platform carbonates, rift margin volcanics and Ophiolite strata. Within the Humber Arm allochthon formations have been generally characterized, but few have been examined in detail.

Considering the size and geological complexities that the Humber Arm Allochthon presents, the regional mapping done by workers such as Williams (1973, 1979, 1985, 1995) in western Newfoundland resulted in superb geological maps.

Within these maps large areas of transported and deformed strata are often grouped together as *mélange*. Over the past five years researchers at Memorial University and the University of Alberta have been have been working in a combined effort under the NATMAP and TGI 2 programs, to re-map this *mélange* into individual formations of the Humber Arm Supergroup. This detailed mapping has included the south side of the Bay of Islands as well as the flanks of the Blow Me Down and Lewis Hills Massifs. The last region where detailed mapping was needed was the coastal sections between Molly Anne Cove and Fox Island River, located at the western base of the Lewis Hills.

The aim of this thesis is to evaluate, compile and understand the stratigraphy and sedimentology of coastal outcrops between Molly Ann Cove and Fox Island River

(Figure 1.2), with particular emphasis on the Blow Me Down Brook formation. This type of detailed study has never been completed on the Blow Me Down Brook formation, and will provide a big step forward in understanding the stratigraphy of lower Cambrian successions of the Humber Arm Allochthon.

This stretch of coastline contains well- exposed sections of Blow Me Down Brook formation. The main body of this thesis will be directed towards compiling the petrography, sedimentology and ichnology of the Blow Me Down Brook formation and interpreting and introducing an informal stratigraphy.

1.2 Location and Access

The study area is in large part a series of measured coastal sections located on the west coast of Newfoundland 50 kilometers south west of Corner Brook (Topographic map sheets 12B/15 and 12B10). It is bounded to the west by the Gulf of St. Lawrence, to the east by the Lewis Hills massif, to the south by Fox Island River, and the northern boundary of the study area is 1.8 kilometers north of Molly Anne Cove (Figure 1.3).

Access to the field area was achieved with small dories and experienced boatmen from the communities of Little Port, Lark Harbour, and Fox Island River. However, landings were often difficult due to high onshore winds and the small number of suitable landing sites. Inland access north of Fox Island River was gained by forestry roads located off Route 460 in the community of Cold Brook and Route 462 in Point au Mal. From these gravel roads a short 2-4 kilometer overland hike was required to reach Fox Island River and the southeastern boundary of the map area.

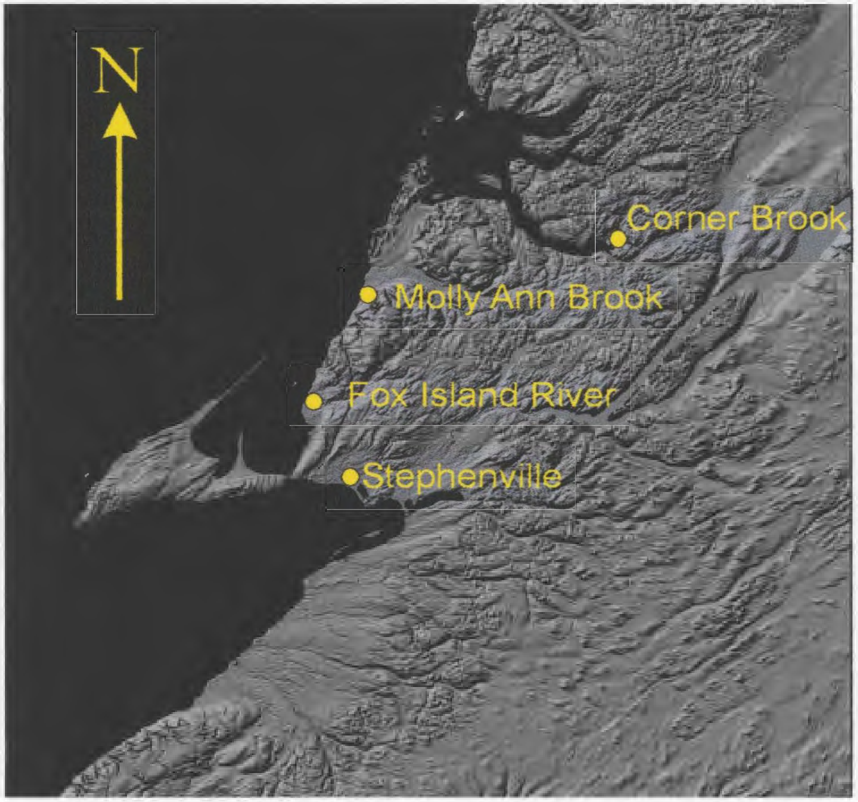

Figure 1.2: Radar image (from Newfoundland Mines and Energy Geological Survey website) showing Molly Ann Brook and Fox Island River localities.

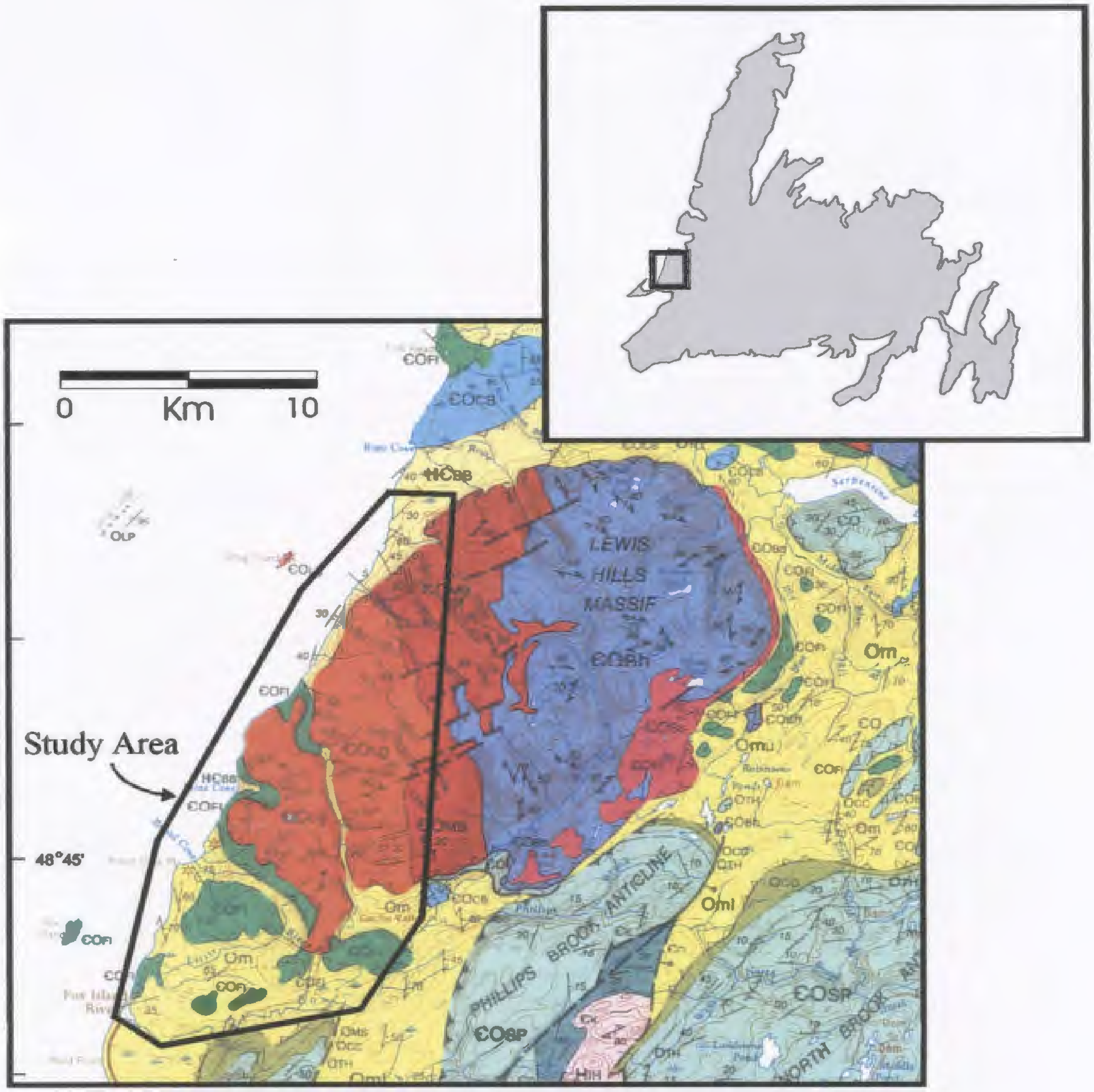

Figure 1.3: Regional Geology of study area. From Williams and Cawood (1989).

CO_{FI}	Fox Island River Group
CO_{Lg}, CO_{MB}, CO_{Bh} Massif	Blow Me Down Ophiolite
Om	Melange

Humber Arm Supergroup

HC_{BB}	Blow Me Down Brook formation
CO	Middle Cambrian Platform sequence
CO_{CB}	Cooks Brook Formation

The terrain on the coast is rugged with cobble beaches and sea cliffs ranging from 10-25 meters in height and extending up to several kilometers along the shore. Most of the structures measured in these cliffs are only visible in two dimensions. In some instances three-dimensional relationships were observed, but this only occurred at the mouth of small streams where good exposure extended up the river. Inland traverses were difficult with dense vegetation, logging debris, and boggy terrain. Therefore, most mapping localities were found in small streams and along scarps.

1.3 Physiography

The topography of the area has been shaped by Tertiary erosion and Pleistocene glaciation. It is dominated by two distinct terrains, Lowland and Plateau.

The lowland terrain is located in the southern part of the map area near Fox Island and Little Rivers as well as along the coastline. Inland, and lying parallel to Fox Island River, are low rolling hills consisting of resistant volcanic and carbonate rock that stand out against the flat lying terrain. Much of this area can be easily accessed, however the low-lying hills tend to be covered with thick stands of spruce and fir which make traversing difficult. Most of the outcrop exposed in this terrain is found in streams, on hillcrests and along small scarps.

The Lewis Hills, a mafic and ultramafic igneous complex, is found to the north and east of the lowlands. It forms the plateau terrain of the map area. This terrain rises from the coastline to 750m above sea level. There is very little vegetation or soil on the crest of the plateau due to glacial scouring and the high magnesium and iron content within the rock.

1.4 <u>Previous work</u>

1.4.1 Regional Setting

Geological mapping of Newfoundland has been an ongoing effort for more than 140 years, beginning with the work of Alexander Murray. Murray surveyed western Newfoundland during 1864 - 1883. With his field assistant J.P Howley, he published a series of revised reports in 1881. In 1907 Howley published a map of Newfoundland listing the central and western portion of the island as "Silurian Sediments" correlating these strata to the "Silurian" successions in Quebec. In this publication he also described the Lewis Hills as "Serpentine and Diorite".

Beginning in 1910 Schuchert began his survey of western Newfoundland with the aid of W.H. Twenhofel (1912), and then later with C.O. Dunbar with whom he published "Stratigraphy of western Newfoundland" in 1934. During this study Schuchert and Dunbar formally grouped the strata of western Newfoundland into seven series based on lithology and fossil assemblages. The Humber Arm series, located at the top of the stratigraphic sequence was limited to the Middle Ordovician due to a graptolite occurrence at Curling. The name Bay of Island Igneous Complex was first proposed by Cooper (1936) "as a general term to include the following separate igneous masses: Table Mountain mass, North Arm Mountain mass, Blow Me Down mass, and Lewis Hills mass." Cooper states that the name Bay of Islands Complex is justified due to the similarity in geology, and the idea that all the masses are thought to be parts of the same lopolith or "thick sheet". In the report by Smith (1958) the name Bay of Islands Complex is used to include all ultrabasic and gabbroic intrusions of the Bay of Islands from Bluff Head to Bonne Bay. Later, Williams (1973) added the metamorphic aureole rocks, sheeted dikes and mafic pillow lavas now included as integral parts of the Bay of Islands Complex. Both Cooper (1936) and Smith (1958) noted that the igneous rocks were lying over the sediments of the region, but continued to argue that the massifs were remnants of a single parent pluton, and that the present masses reached their present position by high angle reverse faulting.

Walthier (1949) produced the first detailed geologic map of the Fox Island River Area. In it the clastic sediments and the volcanics of the area were grouped into the Humber Arm Series and labeled as autochthonous.

A major reinterpretation of the regional geology of western Newfoundland began in 1963 when Rogers and Neale (1963) stated that the clastic and volcanic terrain in western Newfoundland was not a conformable stratigraphic section. Strata derived from depositional sites in the east were thrust westward as Taconic allochthons over the autochthonous carbonate platform. These rocks were therein considered similar to klippe in the Taconic region of the Appalachians in New York State.

The introduction of the plate tectonic theory and oceanic cycles (Wilson, 1966) profoundly changed the geologic models of western Newfoundland (Dewey, 1969). No longer was the geosynclinal model applied (Cooper, 1936; Smith, 1958), instead a model based on the new tectonic theory was introduced. This model explained the formation of the Humber Zone through a variety of tectonic settings, listing the Bay of Islands Igneous Complex as a remnant of oceanic lithosphere (Stevens, 1970; Dewey and Bird, 1971).

1.4.2 Background of the Humber Arm Allochthon

In the early 1960's significant new mapping was being conducted in western Newfoundland. Brückner (1966), in a limited edition conference field guide, compiled the results of a series of student thesis studies and proposed a stratigraphy for many of the allochthonous beds. The hyphenated and lower case moniker Blow-me-down Brook formation was created to identify "greywacke and arkose, with some conglomeratic beds, interbedded with soft, red and green shales" A short time later, a posthumous paper by Lilly (1967) contained editorial work by Brückner. Carefully identified as incomplete by Brückner, Lilly declares his intention to formally propose Blow-me-down Brook formation as the name for the sandstone and conglomerate beds. Declaration of a name is a key element of the North American Stratigraphic Code (Anonymous, 2005). However, without a stratotype and other basic information provided from this or any other subsequent papers, the formation must remain informally designated. In recent years, and in keeping with the proper name for the brook, the formation has come to be spelled Blow Me Down Brook formation.

Stevens (1970) divided the Humber Arm Group into five formations: Summerside, Irishtown, Cooks Brook, Middle Arm Point, and Blow Me Down Brook. As well, Stevens (1970) proposed the term Curling Group for the transported sediment packages underlying the ophiolite. The term Humber Arm Supergroup was coined and is now used to refer to all the transported sediment of the Allochthon.

Williams' (1973) map of the Bay of Islands further subdivided the rocks of higher structural slices into the Skinner Cove formation, the Old Man Cove formation, the Little Port Complex and the Bay of Islands Complex, with each formation represented in a separate structural slice.

In the Fox Island River area an extensive regional mapping project was undertaken by Schillereff (1980) to separate the autochthonous and allochthonous rocks of the area, and to delineate the sedimentary, volcanic and plutonic rocks within the allochthon.

North of Fox Island River in the Serpentine River area (N.T.S. 12B/16) Williams and Godfrey (1980) distinguished allochthonous and autochthonous rock and subdivided strata into Blow Me Down Brook formation, Cooks Brook formation and mélange. The volcanics of this area were mapped as Fox Island River Volcanics and the Lewis Hills Massif as a combination of the Little Port Complex, Mount Barren Complex and Bay of Islands Complex. This data was later compiled in the Williams and Cawood (1987) map of the Humber Arm Allochthon.

Botsford (1988) conducted a regional study of the stratigraphy and structure of rocks in the Bay of Islands area. In using graptolite assemblages he separated the Summerside and Irishtown formations into the Early Cambrian Curling Group and the Cooks Brook and Middle Arm Point formations into the middle Cambrian to early Ordovician Northern Head Group. Within his study Botsford (1988) also compared the calcareous Cooks Brook formation of the Northern Head Group to the Cow Head Group to the north. He found that rather than displaying a proximal/ distal relationship during deposition on the passive margin, these two groups were laterally equivalent and recorded contrasting margin and slope morphology during the Ordovician.

The Blow Me Down Brook formation was origionally thought to contain ophiolite detritus, and was assigned an Early Ordovician age (late Arenigian to early Llanvirnian) (Stevens, 1965, 1970). But in 1989 Lindholm and Casey discovered the trace fossil *Oldhamia* in shales of the Blow Me Down Brook formation. This discovery was significant, for it restricted the age of the formation to the Early Cambrian, therefore placing it at the base of the Humber Arm Supergroup. This discovery of *Oldhamia* aided in differentiating Cambrian, Blow Me Down Brook sandstones from Arenigian, Eagle Island flysch. Quinn (1992) studied the allochthonous Ordovician flysch of the foreland basin and refined the stratigraphic nomenclature of these sediments. Focusing primarily on the Goose Tickle Group and the Lower Head formation, Quinn (1992) placed the Eagle Island formation within her redefined Arenigian age Lower Head formation.

Recent mapping of the Bay of Islands area by Burden et al. (2001) and Calon et al. (2002), has focused on subdividing the mélange surrounding the Blow Me Down and Lewis Hills Massifs into mappable stratigraphic units. Waldron and Palmer (2000) measured detailed stratigraphic sections of the Blow Me Down Brook, Summerside and Irishtown formations east of the Blow Me Down Massif to try and define type sections. Deformation of the rocks and poor exposures prevented the establishment of type sections.

Chapter 2

General Geology

2.1 Geologic Setting

Regionally the Humber Zone is divided into external and internal subzones based on intensity of structural deformation and metamorphic grade, which decreases westward across the Humber Zone (Williams, 1995, 1975). The external portion of the Humber zone, which contains this study area, stretches from the tip of the Great Northern Peninsula southward to the Port au Port Peninsula; it has moderate deformation and low - grade metamorphism.

The geology of the Humber Zone can be divided into three major sequences. They include the crystalline Grenvillian basement sequence, the Cambro-Ordovician autochthonous cover sequence containing a rift succession and overlying platform carbonates, and a structurally overlying allochthonous sequence, composed of sedimentary and igneous thrust slices (Williams, 1975).

The structural assembly of the Humber Zone occurred in three tectonic phases: 1) Rift phase, 2) Drift phase, and 3) Foreland basin phase.

2.1.1 The Rift Phase

Early rifting of the Laurentian craton in the Late Precambrian was related to mafic dyke intrusion, and volcanism (Williams, 1995). So too, grabens formed as the craton rifted were filled with thick sedimentary successions. These strata are known as the Bateau, Bradore and Forteau formations of the autochthonous Labrador Group (Figure 2.1), and the time equivalent Summerside and Blow Me Down Brook formations of the allochthonous lower and intermediate thrust slice assemblage (Stevens, 1970).

Within newly formed rift valleys most sediments were locally sourced from horsts and deposited as fluvial sediments of the Lower Cambrian Bradore Formation of the Labrador Group (Hiscott et al., 1984). As well during this time, the Blow Me Down Brook formation was deposited offshore during the early development stages of the Iapetus Ocean (Lindholm and Casey, 1990).

During the Early Cambrian marine transgression the depositional setting of the Bradore Formation changed from braided fluvial to shallow marine deposits of limestone, sandstone and shale of the Forteau Formation (Debrenne and James, 1981). Around this same time the Summerside formation began to become muddier in the deeper offshore regions of the rift basin. Inasmuch as subsidence continued regionally, a highstand system tract and later marine regression allowed the shallow marine Forteau Formation to pass upward into marginal marine quartzites of the Hawke Bay Formation (Knight, 1977). As the Hawke Bay Formation was deposited near shore in the upper Lower

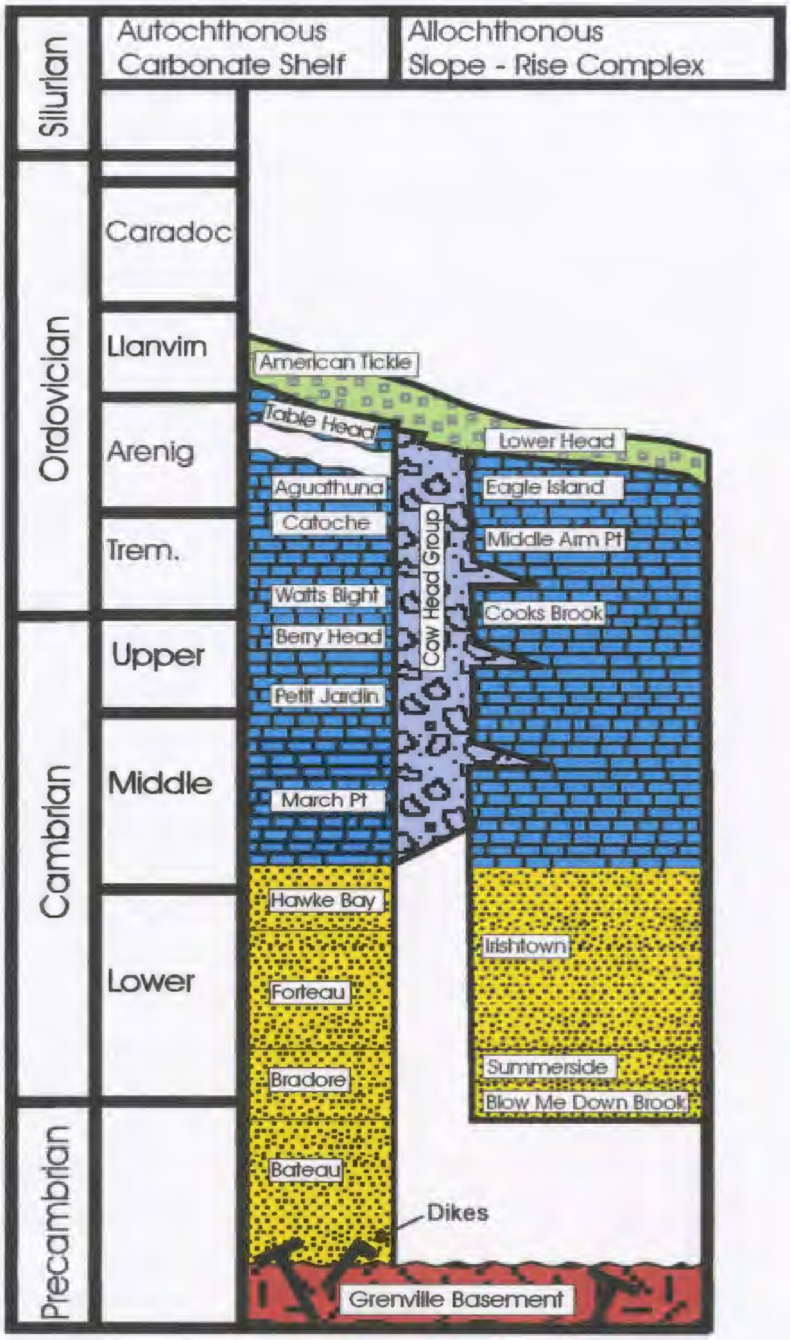

Figure 2.1: Autochthonous and allochthonous stratigraphic sections. (From Lindholm and Casey, 1990)

Cambrian, conglomerate, sandstone and shale in the correlative Irishtown formation represent deeper water offshore deposits.

2.1.2 The Drift Phase

Following rifting, an Atlantic-style passive margin was formed on the eastern edge of the Laurentian continent. The drift sequence was deposited on this passive margin

in the Late Cambrian - early middle Ordovician (Knight et al., 1995). It is comprised of the autochthonous Port au Port and St. George groups, and the time equivalent Cooks Brook and Middle Arm Point formations of the Humber Arm Allochthon (Knight et al., 1995).

Slow, continued subsidence from the Lower Cambrian to the Early Ordovician allowed the rifted margin to evolve into a carbonate platform with offshore slope/deep basin settings. During this time the Port au Port and St. George groups were deposited on this platform, whereas correlative Cooks Brook and Middle Arm Point formations were deposited in deeper water (Knight et al., 1995).

2.1.3 The Foreland Basin Phase

Sedimentation on the passive margin ended by latest Early Ordovician, and Taconic allochthons were thrust over the shelf (Church and Stevens, 1971). Loading of the margin by thrust sheets of oceanic lithosphere and island arc suites caused the collapse of the carbonate platform and the formation of a deep syn-orogenic foreland basin. Warping down of the lithosphere created a peripheral bulge to the west of the foreland basin; both the basin and the bulge migrated westward ahead of the advancing allochthon (Church and Stevens, 1971).

The formation of the peripheral bulge caused faulting, uplift, and erosion of the platform succession, exposing the carbonate platform and creating an irregular karst terrain that is known regionally as the St. George unconformity (Knight et al. 1991).

Stenzel et al., (1989) show a three stage history of the development of the peripheral bulge foreland basin deposition. Stage one consists of the uplift and erosion of the carbonate platform and deposition of the lower Table Head Group under shallow marine conditions on a tectonically unstable shelf. Stage two is the foundering of platform blocks and deposition of deep-water slope carbonates of the upper Table Head Group. The last stage is deposition of siliciclastic flysch of the American Tickle Formation. This unit also contains strata of the Daniels Harbour Member, a carbonate conglomerate formed by gravity flows released from submarine escarpments.

The flysch deposits of the Humber Zone occur both in the autochthonous or 'cover sequence' and in the Humber Arm Allochthon. The correlative Goose Tickle Group of middle Ordovician age represents the flysch of the autochonous sequence. Slightly older Arenig rocks of the Lower Head and Eagle Island formations represent more distal flysch of the allochthonous sequence. The presence of detrital chromite and serpentine in the Eagle Island formation indicates sediment was derived from exposed ophiolite (Stevens, 1965, 1970).

2.2 Autochthonous Rocks

2.2.1 The Labrador Group

The oldest autochthonous rock unit of the Humber Zone is the Labrador Group. This group consists, from oldest to youngest: the Bateau, Lighthouse Cove, Bradore, Forteau and Hawk Bay formations. Strata were deposited upon Grenville basement and are overlain by carbonates, shales and sandstone of Late Cambrian age (Williams, 1995). The lower formations of the Labrador group (Bateau, Lighthouse Cove and Bradore) are composed of quartzite, mafic volcanics, and red arkosic sandstone. Variations in thickness and stratigraphic order indicate that deposition occurred in fault- controlled basins during the rifting phase of Iapetus (Hiscott et al., 1984).

The upper Labrador Group includes the Forteau and Hawke Bay formations, deposited during the late lower Cambrian. Both formations have uniform thickness, and are comprised of limestone, shale, siltstone and minor sandstone.

2.2.2 Port au Port and St. George Groups

The Port au Port Group is middle Late Cambrian in age and is dominated by limestone, dolostone and shale (Chow and James, 1987). The group is composed of the March Point, Petite Jardin, and Berry Head formations. During the deposition of the Port au Port Group the passive margin was a narrow high-energy platform that evolved into a wide low energy shelf as the St. George Group was deposited (Stenzel et al., 1989).

The St. George Group conformably overlies the Port au Port Group. It is dated middle Early Ordovician, and composed primarily of limestone and dolostone. The St. George Group is divided into Watts Bight, Boat Harbour, Catoche and Aguathuna formations (James et al., 1989). The top of the St. George Group is marked by a regional unconformity (the St. George unconformity).

2.2.3 The Table Head Group

The Table Head Group was deposited upon the exposed strata of the St. George Group. The rocks show evidence for the demise of the carbonate platform on the early Paleozoic continental margin (Stenzel et al., 1989). The Table Head Group along with the overlying Goose Tickle Group records the depositional history of the evolving foreland basin during the Taconic Orogeny (Stenzel et al., 1989).

The Table Head Group is divided into the Table Point Formation, which is massive, burrowed, and fossiliferous grey limestone, the Table Cove Formation, which contains thin-bedded, muddy limestone and calcareous shale; and the Cape Cormorant Formation, including shale and interbedded carbonate lithoclast conglomerates (Stenzel et al., 1989).

2.2.4 The Goose Tickle Group

The middle Ordovician age Goose Tickle Group overlies the Table Head Group in the autochthonous sequence. Strata are comprised of a heterogeneous flyschoid package of shale, siltstone, and sandstone deposited in a deep-water anoxic basin, by distal low-velocity turbidity currents (Quinn, 1992).

The Goose Tickle Group is divided into: the Black Cove Formation, a black, non calcareous shale with minor silt laminae. The American Tickle Formation, a non calcareous, black shale; thinly interbedded black shale and greenish silt, with thin beds of green sandstone (Quinn, 1992).

2.3 Allochthonous Rocks

The Humber Arm Allochthon in the Bay of Islands region is a 200 km by 50 km litho-tectonic unit composed of westerly transported thrust slices of diverse lower Paleozoic rocks (Williams, 1975). The composite thickness of the allochthon is approximately 1000-1500 m. It is divided into three levels of thrust slices separated by extensively developed zones of mélange (Williams, 1975). The matrix of the mélange in the Humber Arm Allochthon is mainly derived from the sedimentary rocks of the Humber Arm Supergroup, a mixture of greywacke, dolomitic shale, quartzite, chert and limestone blocks in a black, red or green shaly matrix. Serpentinite mélange containing blocks of serpentinite and gabbro have been observed by Williams (1995) near the base of the Blow Me Down ophiolite at Humber Arm, as well as below the Little Port Complex.

The lower thrust slices of the Humber Arm Allochthon are composed of rift and drift sedimentary deposits of the Humber Arm Supergroup. These rocks consist of an accretionary wedge of tectonically telescoped continental margin succession that was scraped from the distal margin and transported a small distance to be emplaced onto the passive margin (Williams, 1975). The intermediate thrust slices contain the Blow Me Down Brook Formation and the Fox Island River Volcanics. These slices were transported an intermediate distance and deposited upon the margin. The upper thrust slices have been transported the farthest and are composed of a suite of igneous rocks representing oceanic lithosphere, the Bay of Islands Ophiolite complex (485 Ma), and the Little Port Complex. Which is a suite of island arc related igneous rocks dated at 505Ma (Jenner et al., 1991).

2.3.1 The Humber Arm Supergroup

The Humber Arm Supergroup ranges in age from the latest Precambrian (Ediacaran) to late Early Ordovician (Llanvirn). The supergroup includes the Curling (Summerside and Irishtown formations), Northern Head (Cooks Brook and Middle Arm Point formations), and Cow Head groups (Figure 2.1) (Botsford, 1988). The Humber Arm Supergroup ranges in age from the latest Precambrian to late Early Ordovician. Deposition of the Northern Head Group, which overlies the Curling Group, is time equivalent to the deposition of the Cow Head Group.

The Blow Me Down Brook formation is dated to the early Cambrian (Lindholm and Casey, 1990) and is not placed in the Curling, Northern Head or Cow Head Groups, but is placed as a unique entity at the base of the allochthon stratigraphy (Figure 2.1) (Waldron and Palmer,2000).

The Blow Me Down Brook Formation

The Blow Me Down Brook formation is comprised primarily of thick-bedded grey-green coarse-grained arkosic sandstone exposed on the southern and northeastern shores of the Bay of Islands, Woods Island, and the coastline between Rope Cove and Fox Island River. The sandstones of the formation are massive, with intervals of black, green or red shale. The Blow Me Down Brook formation is located in the intermediate thrust slice of the Humber Arm Allochthon, structurally overlying the Humber Arm Supergroup. The structural position and physical features of the Blow Me Down Brook formation originally led to the interpretation that formation was an Early Ordovician flysch unit positioned at the top of the Supergroup (Stevens, 1970). However, the discovery of the trace fossil *Oldhamia* in the shaly strata of the formation indicates that the Blow Me Down Brook is Early Cambrian age and therein placed at the base of the Humber Arm Supergroup (Lindholm and Casey, 1990; Cawood et al., 1988).

From palynomorph studies Lavoie et al. (2003) suggest the Blow Me Down Brook formation may be laterally correlative to the Summerside and Irishtown formations of the Curling Group. In regional correlation Lavoie et al. (2003) propose the Blow Me Down Brook Formation and the Curling Group are coeval with the Labrador Group.

The Curling Group

The Curling Group is composed of the Summerside and Irishtown formations. The group does not have a complete section exposed; therefore the thickness of the succession is estimated from partial sections observed in the Humber Arm area (Waldron and Palmer, 2000).

The Summerside Formation

The Summerside formation is the lowest stratigraphic unit in the contiguous succession of supergroup (Stevens, 1965). Its base is not exposed and the thickness is estimated to be 1000 m (Waldron et al., 1998; Williams, 1995).

Waldron and Palmer (2000) describe the Summerside Formation as maroon and grey-green slates interbedded with very fine to coarse-grained quartz-rich arkosic sandstones. While the fresh surfaces of the sandstone are dominantly grey green in color, the weathered sections are a yellowish white. Graded bedding is seen in thin sandstone beds (1-10 cm), while thicker beds are usually more homogeneous. The sandstones of the Summerside formation have parallel laminations, ripple cross laminations, dewatering structures, and some large scale tabular and trough cross beds. The shales of the formation have parallel laminations and some cross laminations. The top of the formation has a grey-green shale interval sometimes referred to as the Summerside-Irishtown transition.

No body fossils have been found in the Summerside Formation, but small burrows that can be up to 5 mm wide and 10 cm long are present in the Summerside-Irishtown transition shale. The age of the Summerside formation was determined to be Early Cambrian or older from the stratigraphic contact with the overlying Early Cambrian Irishtown Formation, as well correlations inferred with strata of the lower part of the Labrador Group (Waldron and Palmer, 2000).

The Summerside Formation was deposited during the rift phase leading to the opening of the Iapetus Ocean (Williams, 1975). The graded bedding, poor sorting, and dewatering structures of the formation indicate that is was likely deposited by density flows in a deep-water setting.

The Irishtown Formation

The Irishtown formation stratigraphically overlies the Summerside formation. It is composed of grey graphitic, pyrite-bearing shale and sandstone with polymictic conglomerate beds. The graded sandstone beds in this formation commonly display partial or complete Bouma sequences, with flutes, grooves and load structures preserved on the basal surfaces. Dark grey shales contain abundant pyrite, and weather a rusty orange color. The conglomerates of the Irishtown formation include clasts of plutonic and sedimentary rocks, quartz veins, and rare limestone (Stevens, 1965; Waldron and Palmer, 2000).

Botsford (1988) measured approximately 550 m of Irishtown formation and defined three informal members. The lower member encompasses the transition zone between the Summerside and Irishtown formations. It is approximately 30 m thick, and consists of bluish-weathered grey shale with thin beds of coarse to fine sandstone.

Above the transition zone is a thick middle member dominated by thick-bedded quartzose sandstone with interbedded grey to black shales. The sandstones within this interval are quartz rich and can be in part conglomeratic. Clasts of the conglomerates are polymictic. Some clasts are granitic and were probably derived from basement while sedimentary clasts represent facies of the Labrador Group. Within some platform carbonate clasts Early Cambrian trilobites, salterellids and archaeocyathans have been found (Walthier, 1949; McKillop. 1963; Stevens, 1965; James and Stevens, 1982). These imply that the formation is no older than late Early to middle Cambrian age.

The uppermost member of the formation is composed of quartzose sandstone that weathers an orange color. This is interbedded with layers of siltstone passing upward into dark shale. The appearance of orange weathering on the grey shale and siltstone in this uppermost section of the Irishtown is thought to be due to the presence of abundant, medium silt size, euhedral, highly ferroan dolomite that is mixed with abundant quartz, feldspar and mica of similar size (Botsford, 1988).

The Northern Head Group

Botsford (1988) defined this group to consist of the Cooks Brook, Middle Arm Point and Eagle Island formations. Previous studies had included the Cooks Brook and Middle Arm Point formations in the Curling group. Botsford (1988) based his definition of the Northern Head group on distinctive lithological changes from the Irishtown formation to the Cooks Brook formation. The Northern Head group is age equivalent to the Cow Head Group in the northern section of the Humber Arm Allochthon (Lavoie et al., 2003).

The Cooks Brook Formation

The Cooks Brook formation lies above upon the Irishtown formation of the Curling group. Botsford (1988) established the boundary of the Cooks Brook and Irishtown formations as the first calcareous bed overlying Irishtown shale. There is no completely exposed section of the Cooks Brook formation. The thickness was estimated by Botsford (1988) to be 350m. The Cooks Brook formation is dominated by 'ribbon' limestone interbedded with grey to black shale, and carbonate conglomerate.

Within the conglomerate beds of this formation trilobite fauna was reported in boulders collected by Cawood et al., (1988). These indicate that the formation cannot be older than late middle Cambrian; this age correlates with the Port au Port and the lower part of the St. George Groups.

The Middle Arm Point Formation

The Middle Arm Point formation is approximately 120m thick (Botsford, 1988). It conformably overlies the Cooks Brook formation. The base of the Middle Arm Point formation consists silty dolostone of the Woman Cove member. Some sections of this basal unit are overlain by a conglomerate bed composed of pebbles to cobbles of silty dolostone and green shale (Botsford, 1988). Above the Woman Cove member is a lime grainstone unit. Current ripples and bioturbation are present in the lime grainstone (Botsford, 1988). Overlying the lime-grainstone interval is the North Arm Point member, a siliceous green shale with silty dolomite. The uppermost part of the Middle Arm Point formation is shale. This shale member has three major shale lithotypes; red dominated shale, black and green shale and green dominated shale (Botsford, 1988).

Graptolite faunas indicate the Middle Arm Point formation is Early Ordovician in age and spans the Late Tremadoc to middle Arenig (Botsford, 1988).

The Eagle Island Formation

The Eagle Island formation in the lower structural slice of the allochthon is composed of a sandstone - dominated flysch. The contact with the overlying Middle Arm Point formation is gradational. However, and in keeping with provisions of the stratigraphic code, the boundary is placed at the first occurrence of sandstone (Botsford, 1988). Thickness of the Eagle Island formation is not known because the top of the unit is never seen.

The sandstones were deposited in the foreland basin during the middle Ordovician and can be correlated to the Goose Tickle and Table Head froups of the autochthonous succession.

The Cow Head Group

The Cow Head Group represents a more proximal depositional assemblage of the Humber Arm Allochthon (Botsford, 1988) It is composed of the Shallow Bay, Green Point and Lower Head formations, and ranges in age from upper Cambrian to Middle Ordovician (Figure 2.1).

The Shallow Bay Formation is the coarser grained carbonate facies of the Cow Head Group (James and Stevens, 1986).

The Green Point Formation is the offshore equivalent to the Shallow Bay formation. The unit ranges in thickness of 400-500m and is composed primarily of green, red, and minor black shale with some conglomerate and parted limestone intervals (James and Stevens, 1986).

Chapter 3

Methods and Applications

3.1 General Methodology

Analysis of the Blow Me Down Brook formation involved four months of fieldwork in the summers of 2004 and 2005, resulting in a more complete stratigraphy for the formation. In all, 1600 m of section were measured, 970 m is presented in this thesis. A total of 363 samples were collected for petrography and palynology from the formation, as well as the Fox Island River Volcanics. The following chapter outlines field mapping and petrographic techniques used to deduce a stratigraphy for the Blow Me Down Brook formation.

3.1.1 Field Mapping Techniques

Thrust panels of Blow Me Down Brook formation are well exposed in many coastal sea cliffs and river valleys from Fox Island River, north to Rope Cove. Additional outcrops examined for this study occur on Blue Hill Brook, east of the Lewis Hills Massif, along Blow Me Down Brook, north of the Blow Me Down Massif, and on the west end of Woods Island. In compiling a stratigraphy for the Blow Me Down Brook formation, faults make it impossible to a see single, continuous section. Therefore, this stratigraphy is assembled using a series of measured coastal sections, which are then correlated into a model of the stratigraphy.

The process for determining sections began with reconnaissance mapping to identify which of the larger sections would be measured in greater detail. In total, 9 sections were selected to represent the Blow Me Down Brook formation. Once sections were selected, a UTM coordinate was taken and a stake driven at the start point. From this origin, a stake was driven every 30 m to the end of a coastline section. The 30 m intervals were measured using a 30 m tape, and kept aligned using a Silva compass on a set bearing. Where changes in the coastline affected the bearing, a new UTM coordinate was taken and the bearing changed to negotiate the obstacle. Where the section was terminated, yet another marker was placed, the total distance noted on a piece of marking tape and tied to the marker pole, with a UTM coordinate written down.

Once the section had been measured off in 30 m intervals along the coastline, the strata were assessed to find the base. Once the base was established a UTM coordinate was taken, and strata were measured until a break in the stratigraphy was observed. When this occurred a new section was started, either above the break, or in adjacent strata. As strata were measured, samples for petrography and palynology were collected and noted.

3.1.2 Petrographic Techniques: The Gazzi-Dickinson Method

Petrographic analysis of the Blow Me Down Brook formation was carried out using the Gazzi – Dickinson point count method. This method was conceived independently by Dickinson (1970) and Gazzi (1966) to calculate modal percentages of framework grains in sandstone. Using this point counting method, characterization of the sandstone is possible, as is interpreting provenance in tectonically active settings. The primary grain parameters used in this method have been outlined by Dickinson (1970) to include:

1.Stable quartz (Q) as the sum of; a) monocrystalline quartz grains (Qm), and; b) polycrystalline lithic quartzose fragments (Qp).

2. Feldspar (F) as monocrystalline feldspar grains (F), including plagioclase (P), and potassium feldspar (K).

3. Unstable polycrystalline lithic fragments (L), including; a) (Lv) volcanic and metavolcanic; b) (Ls) sedimentary and metasedimentary, and; c) (Lm) metamorphic lithics. The total lithic fragments (Lt) are calculated as the sum of the unstable lithics (L) and the stable quartzose lithics (Qp) (Ingersoll et al., 1984).

In addition to quartz, feldspar and lithics, phyllosilicates, dense minerals, miscellaneous and unidentified grains are counted in the Gazzi – Dickinson method. Matrix within the thin sections is defined as clays and framework minerals less than 0.03mm in diameter (Dickinson, 1970). Cement was counted in this study, however it is not included with the ternary plot data due to the fact that it is a diagenetic texture (Ingersoll *et al.* 1984). The quantity of matrix was noted in the point count data; however, it is not included in corresponding ternary plots, due to the fact that it is composed of grains smaller than the acceptable size for counting (>.0625 mm).

The Gazzi-Dickinson method differs from more traditional counting methods in that larger sand size crystals (>.0625 mm) are counted when intersected by the cross hair, even if they are within a larger rock fragment. Therefore a rock fragment composed of a large quartz crystal within a fine grain matrix, may either be counted as a stable quartz grain, or a sedimentary lithic, depending where it intersects the cross hairs. This aspect of the Gazzi-Dickinson method has become a source of debate for some petrographers who argue that it is unacceptable to classify a detrital grain of sandstone containing smaller volcanic rock fragments as a volcanic rock fragment, if the crosshairs intersect the volcanic grain, instead of the larger sandstone fragment (Suttner and Basu, 1985).

For each thin section in this study a minimum of 300 point counts was recorded, using a point count stage with 1mm grid spacing. A set of twelve defined counting parameters (Table 3.1) was used to calculate the modal percentages of framework grains. Each grain in the target area was counted if it was larger than .0625 mm (sand size). So too, each grain was treated as an individual mineral, no matter if it was isolated as a part of a larger rock fragment.

In total, 95 samples from the Blow Me Down Brook formation were analyzed (The raw data is presented in Appendix 1). The particle size for the samples was commonly medium- to coarse-grained; fine-grained sandstone samples were excluded to allow better comparison between the sections. Grid spacing was monitored to ensure that it was larger than the maximum grain size of the sample. This limits the chance of landing on the same grain twice. Once counts were complete, the samples were plotted on various composition and provenance ternary diagrams after Pettijohn (1975) and Dickinson et al., (1983).

1. Monocrystalline quartz
2. Polycrystalline quartz
3. Plagioclase feldspar
4. Potassium feldspar
5. Volcanic fragment
6. Sedimentary fragment
7. Mica
8. Opaque minerals
9. Cement
10. Porosity
11. Unknown/Miscellaneous
12. Chert

Table 3.1: Parameters used for Gazzi-Dickinson point counts carried out on sandstones of the Blow Me Down Brook formation.

Chapter 4

Tectonostratigraphy of the Blow Me Down Brook formation

4.1 <u>The Blow Me Down Brook formation</u>

From the onset of geological mapping in western Newfoundland there has been mention of a quartzose and feldspathic sandstone unit within strata of the western Humber Zone. Building on the work of Logan (1863) and Schuchert and Dunbar (1934), more detailed studies of this unit were conducted decades later by W.D. Brückner and students.

In a limited edition conference field guide, Brückner (1966) compiled the thesis studies of Lilly (1965) and Stevens (1965) to identify 5 divisions of strata that were worthy of formation status. One division was named the Blow-Me-Down Brook formation, and was described as "brownish, thick-bedded, greywacke and arkose, with some conglomeratic beds, interbedded with some soft, red and green shales." (Lily, 1965, pg. 205)

The Blow Me Down Brook formation is located along Blow Me Down Brook, on Woods Island, along the shore of the Bay of Islands, and the Gulf of St. Lawrence. The formation is commonly described as thick-bedded, grey-green, very coarse - to medium-grained arkosic sandstone, interbedded with black, green or red shale. To date, no defined stratigraphic top or base has been identified for the formation. In the past researchers have speculated that the Blow Me Down Brook formation lies in stratigraphic contact with volcanic rock notably on western Woods Island (Brückner, 1966, Lilly, 1967, Williams, 1973, Waldron and Palmer, 2000). A possible basal contact between

Blow Me Down Brook and Fox Island River Volcanics was recently discovered in the upper reaches of the western tributary of Blue Hill Brook (Fowler, 2005).

Early interpretations for the Blow Me Down Brook formation identified it as a mid-Ordovician flysch, lying stratigraphically above Middle Arm Point formation, and below the Humber Arm Volcanics (Brückner, 1966, Lily, 1967, Williams, 1973). This interpretation was accepted until the work of Quinn (1985), which compared the Sellars formation (Bonne Bay equivalent to the Blow Me Down Brook formation) with similar sandstone units of Precambrian – Cambrian age in the Appalachians. Through these observations, Quinn concluded that the Blow Me Down Brook formation had been misinterpreted in several sections as an Ordovician flysch. Lindholm and Casey (1989) backed this conclusion following their discovery of the Early Cambrian trace fossil *Oldhamia* within the shales of the Blow Me Down Brook formation.

4.2 Regional Mapping

From the fieldwork conducted during this thesis a regional 1:30 000 map was compiled for the study area (Insert I). Building on previous maps of the area (Schilleriff, 1980, Williams and Cawood, 1987) and a much better understanding of the strata this map shows a more extensive belt of the Blow Me Down Brook formation. In the Fox Island River and Cache Valley areas rocks formally described as mélange are now interpreted as broken beds of sandstone and shale of the Blow Me Down Brook formation.

4.3 Stratigraphic Sections

Nine measured stratigraphic sections of Blow Me Down Brook formation (Figure 4.1) are selected as examples of the many outcrops mapped in thrust panels exposed in coastal sea cliffs and river valleys. Within these thrust panels, distinct sub-units are recognized and grouped according to the distribution of feldspar, quartz pebbles and granules, calcarenite boulders, quartzose sandstones, thick red and black shale successions, trace fossils, and carbonate cements. By recognizing lithotypes, stratigraphic relationships and patterns are determined. In this chapter the stratigraphic sections are not presented in order from north to south, or vice versa. Presentation of the sections starts with the structural contact between the Blow Me Down Brook formation and the Northern Head Group, which is common to three of the nine sections. Subseqently, the sections are introduced based upon their common characteristics to the previous section discussed. As well, the structural interpretations of sections are discussed previous to the stratigraphy of the formation, because a clear understanding of the structure is a necessity to understand and delineate the stratigraphy.

Measured stratigraphic sections are commonly cut by faults, making it impossible to see a single, continuous section anywhere in the study area. A composite stratigraphy is assembled using a series of measured coastal sections that are correlated into a logical model of the stratigraphy.

The strata within this region of western Newfoundland have been deformed in a complex manner. During the Taconic Orogeny, westward verging thrusts placed older Blow Me Down Brook formation over Late Cambrian-Early Ordovician Northern Head

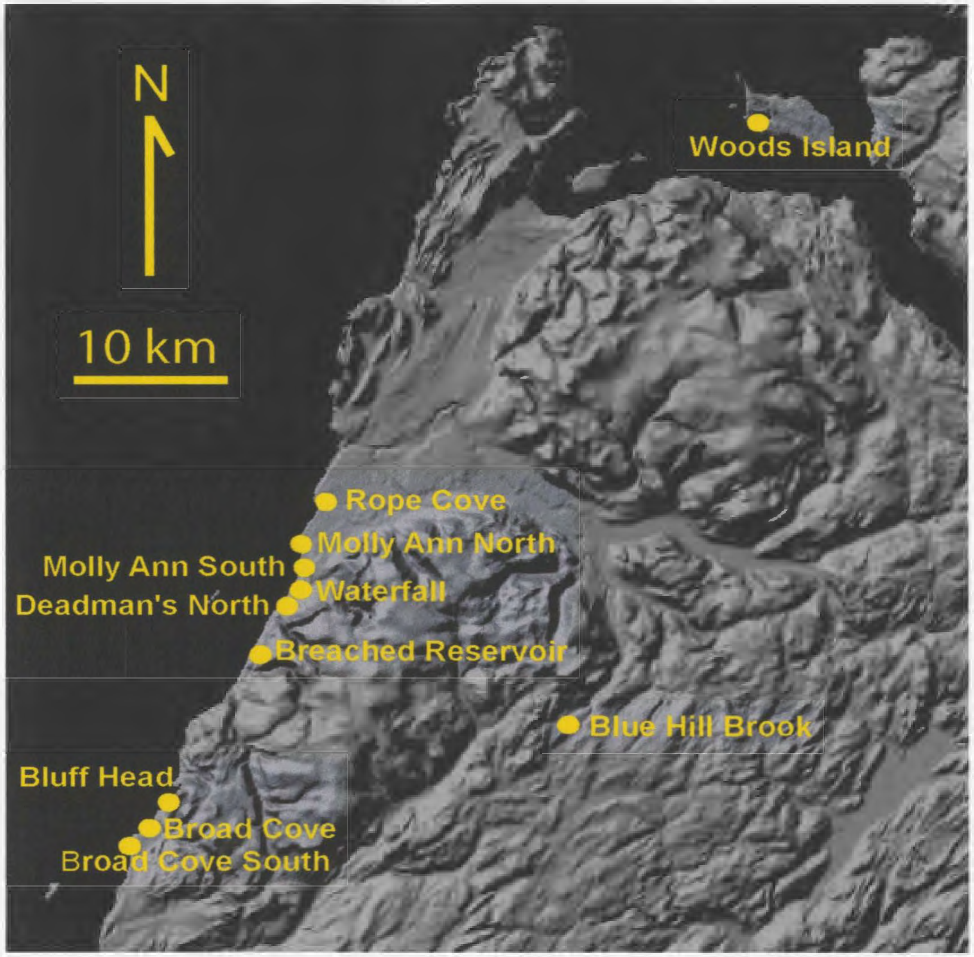

Figure 4.1:Radar image (from Newfoundland Mines and Energy Geological Survey website) showing localities and sections of examined in this study.

Group carbonates. This structural relationship is well displayed in coastal sections at Molly Ann South, Molly Ann North and the "Breached Reservoir" at Sluice Brook.

4.3.1 The Breached Reservoir section

The breached reservoir section is located at UTM coordinates (0385181, 541552). This section is composed of petroliferous sandstones thrust over folded and faulted calcarenites of the Northern Head Group. This belt of outcrop shows a section of a "breached" or broken reservoir.

The breached reservoir section extends along the coast for 500m (Figure 4.2). Strata display a crudely antiformal shape in a refolded F_1 thrust (Figure 4.3). Here, Blow Me Down Brook strata lie upon and in sharp contact with younger Northern Head Group rocks. The timing given for many of the thrusts within coastal sections is unclear. Without a more precise understanding of the larger structures, the internal structural fabric, and the strata, it is often very difficult to differentiate F_1 and F_2 thrusts. For this section the core of the antiform is tightly folded and faulted Northern Head Group strata. Limestone and shale beds form a small east plunging anticline (28→098), in the hangingwall of a south verging F_2 thrust. Accommodation faults in the form of a blind back thrust (F_2) located on the backlimb, and a wedge thrust (F_2) within the forelimb of the hanging wall anticline disappear in the overlying shaly strata.

The footwall strata lying beneath the main F_2 thrust are close to sea level and are mostly covered with beach boulders. Steeply dipping limestone beds lie directly below the subplanar F_2 fault ramp. A short distance south (at 250m along traverse), beyond the

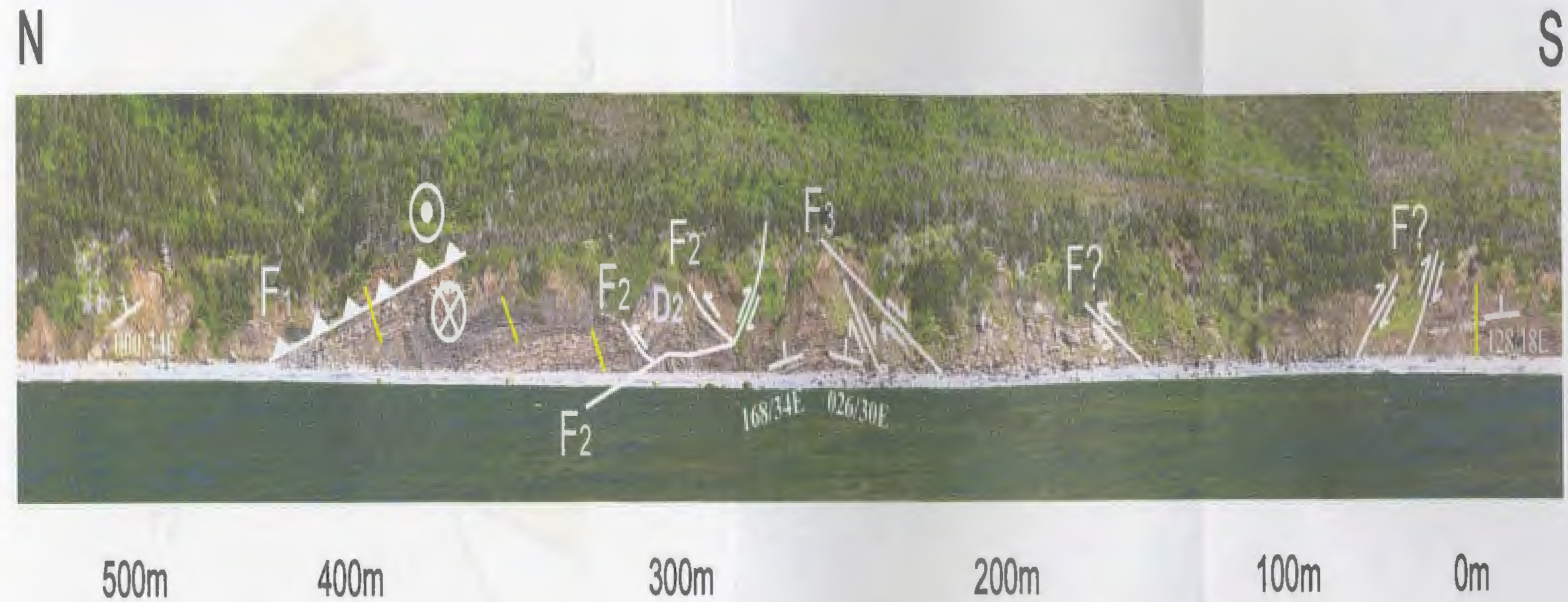

Figure 4.2: Panorama of Breached Reservoir section at present day sea level. Older Blow Me Down Brook sandstones have been thrust westward over younger limestones of the Northern Head Group (F1). The section was then folded into an antiform, resulting in accommodation faulting (F2). Post folding a large F3 normal fault breached the antiform structure and dropped the south limb down to sea level.

Location of measured sections are outlined in yellow.

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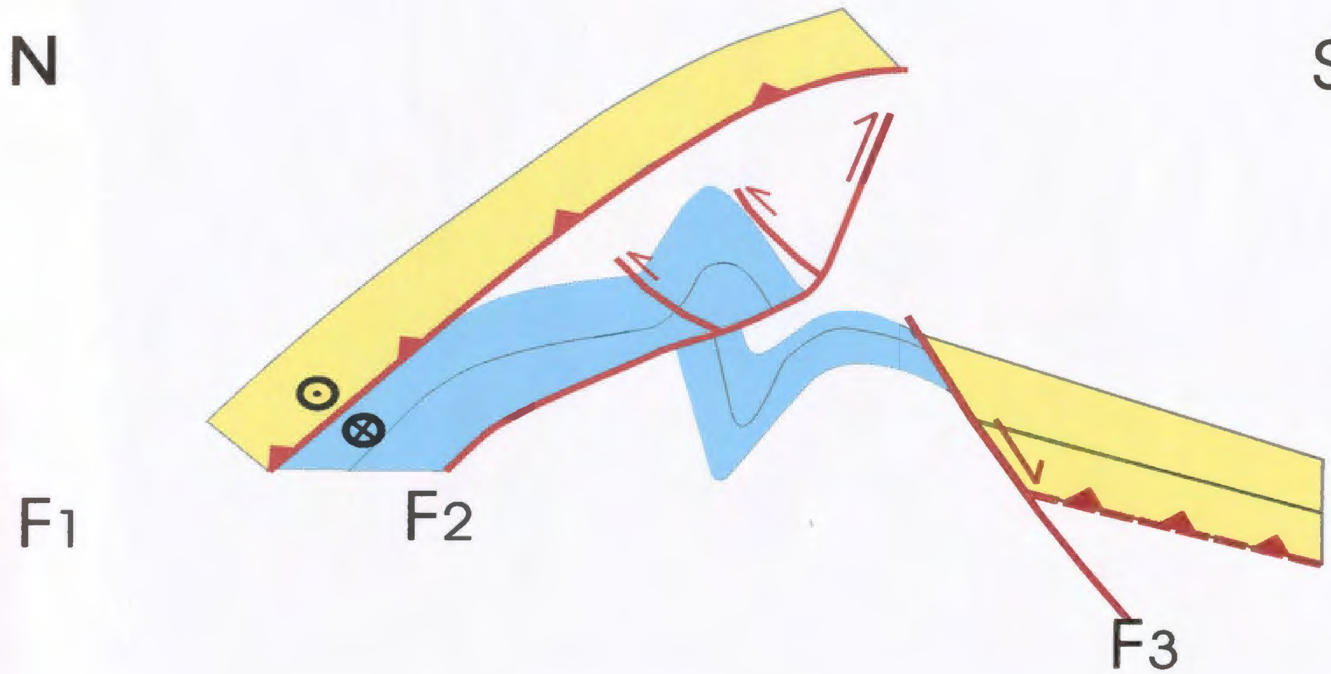

Figure 4.3: Schematic cross section showing the principal elements of the wedge thrust system and broken D2 antiform. Northern Head Group - blue; Blow Me Down Brook formation - yellow.

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steeply dipping rise of the F_2 thrust, the limestone beds apparently form the north limb and crest of a small plunging anticline (10→181). All of the exposed limestone beds of the footwall appear similar to the lowest limestone beds in the anticline in the hangingwall. This suggests a relatively small amount of displacement on the F_2 forelimb thrust. So too, the length of this F_2 fault is unknown; with no outcrop exposed in the hills it simply ends as a blind thrust in an accommodation zone in thickened and deformed shaly strata on the crest of the larger antiformal structure.

Broken shaly, silty and sandy strata lie above the limestone beds of the Northern Head Group. These beds are thought to represent the fault zone of a west verging F_1 thrust carrying Blow Me Down Brook strata over Northern Head Group rocks. It is possible that during this event, some of the less competent Northern Head Group rocks were folded as the Blow Me Down Brook strata were thrust over them. Never well-exposed in the section, these broken beds are seen in the valley wall and near the mouth of a small stream on the northern limb of the larger antiform, 420m along traverse. These beds are not seen on the southern limb of the D_2 antiform; a late stage normal fault F_3 (at 160 m) has dropped the F_1 fault zone below sea level.

The measured section of Northern Head Group strata, in the footwall panel below the F_1 thrust, has a total thickness of 40m (Figure 4.4, 4.5). The base of the section is composed of light brown weathered calcarenite, interbedded with black shale. The limestones beds within the first 14 m of the section measure 10-30 cm in thickness and contain abundant sedimentary structures, including, planar, cross and wavy laminations, load casts, asymmetric ripples and climbing ripples (Figure 4.6) The black shales interbedded with these limestones have a "greasy" texture. In tests for total organic

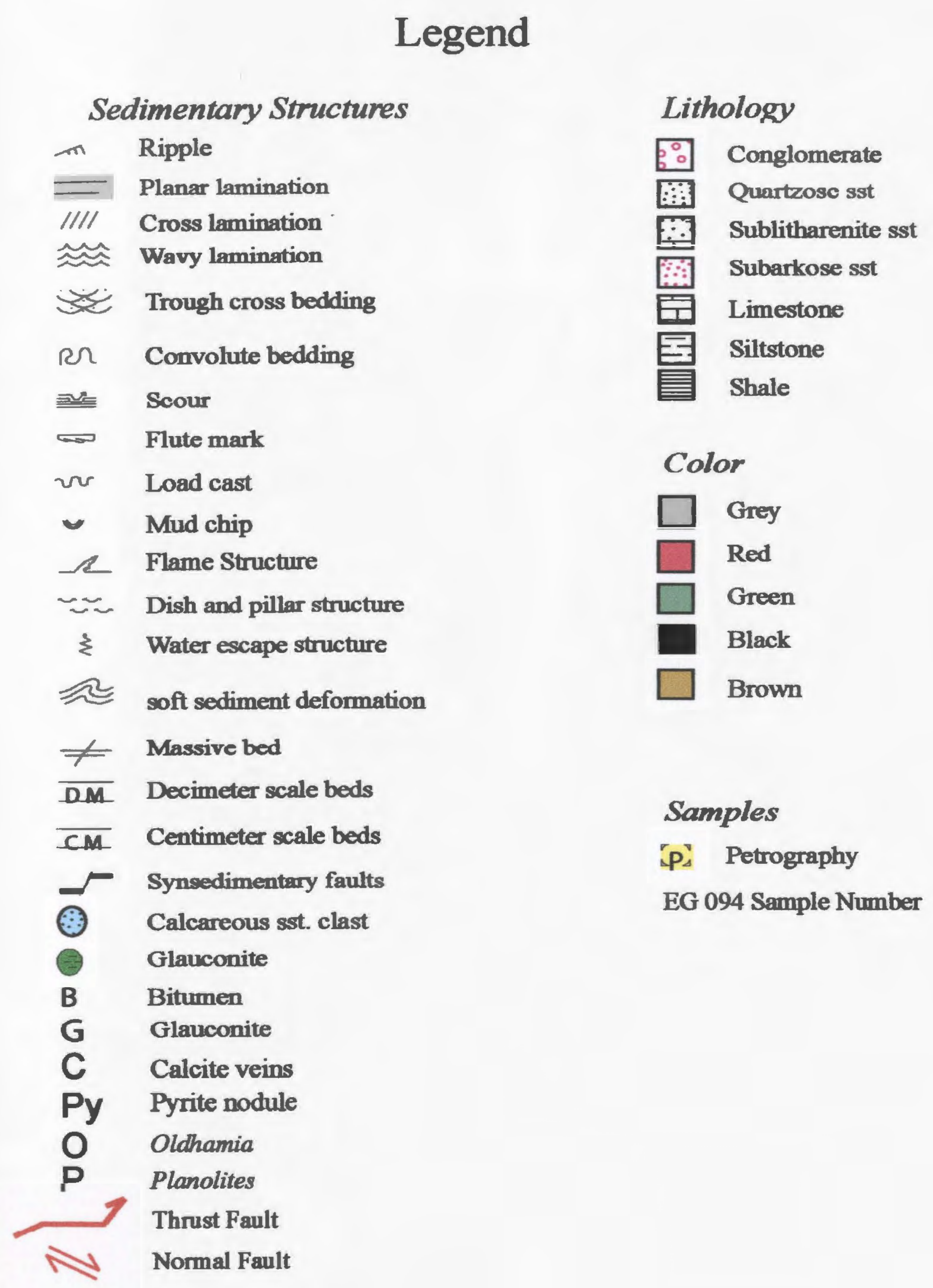
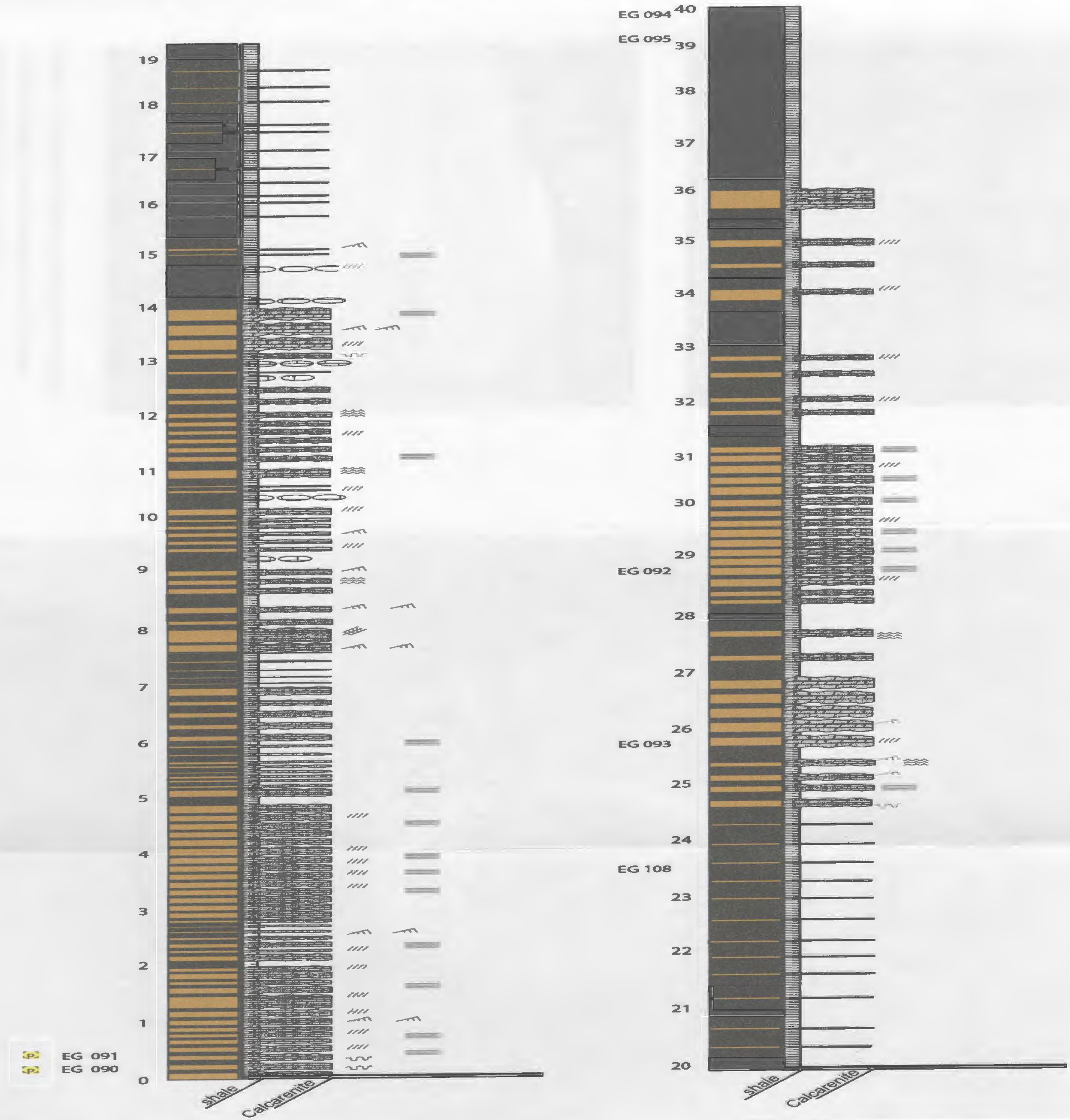


Figure 4.4: Legend for all measured stratigraphic sections.

Figure 4.5: Breached Reservoir section, Northern Head Group. Vertical scale shown in meters. Figure 4.4 for section legend.

Carbonate Stratigraphy for Breached Reservoir Section



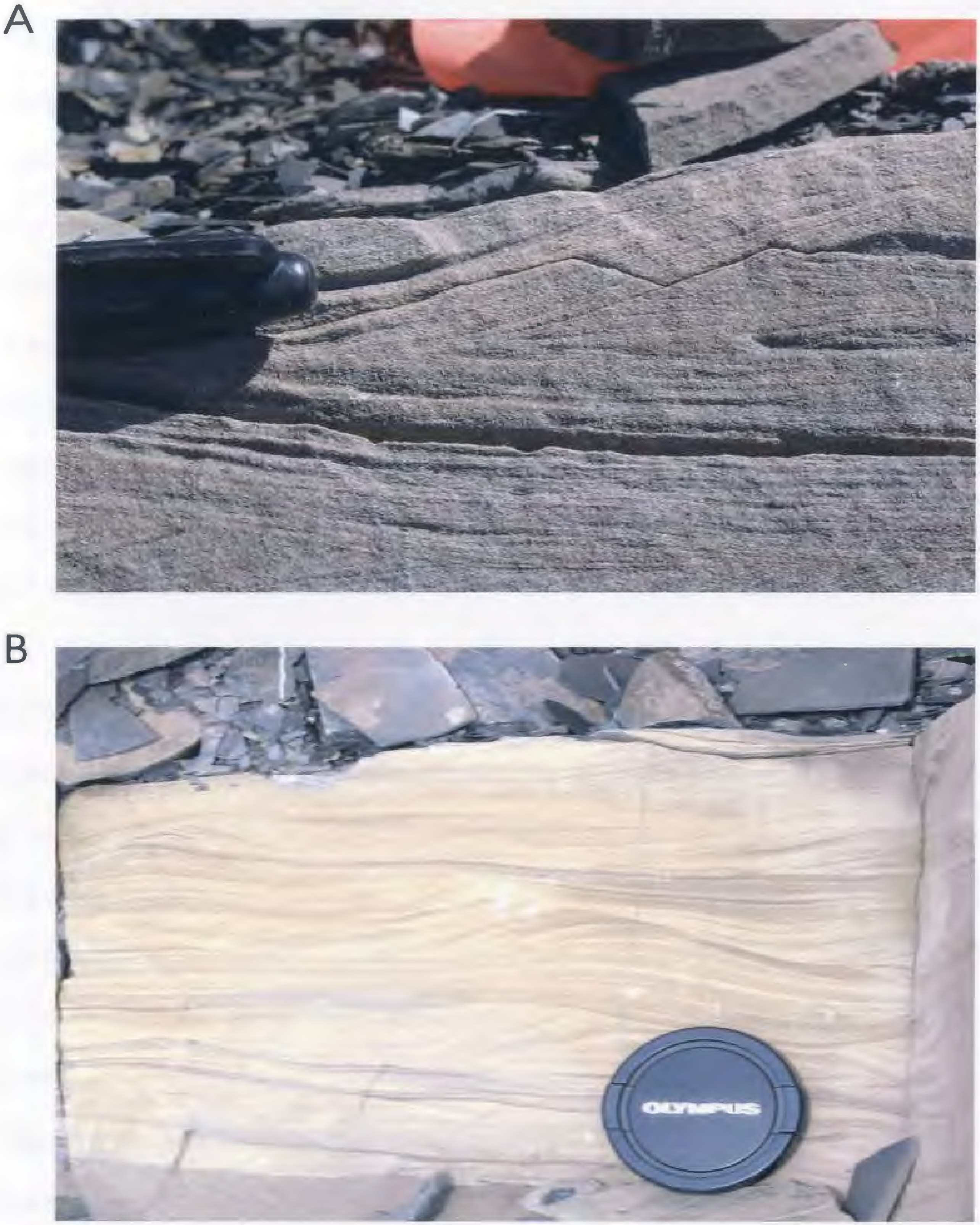


Figure 4.6: A) Asymmetric ripples and planar lamination within the Northern Head Group. Beached Reservoir section. B) Climbing ripples and wavy lamination of same group.

carbon, they show TOC of over 2%, and a hydrogen index of up to 200 (Fowler, M. pers. comm. 2005).

Between 14 and 24 m the section becomes dominated by black shale. Thin layers and lenses of limestone 5 to 6 cm thick punctuate the black shale. The shale beds within this interval are somewhat micaceous and no longer have the "greasy" texture of beds found near the base of this section.

Above 24 m the section coarsens upward, limestone beds are more common, and beds thicken to 10 - 50 cm thick. The section is now composed of 50% limestone and 50% black shale. Within the limestone beds, planar, wavy, and cross lamination are abundant. Paleoflow restored azimuths of (030, 027 and 029) indicate a northeasterly flow.

At 31m the limestone beds become thinner, finer-grained and grade to black shale. Rare, thin, 10 to 40 cm beds of limestone, containing cross lamination are randomly spaced through the massive black shales.

The hanging wall panel, lying above the F_1 thrust plane, is blackened, oil-stained sandstone, interbedded with black shale of the Blow Me Down Brook formation. These petroliferous sandstones are broken throughout the section, and did not allow for easy measurement of the stratigraphy. A continuous section of these sandstones was measured at 0 m (Figure 4.2), but does not represent the entire Blow Me Down Brook succession present in the breached reservoir section. The thickness of this sandstone shale succession is 29 m (Figure 4.7). Basal sediments are composed of 3.5 m of black micaceous shale, followed by 8m of interbedded grey sandstone beds, 2 to 25 cm thick, and micaceous black shale. Medium to thick petroliferous sandstone beds and black shale occur from

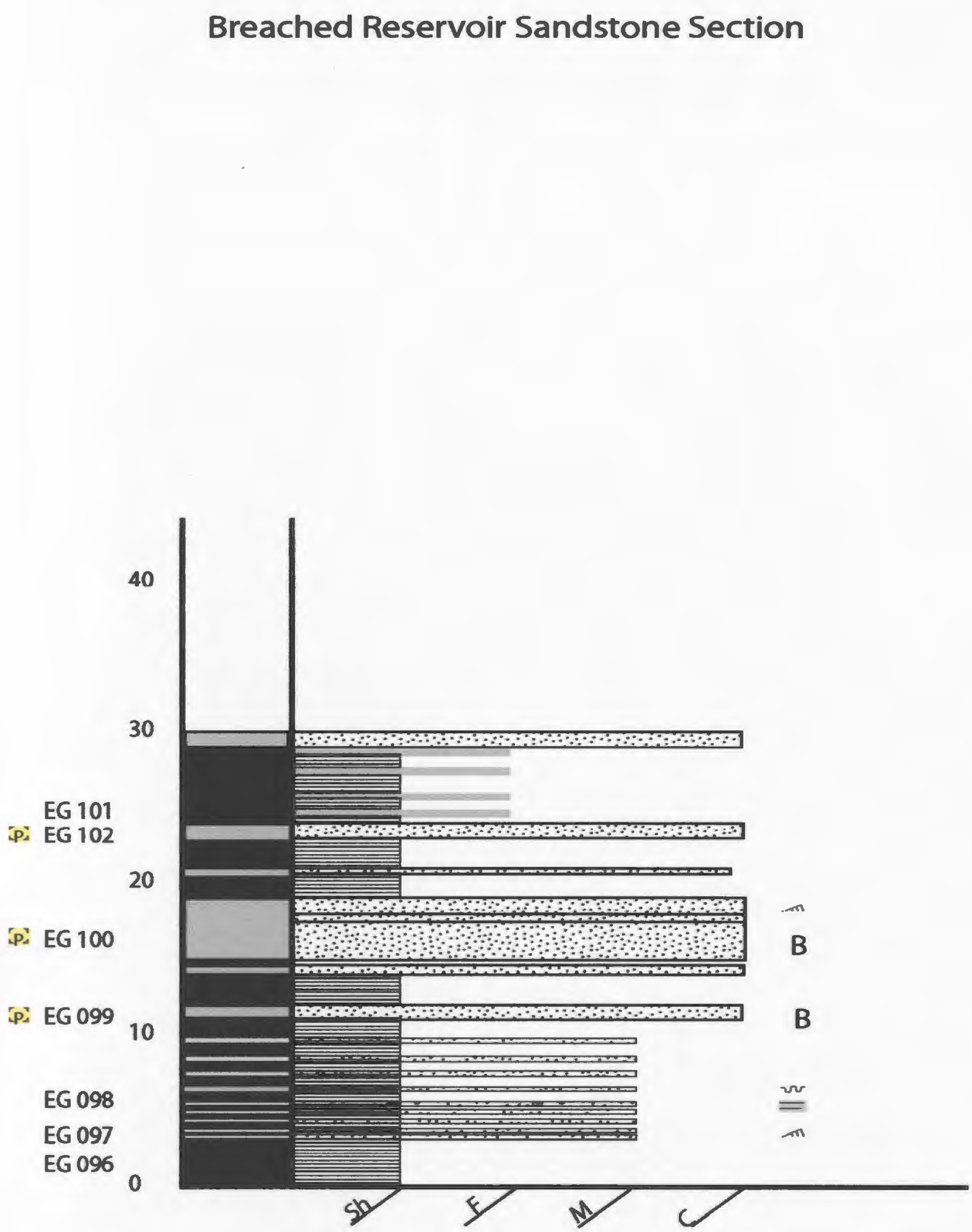


Figure 4.7: Breached Reservoir section, Blow Me Down Brook sandstone and shale. Vertical scale shown in meters. For legend see Figure 4.4.

12 m to 24 m. These sandstones are coarse – grained and poorly sorted, they commonly measure 0.5 to 2 m in thickness. Above thick petroliferous sandstones, the strata become thinner and finer-grained, grading to thick black shale beds punctuated by thin wavy beds of medium-grained sandstone, near the top of the sea cliff.

By traversing up the small stream at 420m along the coastline section, thick petroliferous sandstones seen on the coast at 500m can be observed in contact with black shale. This black shale then grades into thick, massive red shales that continue upstream for approximately 40m. Sedimentary structures within the siliciclastic rocks of this section are rare; ripples are seen near the tops of thinner beds; thicker sandstone beds locally contain planar lamination and load structures.

4.3.2 Molly Ann South section

Beginning approximately 1.3 km south of Molly Ann Brook (UTM 386791, 5414216) (Figure 4.1), the Molly Ann South section extends north along the coast for about 500m (Figure 4.8). This section of the coastline displays the strata of the Blow Me Down Brook formation, and a small thrust sheet of chaotic and broken Northern Head Group (Figure 4.9). Timing of many of the structural features within this section are not well understood, and are difficult to interpret; no obviously different structural fabrics are seen.

From 0m to 200m along the traverse, the section is cut by two F_1 thrusts. The footwall of the most southerly F_1 thrust is a headland composed of interbedded quartzose sandstones and black shales (Figure 4.10). Hydrocarbon staining is present within the

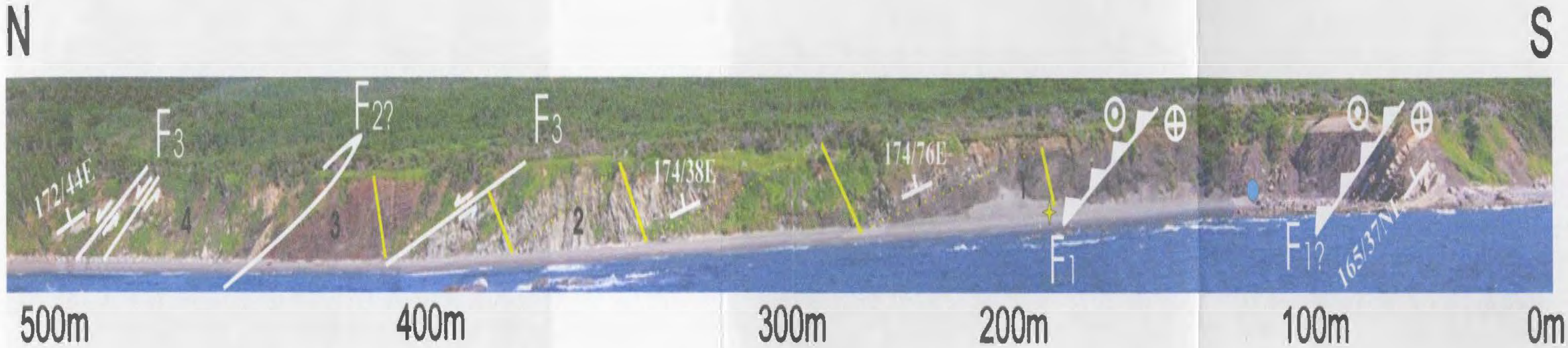


Figure 4.8: Panorama of Molly Ann south section at present day sea level. The section extends for 500m along the coastline. Thrust Faults (F1) cut coastline and bring Northern Head Group (calcarenite block location marked by blue circle) over Blow Me Down Brook formation. An F_2 thrust lies at 450m. Above, there rests a repeat section of interbedded quartzose sandstone and black shale, equivalent to the first 70m of the stratigraphic section. Normal faults (F3) at 500m show little offset. The stratigraphic measure is outlined in yellow; star indicates base of section. 1) Deformed black micaceous shale coarsening upward to interbedded grey green sandstone and shale. 2) Massive quartzose sandstone. 3) Massive red micaceous shale. 4) Repeat section of interbedded sandstone and shale.

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Figure 4.9: Northern Head Group in of chaotic black shale.
Molly Ann South section.

Figure 4.10: Headland of Molly Ann South Section. Interbedded petroliferous sandstone and black shale. View to North.

uppermost sandstone of this headland; when struck with a hammer it has a strong petroliferous odor.

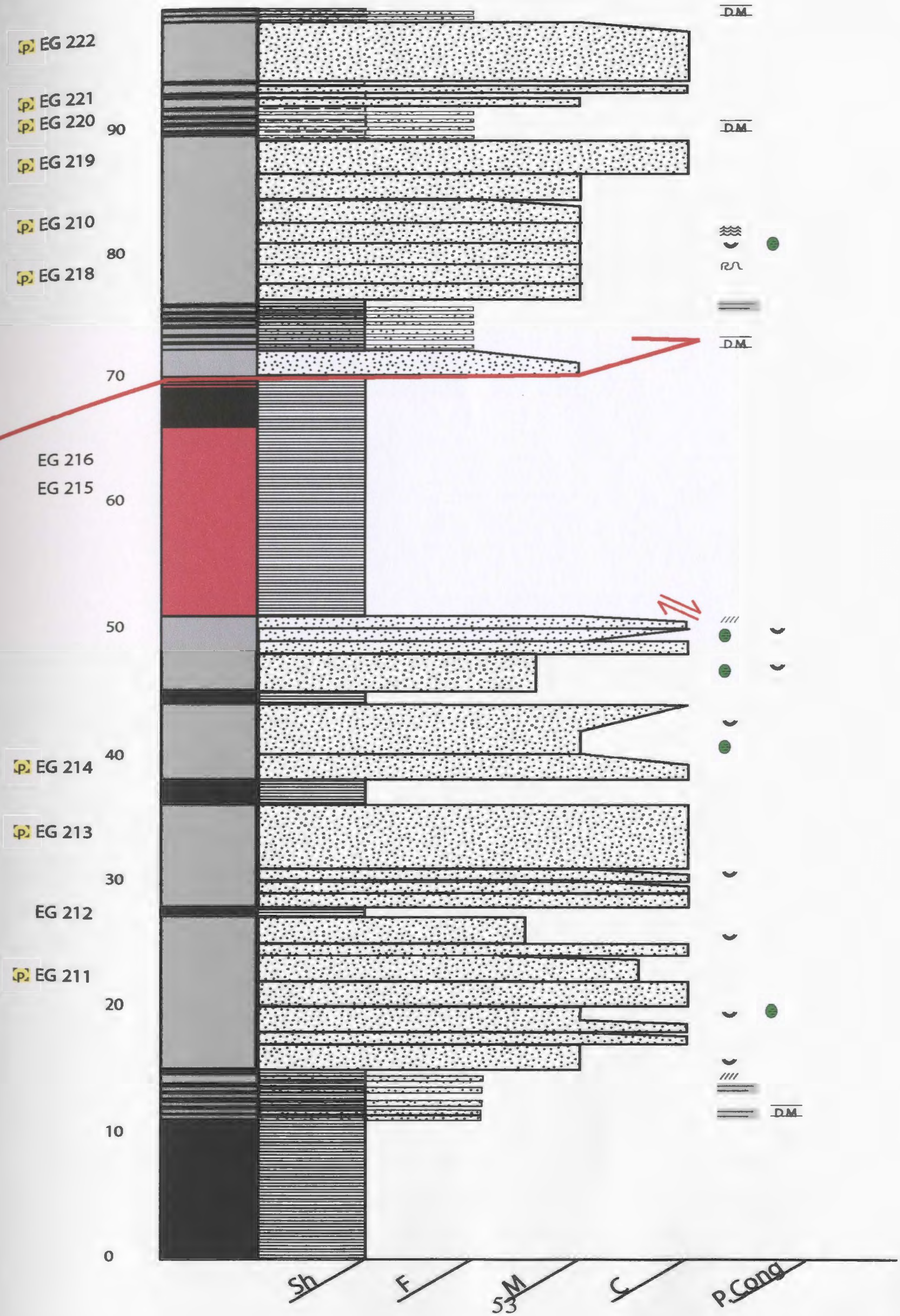
The hangingwall of this F_1 thrust is composed of chaotic blocks of Northern Head Group strata, including calcarenite and deformed black shale. The calcarenite (Figure 4.9) consists of light brown ribbon limestone, in beds measuring 10-15 cm in thickness. This unit represents a "broken" formation, of an out-of-sequence breaching of a pre-existing Blow Me Down Brook formation duplex.

The hangingwall of the out-of-sequence F_1 thrust at 180 m marks the base of the Molly Ann South stratigraphic section (Figure 4.11). Basal strata consist of 11m of black micaceous shale. From 11 m to 15 m, there is a gradational shift to interbedded black shale and decimeter scale, grey–green quartzose sandstone beds. At 15m sandstones thicken and coarsen upward into 30 m of meter- scale, massive, coarse-grained beds. These thick sandstones are moderately to poorly sorted and contain upward fining successions, with common mud chips, glauconite, and cross lamination near bed tops. The thick quartzose sandstones are separated by 0.5 to 2 m intervals of black, micaceous sandy shale.

At 50 meters on the stratigraphic column (410m along traverse), a 20m thick interval of red and black micaceous shale lies in a structural contact (F_3?) with thick quartzose sandstones. This boundary is thought to be an F_3? normal fault based on stratigraphic arguments and relationships brought forth in Chapter 6 of the thesis. The shale beds are extensively deformed making it difficult to measure true thickness with absolute certainty. Based on the stratigraphic relationship seen at the Breached Reservoir section between the red and black shales with the thin grey Blow Me Down Brook

Figure 4.11: Molly Ann South measured lithological column. Vertical scale shown in meters. See Figure 4.4 for column legend.

Molly Ann South Section



sandstones, the author believes that there is little displacement on this fault and that the red shales lie stratigraphically above the massive quartzose sandstones.

A bedding parallel F_2? thrust cuts the section at 70 m (450 m along traverse). Above there rests a repeat section of interbedded quartzose and glauconitic sandstone and black shale. These rocks are nearly identical to those seen in the first 70m of the stratigraphic section.

4.3.3 Molly Ann North section

The Molly Ann North section commences at NAD 27 UTM coordinates (0387535, 5417168) (Figure 4.1) and covers 500 m of coastline (Figure 4.12). Unlike other coastal sections discussed in this chapter, the Molly Ann North section does not have particularly well-exposed strata, and has a more complicated structure.

From 0m to 140 m along the coastal traverse, strata consist of overturned footwall limestone beds of Northern Head Group. These 'ribbon' limestones are similar to those seen at the Breached Reservoir and Molly Ann South localities. Here, they are composed of calcarenite beds measuring 5 to 25 cm thick with interbedded black shale. Sedimentary structures include, cross lamination, asymmetrical ripples, forset beds, load structures, and common *Planolites* traces on bed bases.

At 130 m along traverse an F_1 structural contact occurs between footwall strata of the Northern Head Group and the older Blow Me Down Brook formation in the hangingwall (Figure 4.13). At this locality right way up, petroliferous Blow Me Down Brook sandstones overlie younger, overturned Northern Head limestones. The

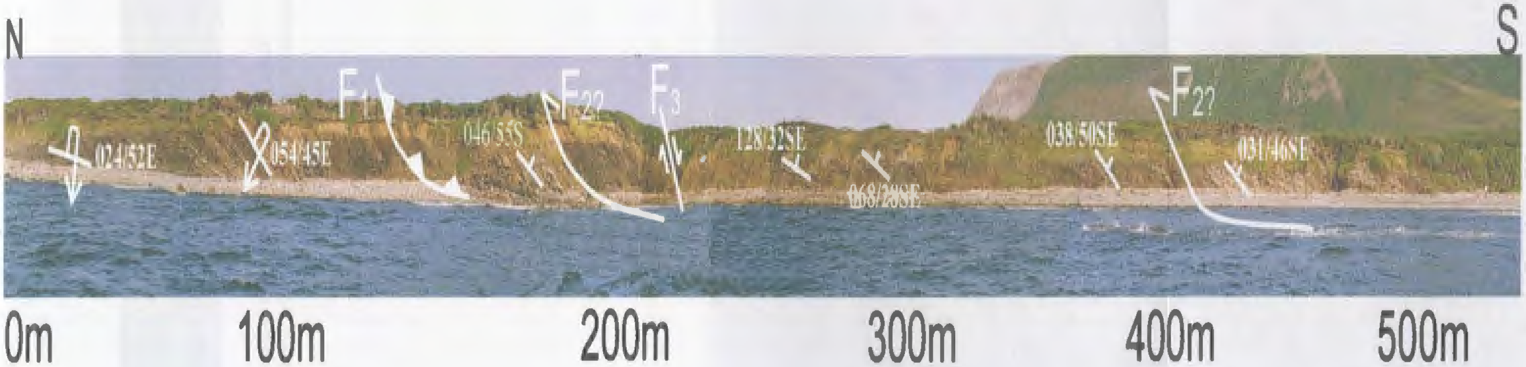


Figure 4.12: Panorama of Molly Ann North section at present day sea level. The base of the section has overturned Northern Head limestones from 0m-120m. The thrust panel at 140m contains petroliferous Blow Me Down Brook formation oriented right way up. Between 180m and 450m black shales which have weathered to a rusty brown dominate the section. These shales are extremely deformed around thin, competent sandstone beds. Light grey, quartzose sandstones between 450m and 500m mark the end of the section.

Figure 4.13: Structural contact between overturned Northern Head Group and petroliferous Blow Me Down Brook formation. Location of thrust is approximated in the cliff face.

relationship between these two formations is problematic; the contact zone is obscured by till and scree on the cliff face.

The Blow Me Down Brook formation in the Molly Ann North section has several different lithologies. The first of the F_1 hanging wall beds are petroliferous sandstones at 150 m-180 m along the coastal traverse. These sandstone beds are 1 to 2m in thickness, coarse-grained to granular, with common mud chips and calcite veins, and rare load casts.

The second lithology encountered is a thick succession of rusty weathered, black shales with rare, thin sandstone beds. These shales outcrop between 180m to 420m along traverse. It is difficult to conclude if the shales are displaying a true thickness, or are structurally thickened by imbricate thrusts, which can be subtle and very difficult to distinguish in outcrop.

The third lithology of Blow Me Down Brook formation is thickly bedded, grey, quartzose sandstones at 450m. These sandstones are granular to coarse-grained, with common hummocky cross bedding, convolute bedding and dewatering structures.

4.3.4 Waterfall section

The Waterfall Section begins at UTM coordinates (386609, 5413838) and continues southward along the coast for an additional 540m (Figures 4.1 and 4.14). Small, unbroken, parts of the section were measured and then organized to produce a more complete stratigraphy for this location. In total 86m of strata form this section (Figure 4.15).

In the field, the Waterfall section displays a crudely shaped antiform. Within the core of this antiform the competent Blow Me Down Book sandstones exhibit a series of

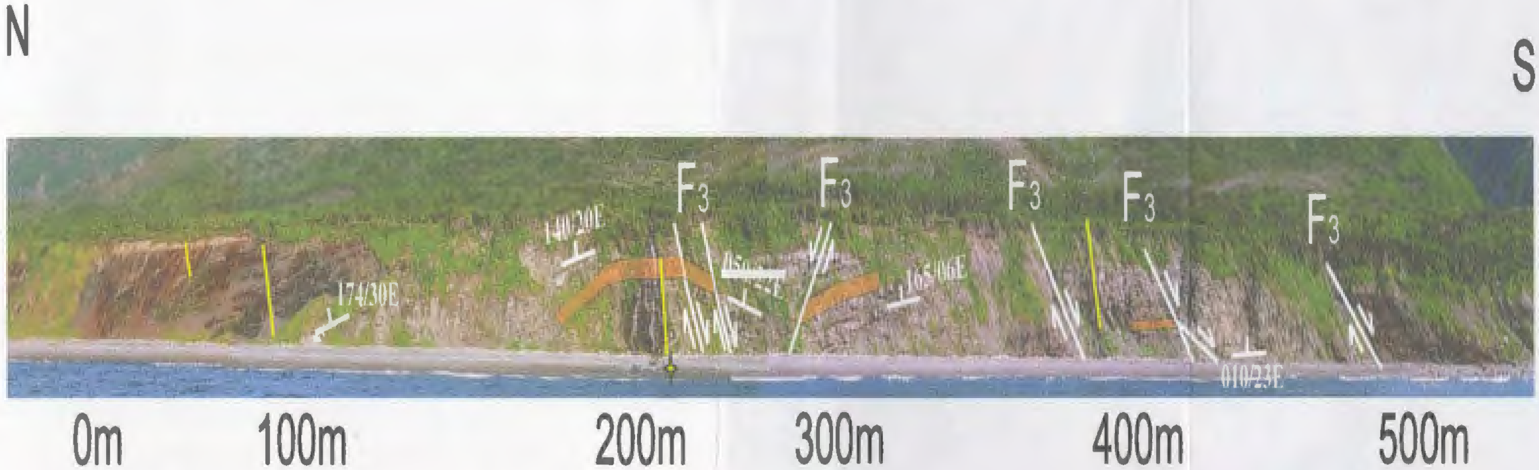


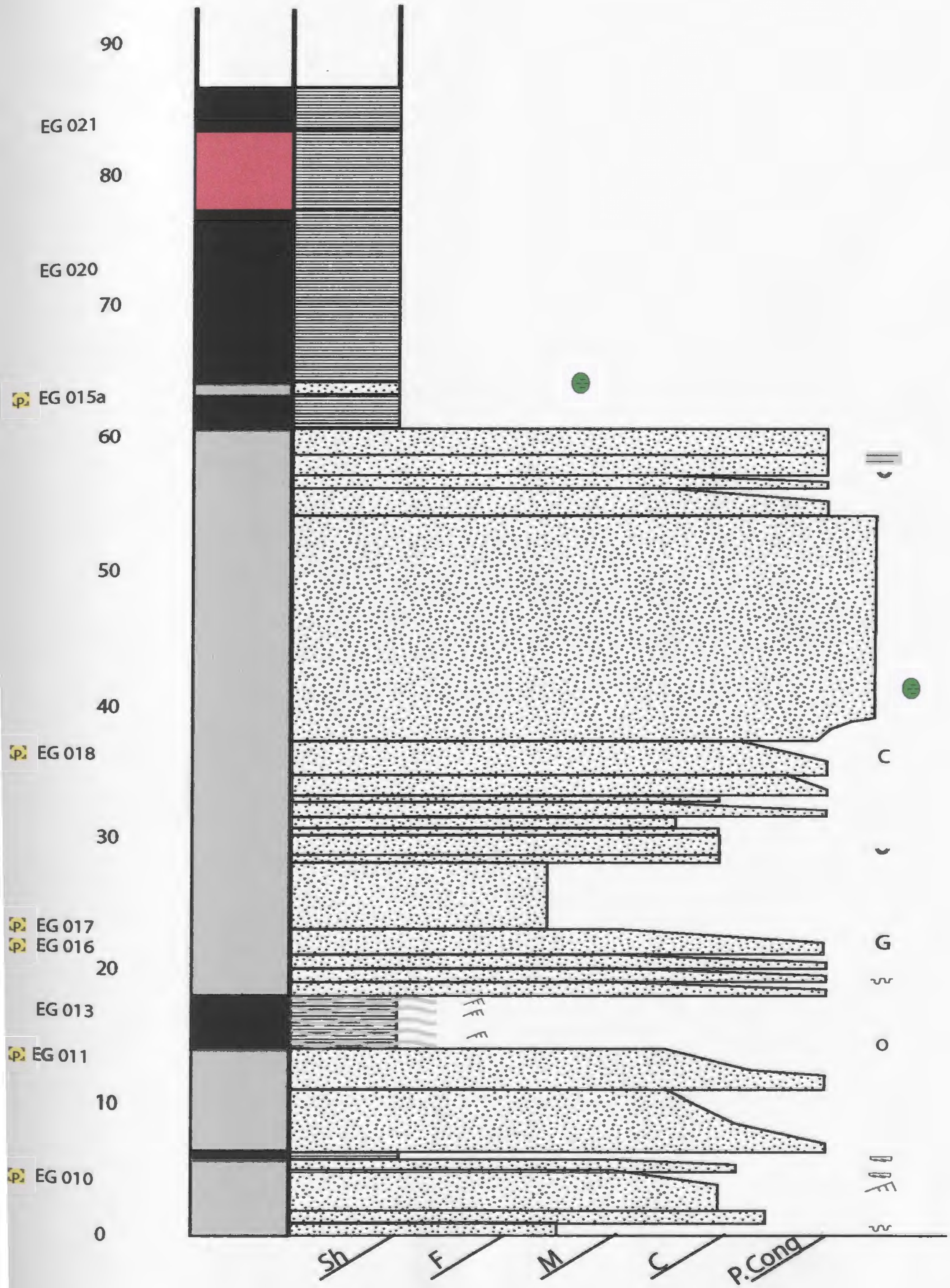
Figure 4.14: Panorama of the Waterfall section (Slight vertical exaggeration) at present day sea level. A crude antiform is preserved within this section. Associated with this folding are common F3 normal faults cutting the competent quartzose sandstones. A large F3 normal fault located at 490m has dropped the south limb of the antiform down to sea level.

Locations of measured sections outlined in yellow. The base of the section is marked with a yellow star. The section is continued at 400m, and above a 4m shale and sandstone marker bed (highlighted in orange). Overlying red and black shale beds were measured at 100m and 40m localities.

Traverse spacing looks inconsistent on panoramic photo due to curved coastline shape.

Figure 4.15: Waterfall lithological column. Vertical scale shown in meters. See figure 4.4 for column legend.

Waterfall Section



normal faults with little offset (F_3), (usually less than 5m). As well, a larger normal fault at 490m has dropped overlying red and black shale of the anticline's south limb down to sea level. In some respects the structure of this section is similar to that of the breached reservoir section.

The lowest strata in this section are found at the base of the waterfall. They consist of thick-bedded, coarse-grained, grey-green sandstones, with common fining upward sequences. Commonly flute casts are seen on the base of these sandstone beds; load casts are rare.

A 4m interval of interbedded black shale and fine-grained grey sandstone occurs at13m in the stratigraphic section (Figure 4.16). Here, the thin sandstone interbeds display wavy bedding. The sandstones also contain rare but well defined ripples showing a southerly paleoflow direction. The black shales are both laminated and bioturbated. Trace fossils include *Oldhamia antiqua, Oldhamia flabellata, Oldhamia radiata, Cruziana problematica, Helminthopsis tenuis, Treptichnus,?Trichophycus, Phycodes, Skolithos, Planolites, Squamadictyon,* and *Skolithos* (French, 2005). As well, wrinkle structures are commonly preserved on the tops of shales, usually within the same bedding plane as *Oldhamia, Helminthopsis,* and *Planolites* (French, 2005). This distinctive package of strata is seen outcropping across the Waterfall section and can be used as a marker to aid in reconstructing the stratigraphic section, highlighted in orange on the section panoramic, and determining the extensional nature of the faults cutting the crest of the anticline (Figure 4.14).

Figure 4.16: Base of Waterfall Section. Coarse - grained, green - grey sandstone overlain by 4 m succession of fossiliferous black shale and fine - grained, grey sandstone.

Thick, massive, quartzose sandstone beds overlie this fossil-rich sandstone/shale interval. Sandstone beds range in thickness from 0.5 to 15m. Typically, they have sharp bases, with planar lamination and mud chips; load casts are rare. Some of the most massive sandstone beds fine upwards from granular to coarse-and medium-grained beds; weathered surfaces of sandstones have a friable texture.

As with the Breached Reservoir and Molly Ann South sections, the uppermost strata of the Waterfall section consists of 26m of highly deformed siliceous red and black shale. The base of this shale at the Waterfall section displays parallel bedding to the underlying sandstones. However, shales seen in the upper portions of the cliff face are extensively folded and cleaved, therefore the uppermost stratigraphic measure through these shales is only an estimate.

4.3.5 Deadman's North section

Deadman's North section begins at UTM coordinates (0386096, 5413174) and continues south for 330m to the mouth of Deadman's Brook (Figures 4.1 and 4.17). The section has poor outcrop exposure due to vegetation cover, and displays abundant F_3 normal faults, resulting in common repeated sections. To compile a stratigraphy for this section, multiple smaller sections were measured and compiled for a total stratigraphic thickness of 25 m (Figure 4.18). The base is located at 90 m south of the northern UTM coordinates.

Repeat successions in between 100-200m along coastal section are commonly 10m thick. They are composed of thickly bedded quartzose sandstones with overlying red shale beds. These repeated sections of quartzose sandstones are separated by normal

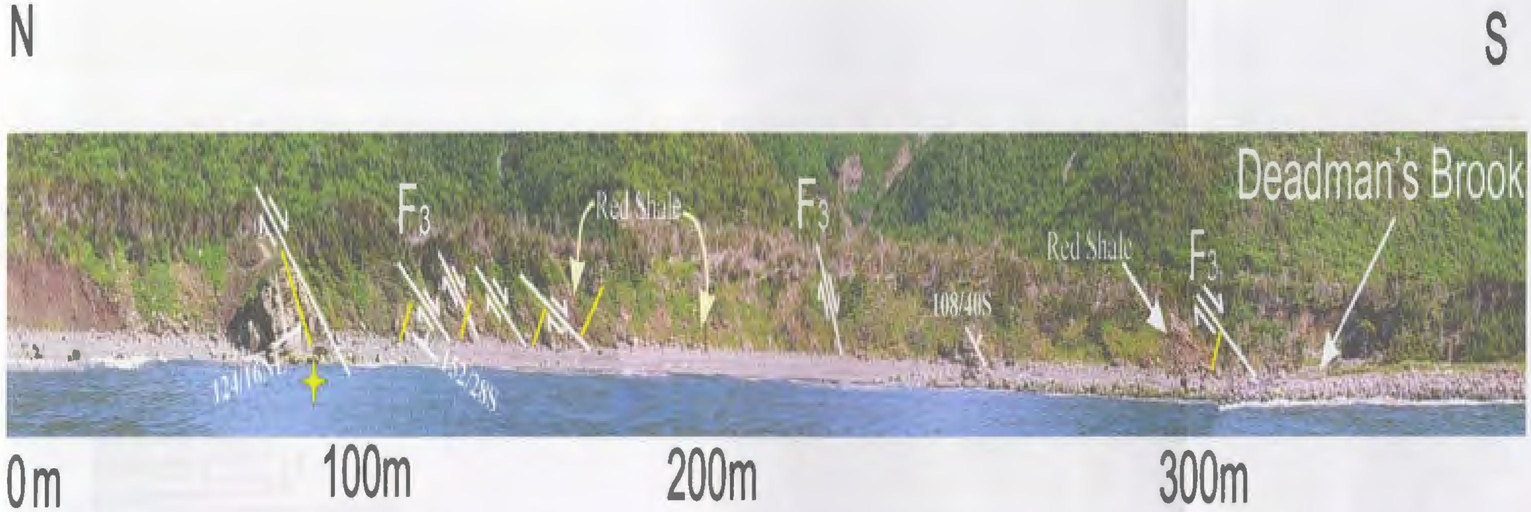


Figure 4.17: Panorama of Deadman's North section at present day sea level. The section has poor exposure due to vegetation cover, and abundant normal faults (F3).
Small faulted sections between 100-200m provide the best exposures. The base of the stratigraphic section is marked by a yellow star, small sections measured are outlined in yellow.

Deadmans' North Section

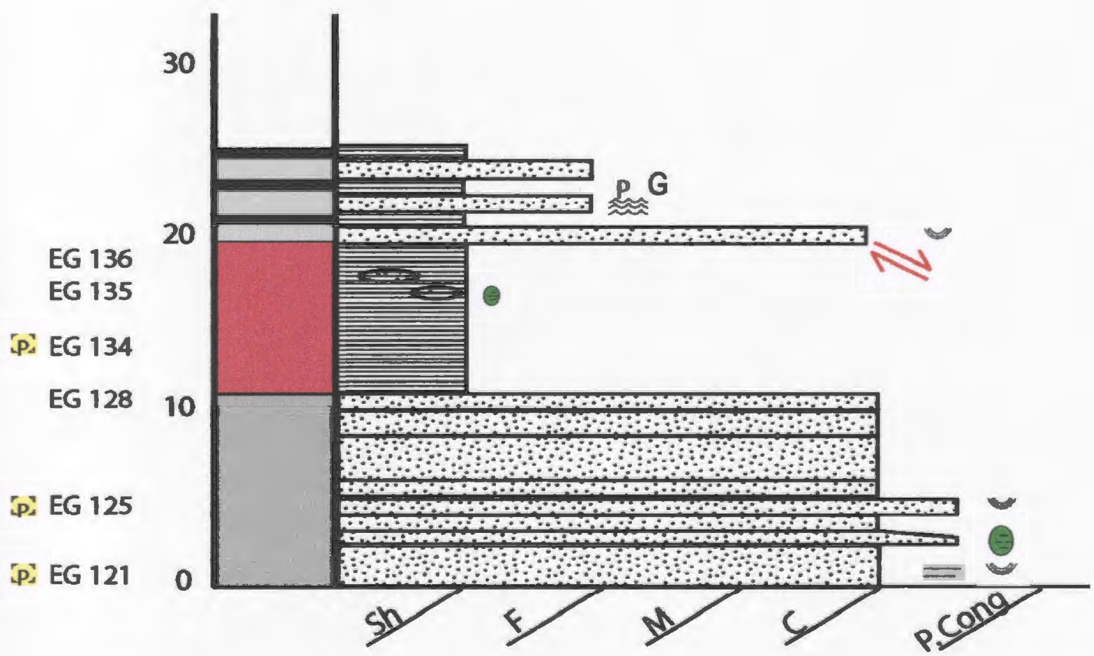


Figure 4.18: Deadman's North section. Vertical scale in meters. Red shales on stratigraphic column can be seen at 175m along traverse, on figure 4.17. See figure 4.4 for column legend.

faults (F_3). These outcrops are composed of massive 0.5m-3m beds of greenish-grey, coarse to granular, quartzose sandstone. Imbricate mud chips and glauconite grains are commonly situated within the sandstone beds. Planar lamination is present near the top of some sedimentary beds. Structurally, above the sandstone (at 175m along the traverse) is a 10m thick section of red, micaceous shale, which is devoid of trace fossils. The stratigraphic contact between these red shales underlying and overlying quartzose sandstones is seen in a small outcrop in Deadman's Brook. Here, there is little or no evidence to show any displacement. The author believes this shows the general relationship of the undeformed contact between the quartzose sandstone and red shale of the Deadman's North and other coastal sections.

The upper 6m of the section is comprised of interbedded coarse to fine-grained quartzose sandstone, and black micaceous shale. Unlike the underlying red shales, *Planolites*, and *Gordia* traces are commonly found; no *Oldhamia* traces were identified.

Along with the work along the coast of Deadman's Brook, a traverse upstream was also completed. A few hundred meters upstream large boulders of very coarse, calcareous, and feldspathic Blow Me Down Brook formation were exposed in the riverbed. The origin of these boulders is assumed to be farther upstream; however, the exact location was never discovered. These boulders are quite different from the coarse–grained subarkosic to quartzose sandstone outcrops within the brook and along the coast.

4.3.6 Broad Cove section

The Broad Cove section starts at UTM coordinates (378647, 5400594) and continues northward for 420 m along the coastline (Figures 4.1 and 4.19). This section is

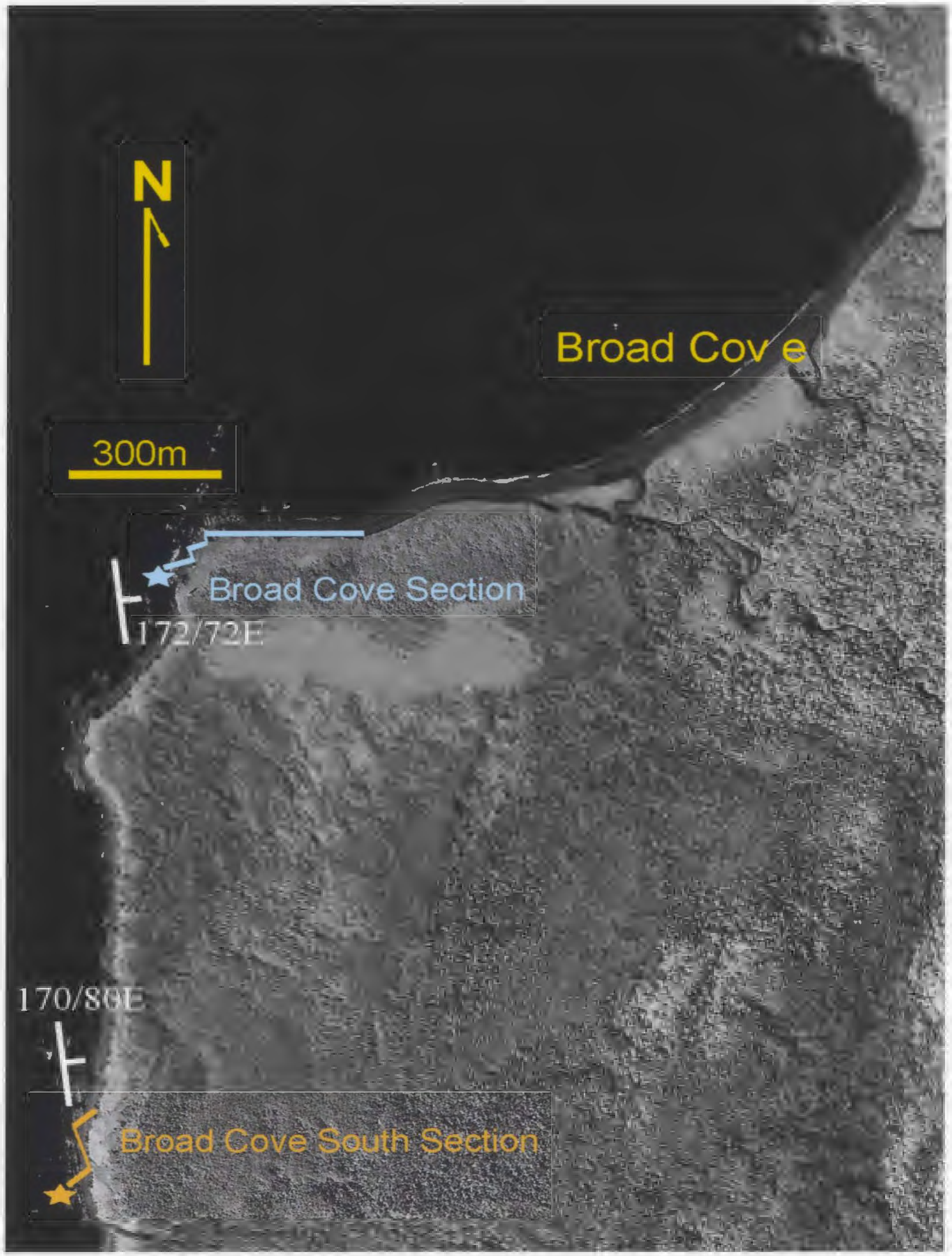


Figure 4.19: Aerial photograph of Broad Cove showing locations of measured stratigraphic sections. The Broad Cove section is marked by a blue line, and the Broad Cove South section by an orange line.

Colored stars mark the base of the sections.

comprised of interbedded sandstone and shale beds oriented perpendicular to the shoreline. The beds of this section show minor faults and tight folds near the base of the section. An overall thickness of 225 m has been measured for the Broad Cove section (Figure 4.20), with an overall 172/72E orientation for the beds of this section.

The basal 12 m of section is composed of a thick calcareous boulder conglomerate bed. Boulders within this bed range in size from 10 to 65 cm in length, and have an oblate shape. Common imbricate mud chips, and planar lamination are seen within the boulders. The matrix of the conglomerate contains feldspar laths and quartz grains measuring 1-1.5 cm. The feldspar laths are pink in color and have an angular shape. Quartz grains are rounded and are milky white to grey in color. The top of this calcareous conglomerate bed is marked by a sharp contact with overlying granular, massive subarkosic sandstone. These subarkosic sandstone beds are commonly 2 to 10 m thick and display fining upward sequences from granular to coarse-grained. Calcite veins are common within the stratigraphically lower beds. While scours, planar lamination, and convolute bedding prevail in the higher beds of sandstones.

At 140m the lithology changes from a subarkose to quartz sandstone, with abundant glauconite. Here, bed thickness ranges from 1-6m, with common fining-up sequences from granular to coarse-grained sandstone. Sedimentary structures seen within the sandstone consist of parallel and cross lamination, asymmetric ripples, load structures, convolute bedding and mud chips. Beds of red, green and black shale commonly separate the quartzose sandstone beds. Many of these shale beds contain *Oldhamia* and *Planolites* traces as well as pyrite nodules.

Figure 4.20: Broad Cove lithological column. Vertical scale shown in meters. See Figure 4.4 for lithologic column legend.

Broad Cove Section

4.3.7 Broad Cove South section

The Broad Cove South section commences at UTM coordinates (378647, 5400594) (Figures 4.1 and 4.19) and continues northward in sea cliffs for about 85 m. This section is composed of thickly bedded red and grey sublitharenitic to subarkosic sandstones, interbedded with red and green shales; stratigraphic thickness is 80.5 m (Figure 4.21). The beds in this section are oriented 170/80E; some small normal faults are present. However, to the north of this section bedforms become folded and faulted (UTM 378668, 540677); stratigraphic measures beyond this point are difficult.

The Broad Cove South section is composed of coarse-grained poorly sorted subarkosic to sublitharenitic sandstone, interbedded with red and green micaceous shale. Sandstone beds are massive with rare planar laminations and mud chips. The unique feature of this section is the color variation of the sandstones. The sandstones at the base of the section are grey in color, but then shift to thick-bedded, massive, red, hematite-stained sandstones at 10 m, 21 m and 42 m (Figure 4.21). Another distinctive characteristic is found near the top of this section at 80.5 m. Here, a large calcareous sandstone clast is contained within granular arkosic sandstone. This is thought to be the first and stratigraphically lowest sedimentary bed in the Broad Cove region where calcareous clasts are observed.

Shales that occur in the lower 70 m of the Broad Cove South section contain no macro or trace fossils. The first *Oldhamia* trace is found in the section at 75 m, in a black micaceous shale bed.

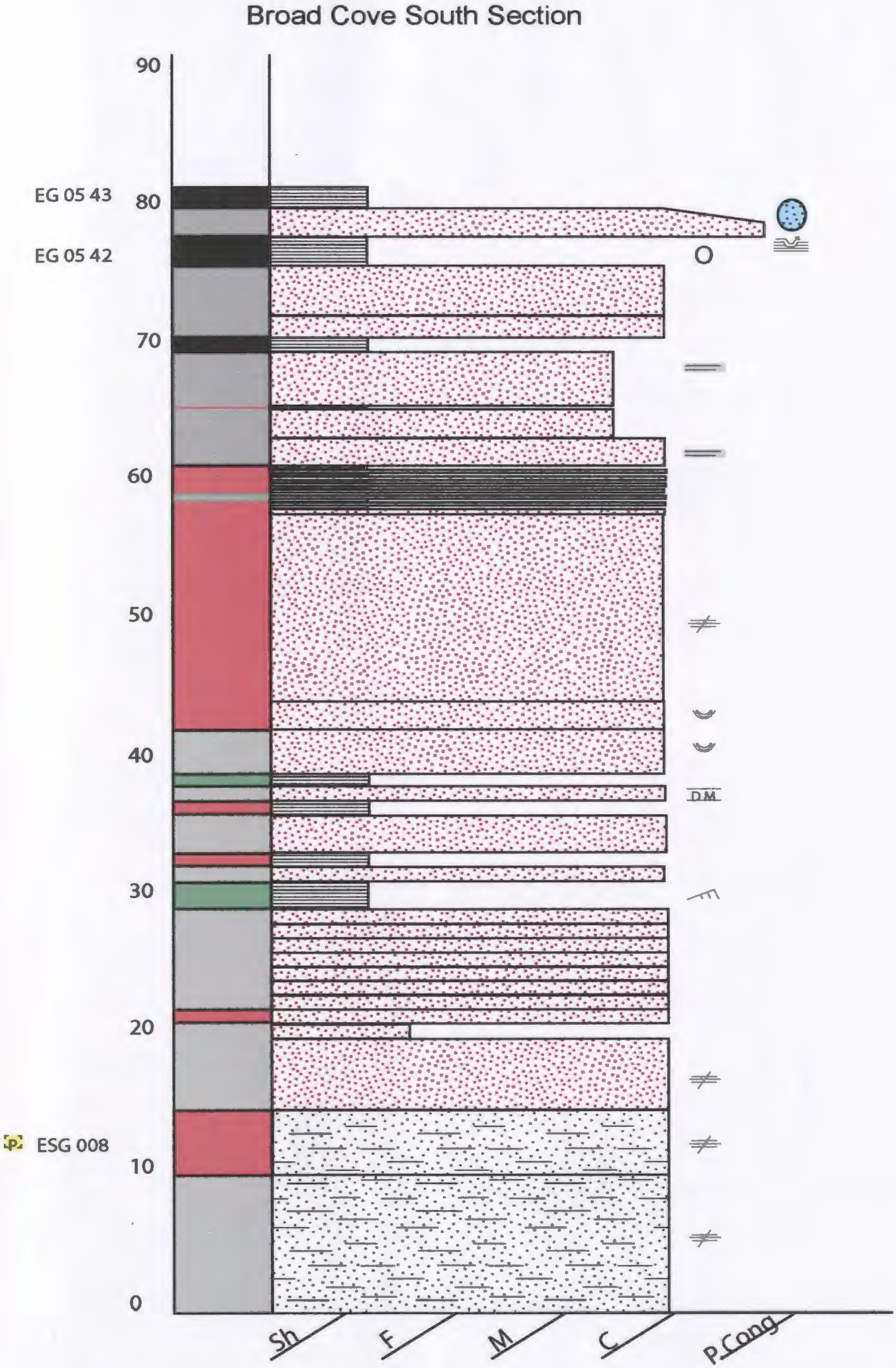


Figure 4.21: Broad Cove South section. Vertical scale shown in meters. See figure 4.4 for column legend.

4.3.8 Bluff Head section

The Bluff Head section begins at UTM coordinates (379977, 5402419). Here, the succession occupies a synclinal structure and the sandstone is grey in color, massive, coarse-grained.

Thick sandstone beds in the core of the syncline display normal faults with little offset (F_3) (Figures 4.1 and 4.22).

The base of the section lies on the shore near the hinge of the syncline. By traversing southward along the coastline a 57m thick succession of strata was measured (Figure 4.23). Additional underlying beds located several hundred meters north are not easily accessed; these beds are not included here.

The basal 17 m of section is composed of poorly sorted, coarse-grained to granular, grey sandstone. From 17 to 27 m, there are common 1 m to 2 m thick beds of sandy shale interbedded with grey colored granular to coarse-grained sandstone, which commonly display fining upward sequences. The shale is grey-brown in color and micaceous. Most of the finer grained intervals are devoid of sedimentary structures. However, a 1.5 m thick bed of siltstone located at 23m contains planar lamination, load casts and flame structures (Figure 4.24).

From 27 to 42 m the sandstone of the Bluff Head section is massive, granular, and thickly bedded. Imbricate mud chips are occasionally seen at the top of granular beds.

Above 42 m a grain size shift occurs; beds become granular to pebble conglomerate; pebbles are composed of quartz. Scours are frequently seen at the base of thickly-bedded strata (Figure 4.25).

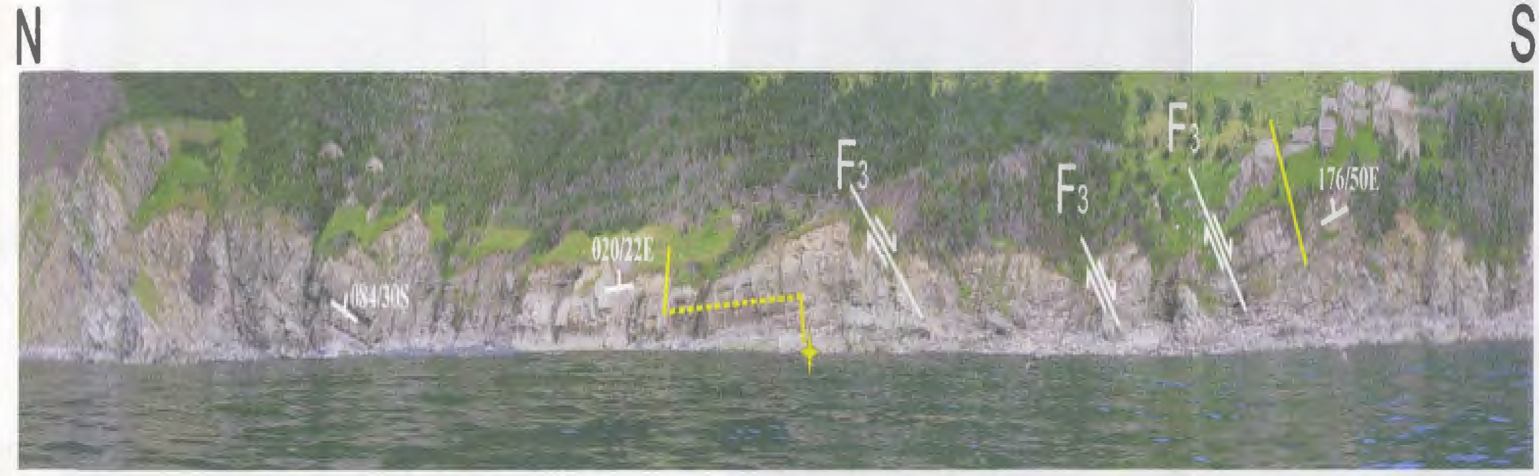


Figure 4.22: Panorama of Bluff Head Section, down to present-day sea level.. Blow Me Down Brook sandstones folded in synclinal structure, with normal faults cutting the syncline limbs. The measured section is outlined in yellow, star indicates bottom of section..

Note, there is slight vertical exaggeration on the panoramic photograph.

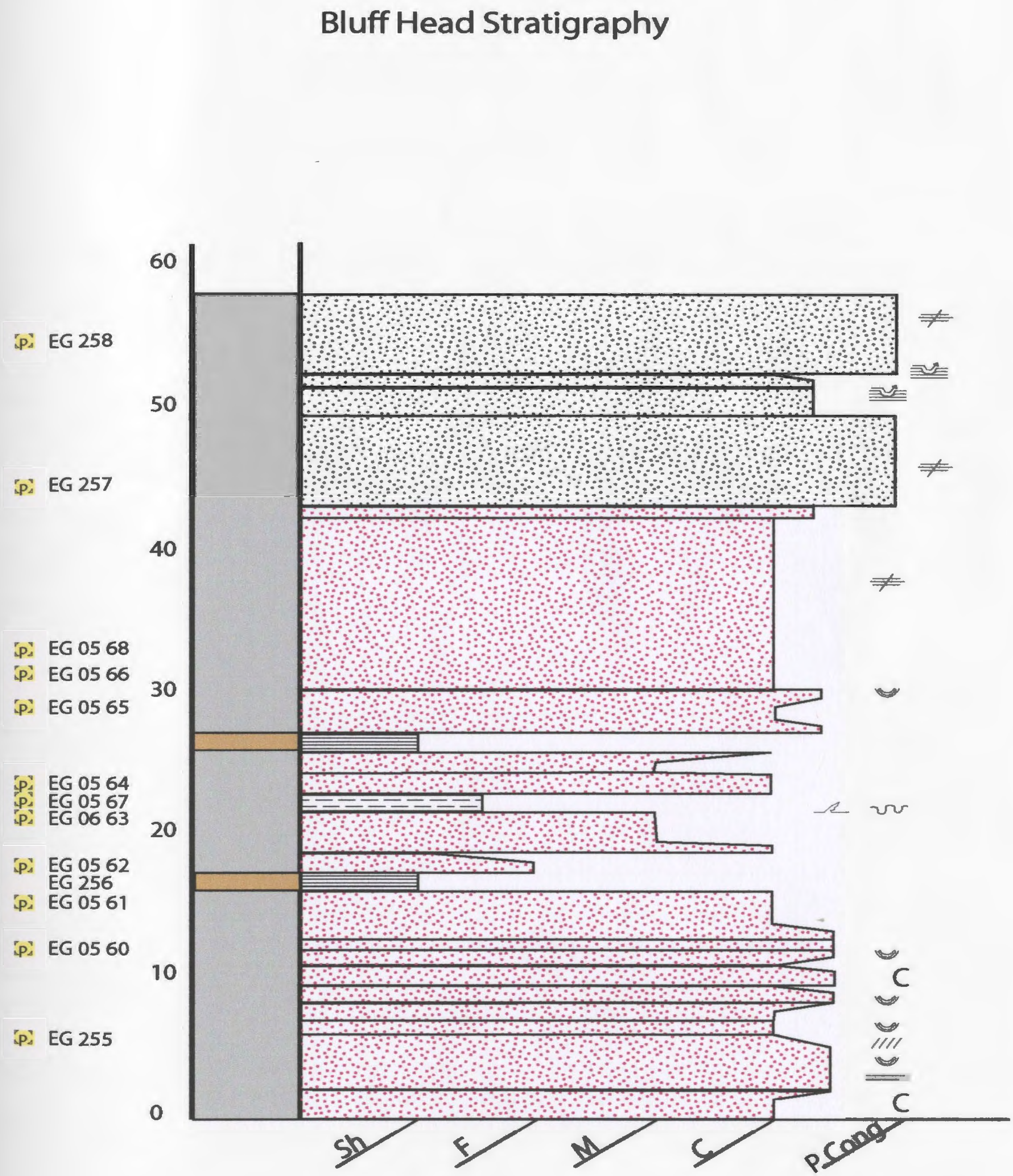


Figure 4.23: Stratrigraphic column for Bluff Head Section.

A

B

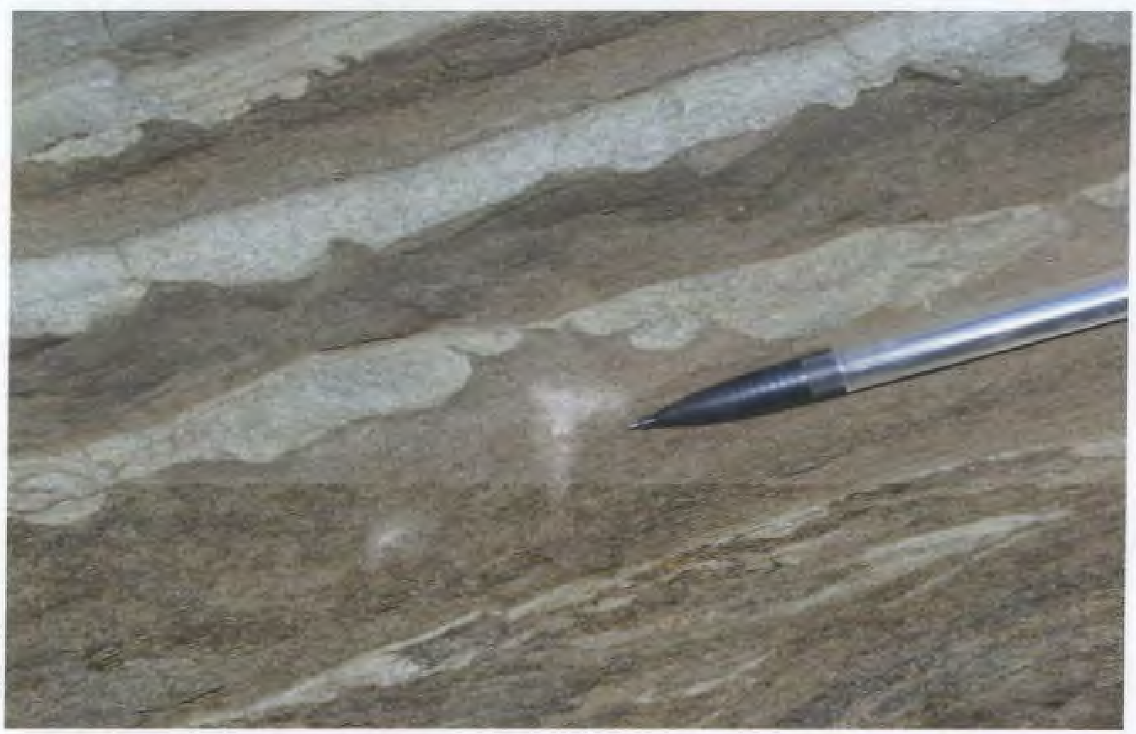


Figure 4.24: A) Siltstone beds located at 23m in the section, note load structures and planar lamination. B) Load and flame structures observed within the interval.

Figure 4.25: Pebble conglomerate with scoured base, in uppermost bed of the Bluff Head section.

4.3.9 Woods Island section

The Woods Island section is located in the Bay of Islands, on Woods Island. UTM coordinates: (410413, 5438820) (Figure 4.1). The Woods Island section was measured by Waldron and Palmer (2000), and considered as a possible type locality for the Blow Me Down Brook formation. Waldron and Palmer (2000) show 400 m of measured Blow Me Down Brook strata, within which thrust faults are labeled but, apparently, no report is made on offsets.

The Woods Island section begins on the east side of the Southern Harbor and extends east along the south coast of the island. The area has abundant normal faults dipping to the west. In total, 275 m of Blow Me Down Brook formation was measured (Figure 4.26); this does not represent the total thickness of the section reported in Waldron and Palmer (2000).

The basal 90 m is composed of granular to pebble conglomerate and arkosic sandstone. Sandstone beds, commonly truncated by synsedimentary normal faults, are 2-5 m in thickness and display fining upward sequences (Figure 4.27). Sedimentary structures consist of abundant scouring at the base of sandstone beds, common planar lamination, and rare trough cross bedding.

At 90 m there is a lithological shift from subarkosic to quartzose sandstone. Between 90 m and 175 m the sandstone beds continue to range in thickness from 2-5 m, with common scours at their bases. There are abundant fining upward sequences within these beds from pebble conglomerate to granular/coarse-grained sandstone. Planar

Woods Island Section

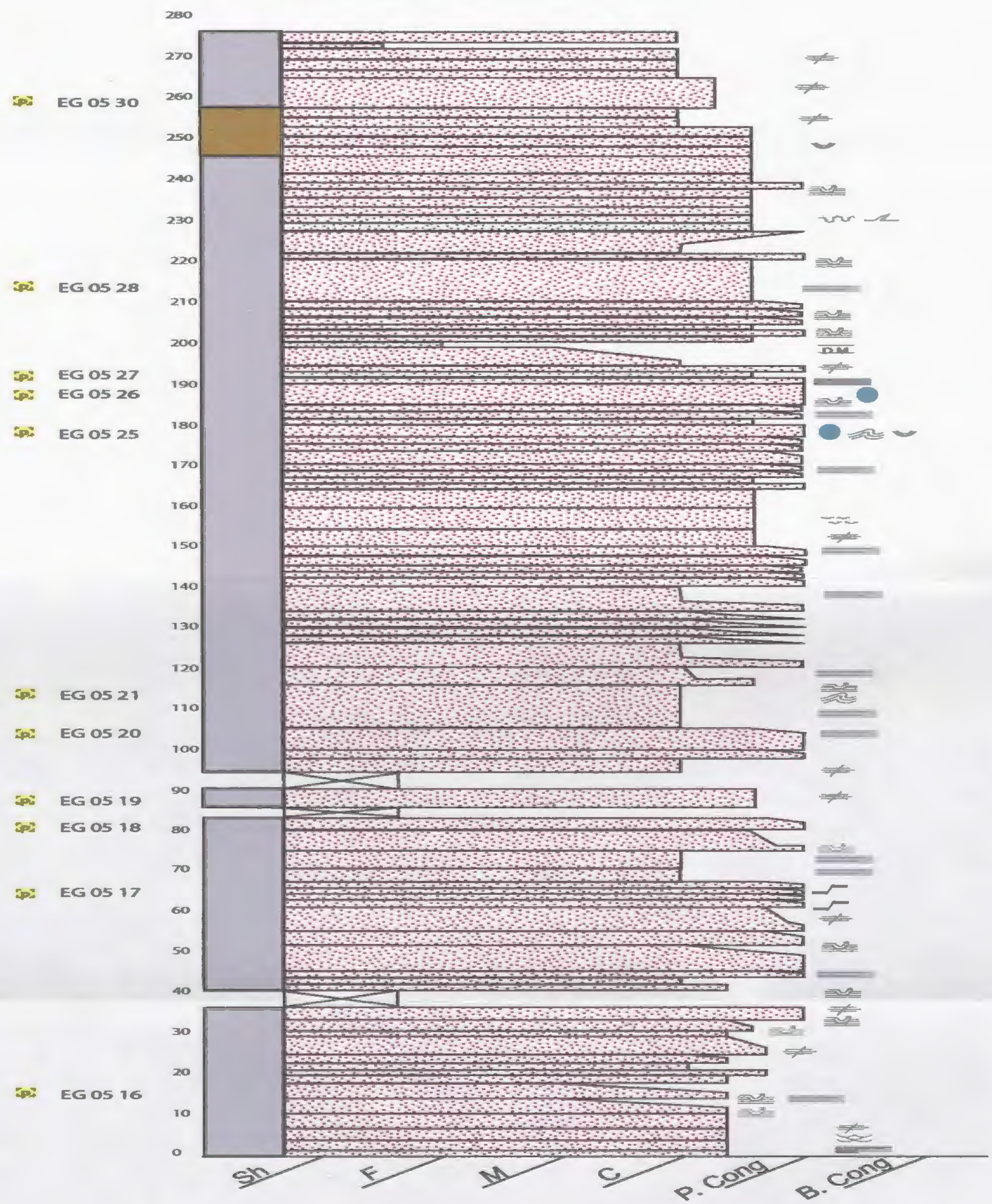


Figure 4.26: Woods Island section. Vertical scale shown in meters. See figure 4.4 for lithological column legend

Figure 4.27: Pebble conglomerate and granular sandstone with synsedimentary faults. Woods Island location.

lamination is common near the tops of sandstone beds; rare soft sediment and dish structures are also preserved.

The first large calcareous sandstone boulders are encountered at 178 m. These boulders range in size from 10-25 cm; each is composed of granular quartzose sandstone, cemented with calcium carbonate. Soft sediment structures, mud chips, and planar laminations occur within these calcareous boulder beds. These boulders are similar to those encountered at the Broad Cove sections, as well as those upstream at Deadman's Brook.

From 190 to 275 m the sandstones of the Woods Island section are commonly thick-bedded, massive quartzose grey-green sandstone, with scoured bases. Within these beds planar laminations, load casts and flame structures are observed.

Chapter 5

Sandstone Petrography of Blow Me Down Brook Formation

5.1 General Textural Features

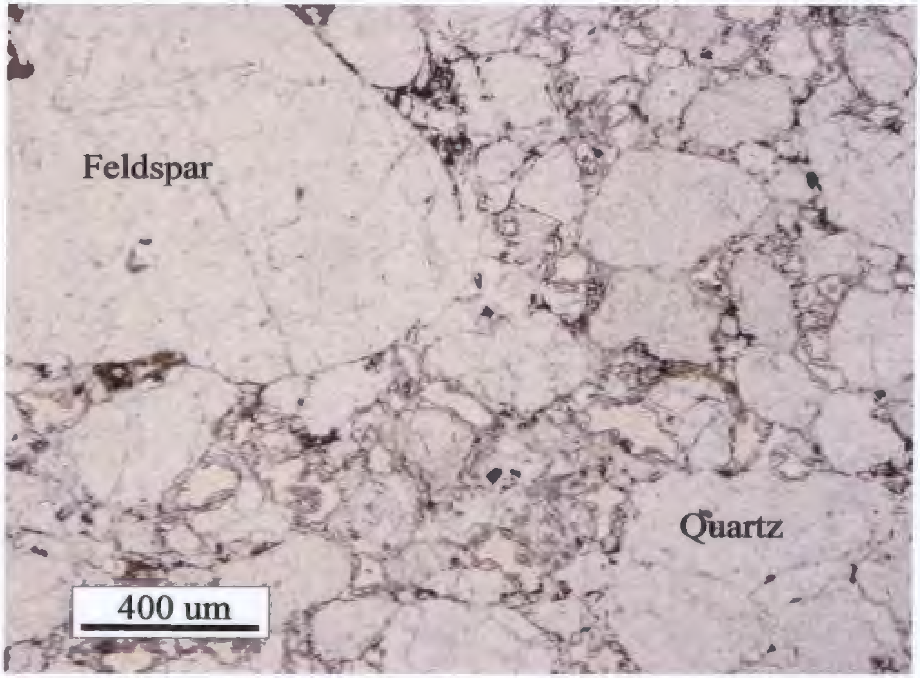
For petrographic analysis of the Blow Me Down Brook sandstones the Gazzi-Dickinson point count method was applied (see section 3.1.2). The samples selected for petrography were primarily medium- to coarse-grained sandstone, with a few samples of fine-grained sandstone. The sandstone is moderately well-sorted, with sub-rounded to sub angular grains; some rare samples contain angular grains.

Sandstone petrography can be variable. Samples are composed primarily of quartz grains that are closely packed, with sutured grain contacts and minor porosity (Plate 5.1). In other less common instances, grains can show point-to-point contacts, with high porosity.

Matrix material is primarily clay. This too varies in abundance from sample to sample. In general, the more lithic and feldspathic sandstones tend to contain larger quantities of clay matrix than the quartzose sandstones.

Carbonate cement is common in some sandstones, although the amount varies throughout the formation. Commonly seen in the quartz-dominated thin sections, the carbonate cement fills pore space and can be described as 'patchy' (Plate 5.2). In other samples, the thin section may be dominated by carbonate cement wherein grains of

A)



B)

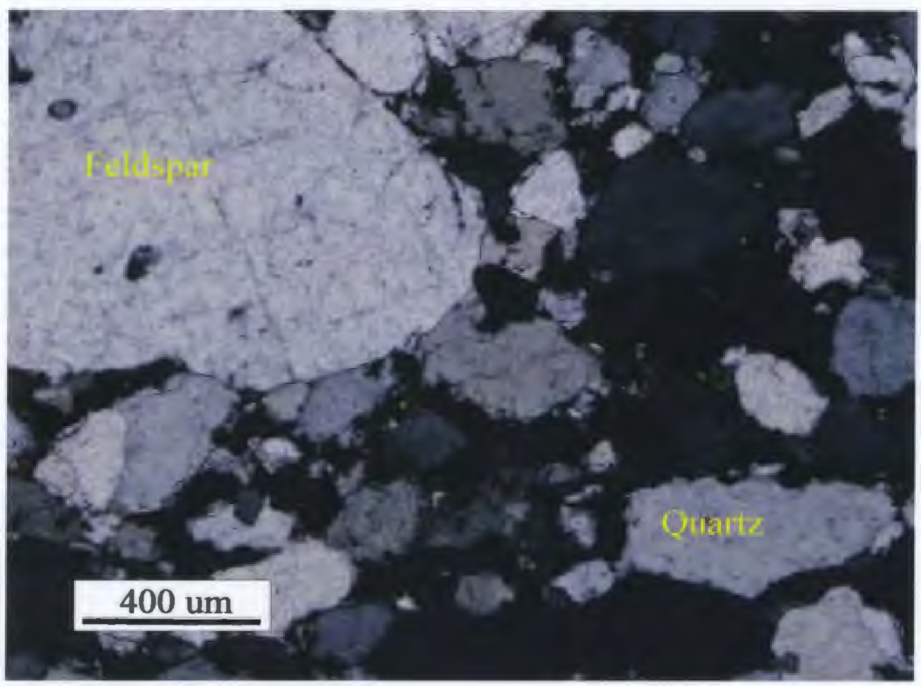


Plate 5.1: Sample EG 166. This sample displays the typical appearance of the sandstone. Abundant quartz and rare alkali feldspar grains display subrounded shape with sutured and planar grain boundaries. A) Plane polarized light photograph. B) Crossed polar view.

quartz, feldspar and lithics are commonly seen "floating" in a cement matrix (Plate 5.3). Carbonate cement can also be seen replacing framework grains (Plate 5.4). Examples of this are found in the Molly Ann North section, near the structural contact with overlying ribbon limestones of the Cooks Brook formation, and in the Broad Cove section, near the calcarenite boulder conglomerate bed.

In one sample, from Molly Ann North section a low birefringent mineral (chlorite) rims the quartz grains (Plate 5.5). So too, in the red sandstones of the Broad Cove South section hematite rims are present around quartz, feldspar and lithic grains.

5.2 Framework Grains – General Characteristics

5.2.1 Quartz

Two types of quartz were observed in the thin sections.

Type 1: Monocrystalline Quartz

Monocrystalline quartz grains typically display straight to undulose extinction. The quartz grains are rounded to subrounded, variable in grain size (Plate 5.6), and have rare quartz overgrowths. In compacted quartz arenite samples, grains commonly have sutured or planar contacts (Plate 5.7). Monocrystalline quartz grains within sublitharenite or subarkose sandstones tend to be less closely packed and have point or planar contacts with one another.

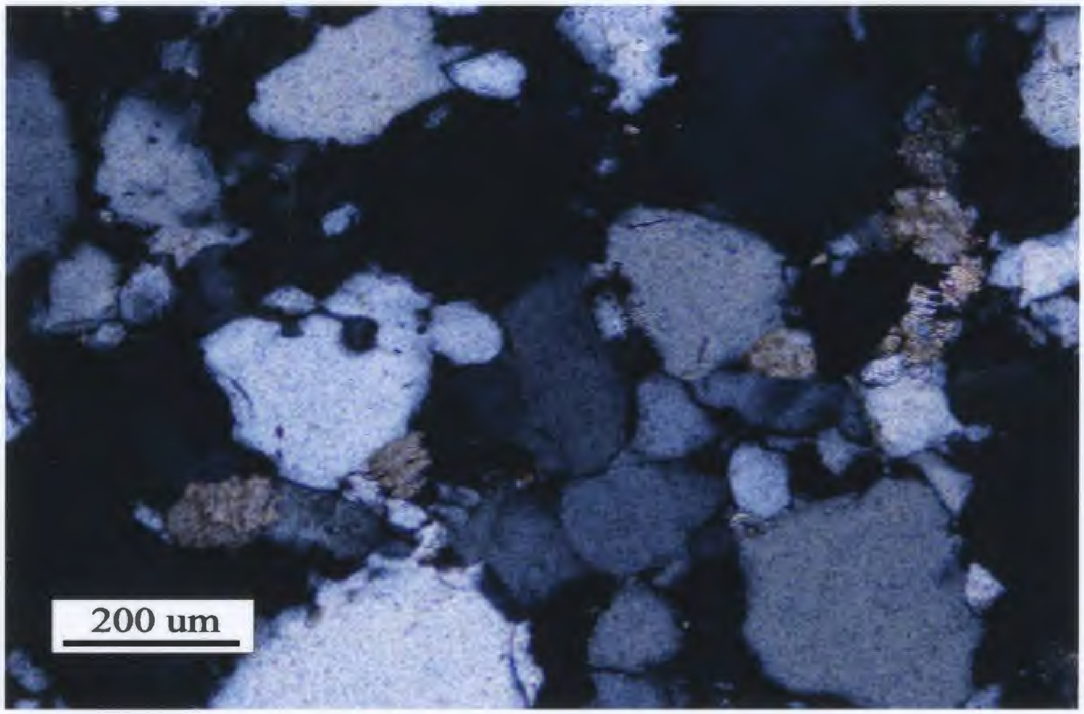


Plate 5.2: Sample EG 193. Quartzose sandstone with patchy calcite cement infilling pore space. Crossed polars.

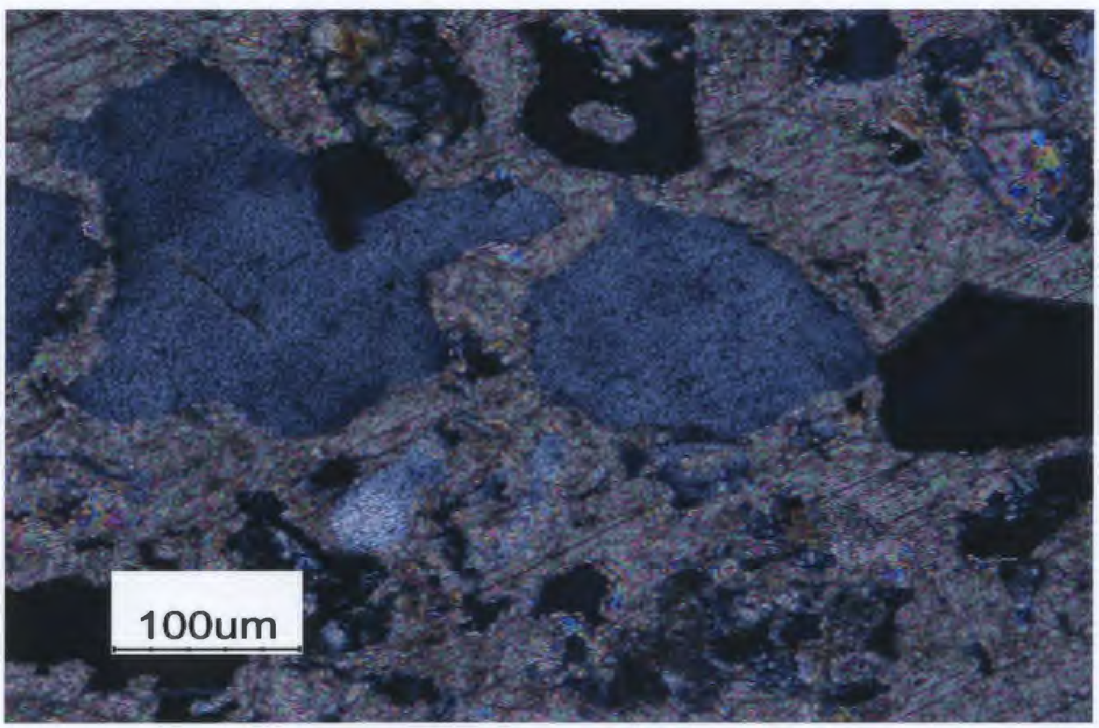


Plate 5.3: Sample EG 274. Quartz grains "floating" in carbonate cement. Crossed polars.

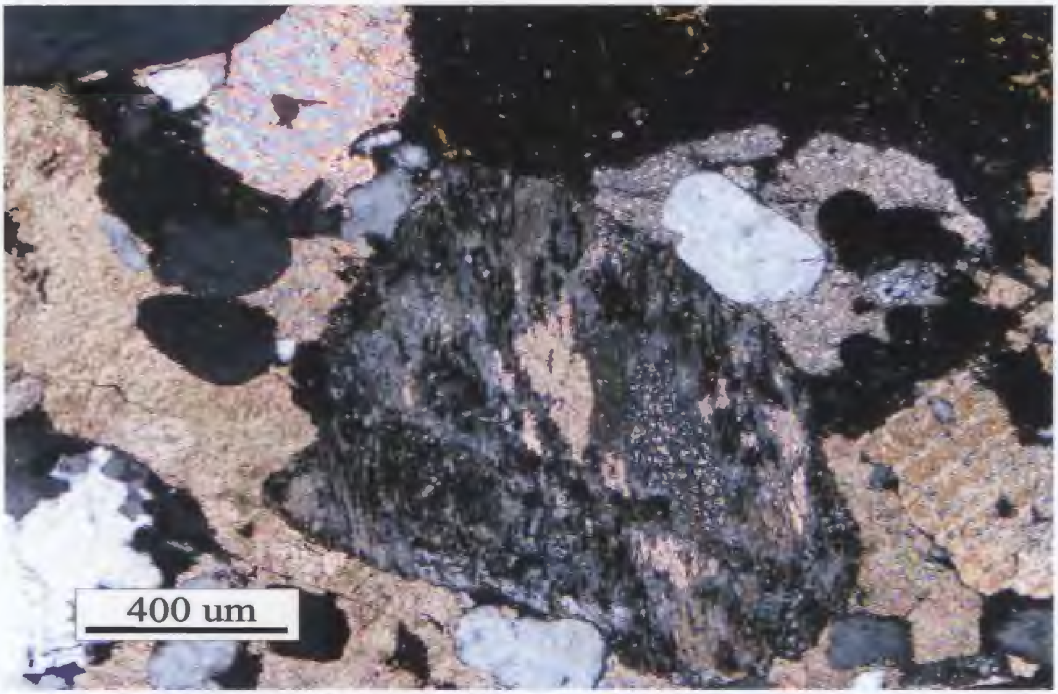


Plate 5.4: Sample EG 168 displaying carbonate cement replacing a feldspar grain. Crossed polars.

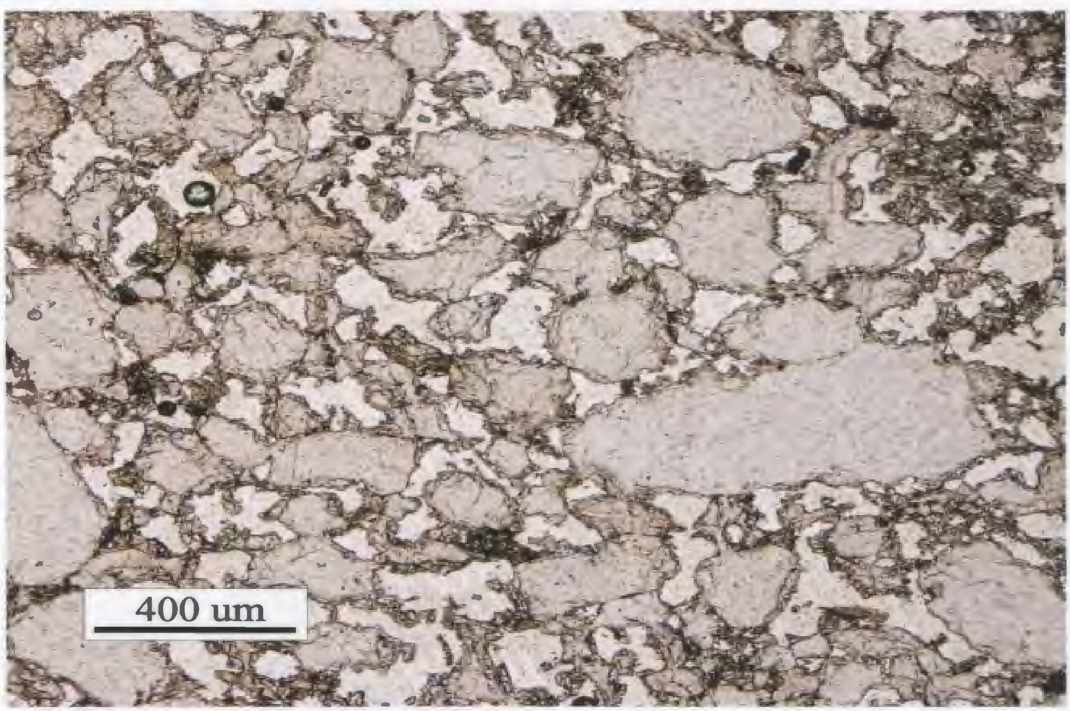


Plate 5.5: Sample EG 186, quartz grains rimmed with chlorite? Sample displays abundant porosity.

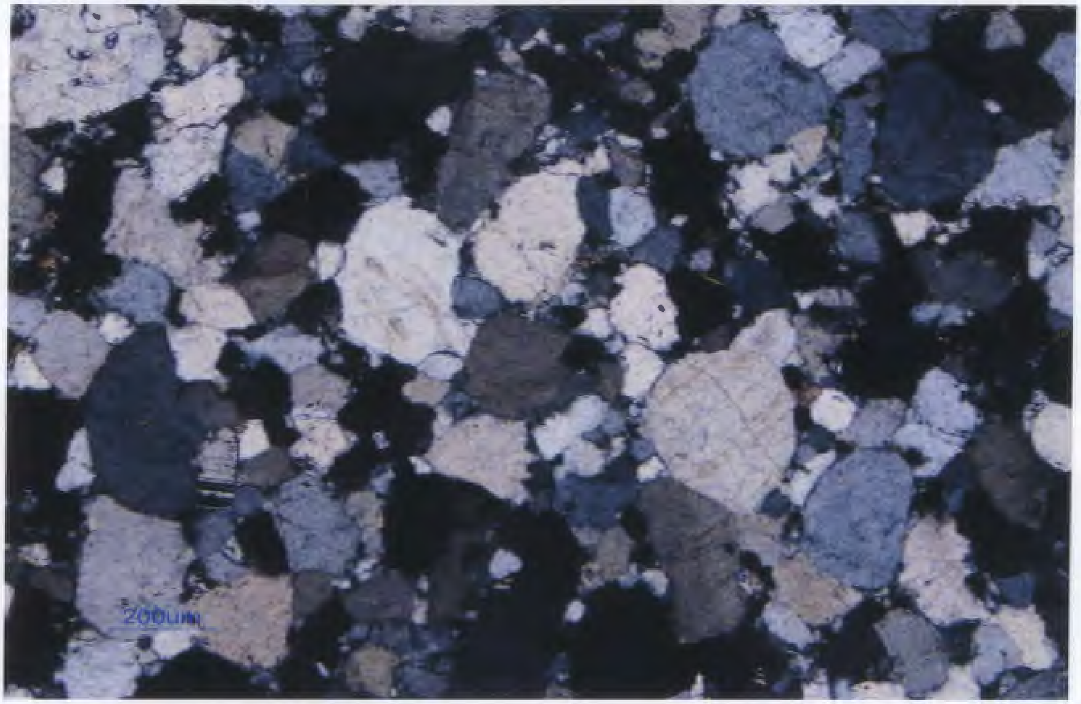


Plate 5.6: Sample EG 224. Subrounded quartz grains, with variable grain size. Crossed polars.

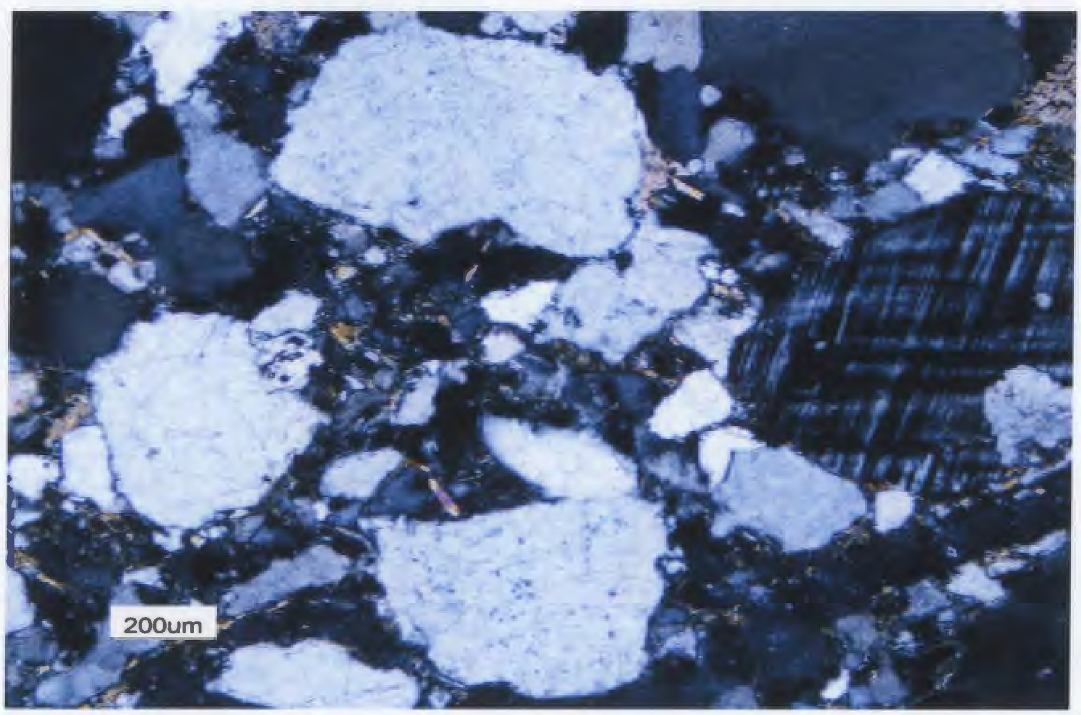


Plate 5.7: Sample EG 273. Monocrystalline quartz grains with sutured and planar contacts. Crossed polars.

Type 2: Polycrystalline Quartz

Polycrystalline quartz grains commonly host 10 to 25 subgrains. Polycrystalline grains within the Blow Me Down Brook formation vary in appearance, but are commonly larger than the mean grain size and have a subrounded shape. Rare polycrystalline subgrains are stretched and elongate in shape with intensely sutured contacts, suggesting a metamorphic source (Plate 5.8). Other subgrains have a subangular shape and display sharp planar crystal boundaries (Plate 5.9).

5.2.2 Plagioclase Feldspar

Three types of plagioclase feldspar crystals were observed in the Blow Me Down Brook formation.

Type 1: Albite Twinning

Grains showing albite twinning are commonly smaller than the mean grain size and are clear and colorless in plane light (Plate 5.10).

Type 2: Carlsbad Twinning

Albite grains showing Carlsbad twinning are commonly subhedral and display a lath shape (Plate 5.11). Within some samples calcite has partially replaced these plagioclase grains.

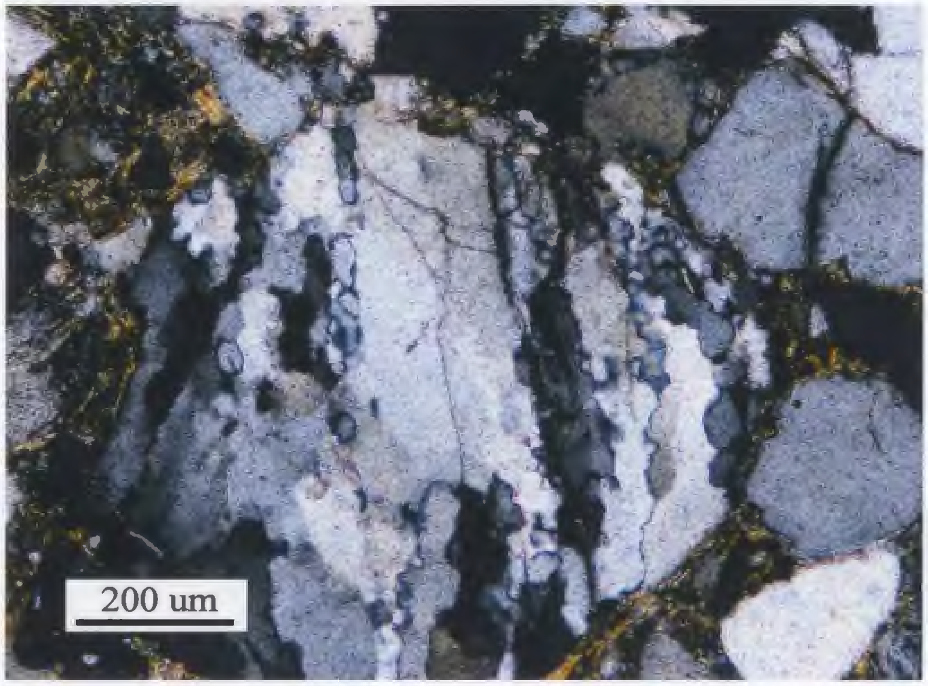


Plate 5.8: Sample EG 257. Polycrystalline quartz grain, with subgrains that are elongate in shape and have sutured contacts. Crossed polars.

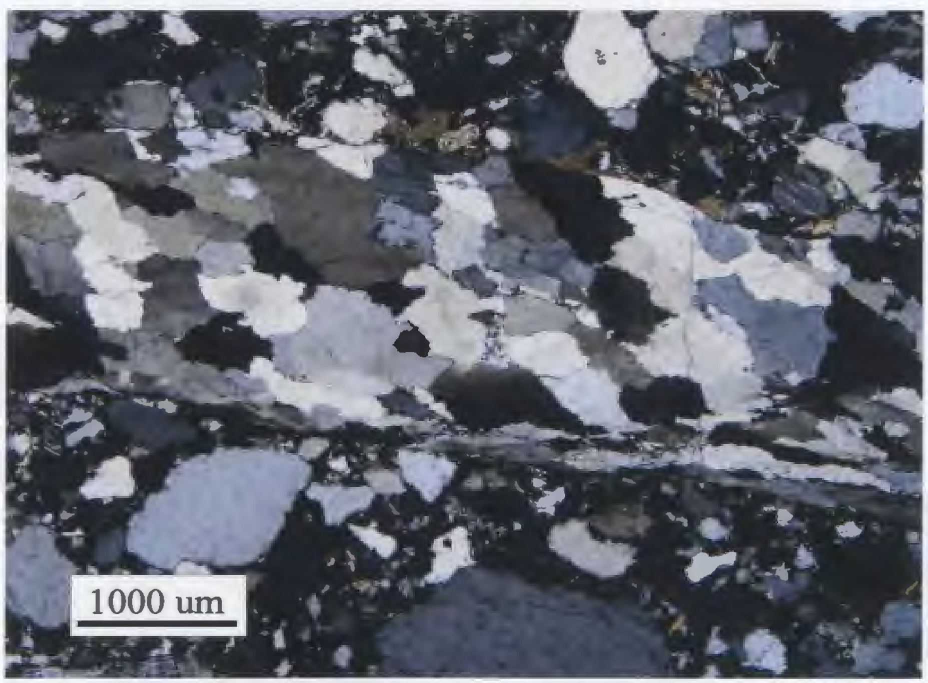


Plate 5.9: Sample EG 276, a polycrystalline quartz grain with fused subangular subgrains. Crossed polars

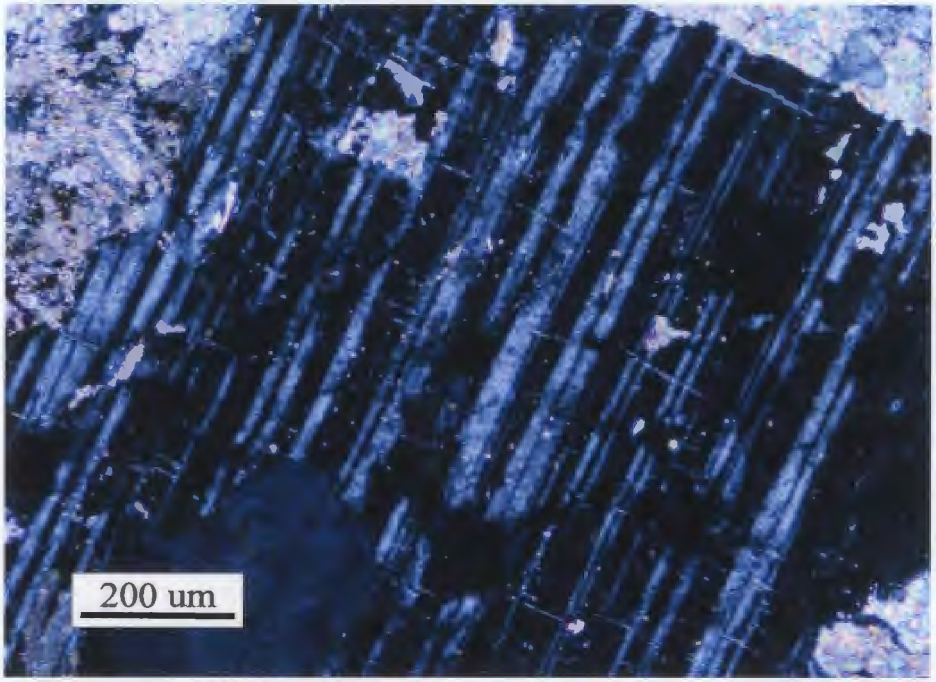


Plate 5.10: Sample EG 168 has albite twinning of plagioclase feldspar; note patchy carbonate replacement of the feldspar. Crossed polars.

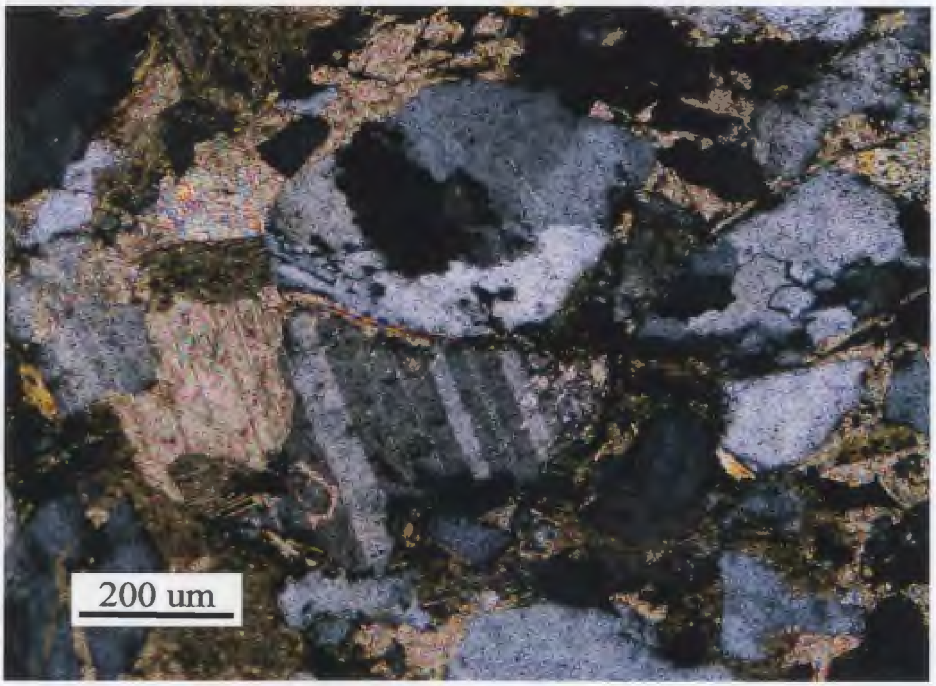


Plate 5.11: Sample EG 280 has thick carlsbad twinning in plagioclase feldspar. Quartz and feldspar grains are surrounded by carbonate cement. Crossed polars.

Type 3: Untwinned

Grains are untwinned, and cloudy in color. They can be difficult to distinguish from quartz. Under plane polarized light these feldspars can be cloudy in appearance, whereas quartz is colorless. Interference figures were also used when trying to distinguish between quartz and feldspar; no figures were obtained on feldspar grains, but quite often quartz grains provided a uniaxial figure.

5.2.3 Orthoclase (Potassium) Feldspar

Type 1: Microcline

Distinct tartan twinned grains are commonly rounded in shape and are larger than the mean grain size (Plate 5.12).

Type 2: Microperthite

Grains are clear and colorless, subrounded in shape, and show spindle shaped exsolution lamellae (Plate 5.13).

5.2.4 Sedimentary Rock Fragments

Type 1: Shale

Shale fragments are light to dark brown in color, with elongate subrounded shape (Plate 5.14). Grains are commonly larger than mean grain size, and may display laminations.

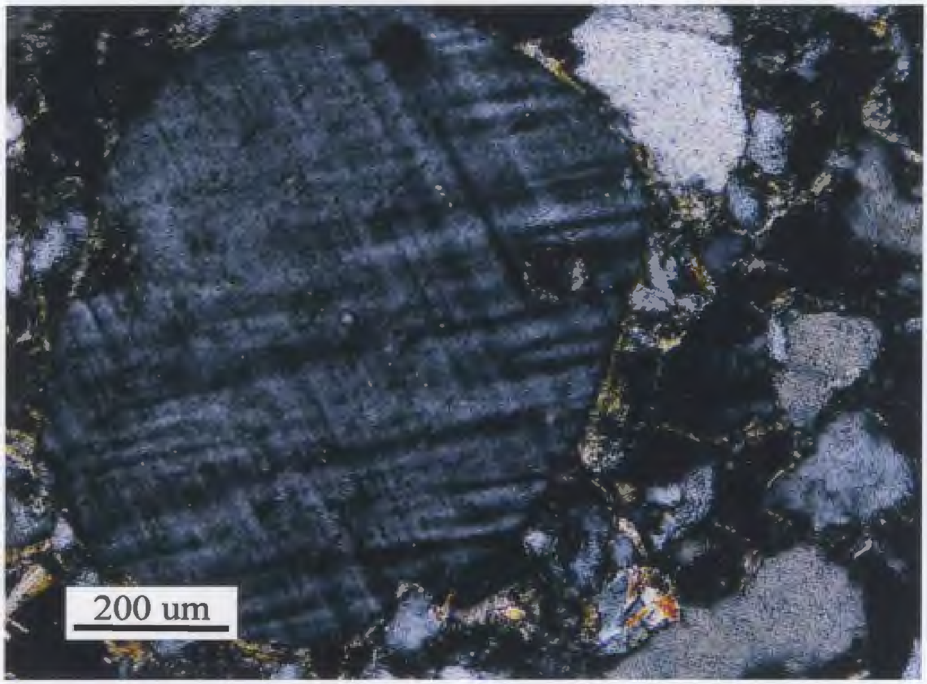


Plate 5.12: Sample EG 05 60. Microcline feldspar displaying tartan twinning. Feldspar seems less prone to pressure solution than surrounding quartz grains. Crossed polars.

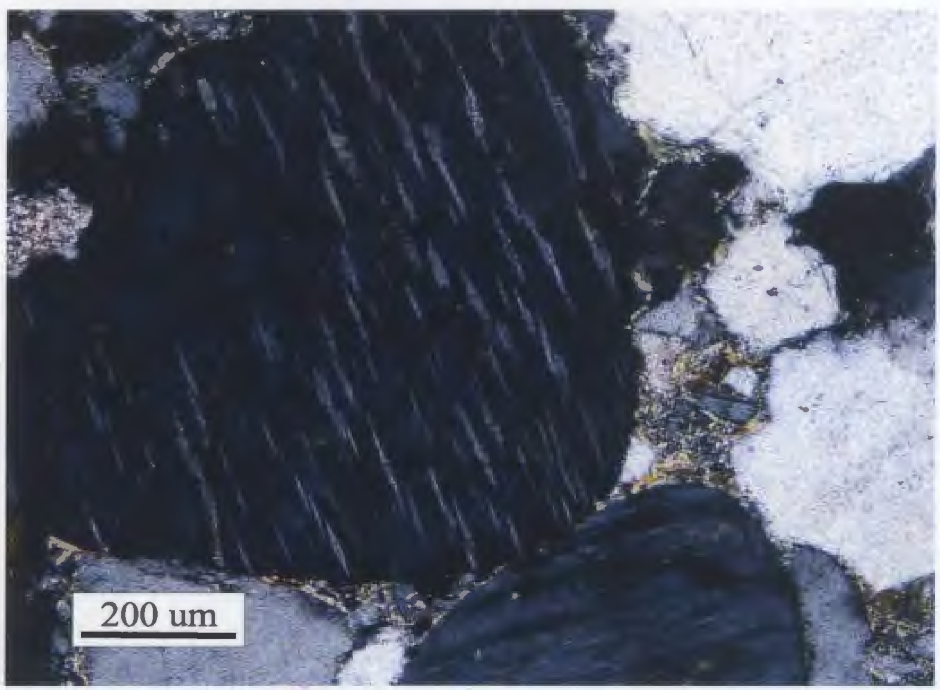


Plate 5.13: Sample EG 276. Alkali feldspar grain with microperthite texture and a sharp, rounded grain boundary. Quartz grains within this rock are sub-angular in shape and have ragged grain boundaries due to pressure solution. Crossed polars

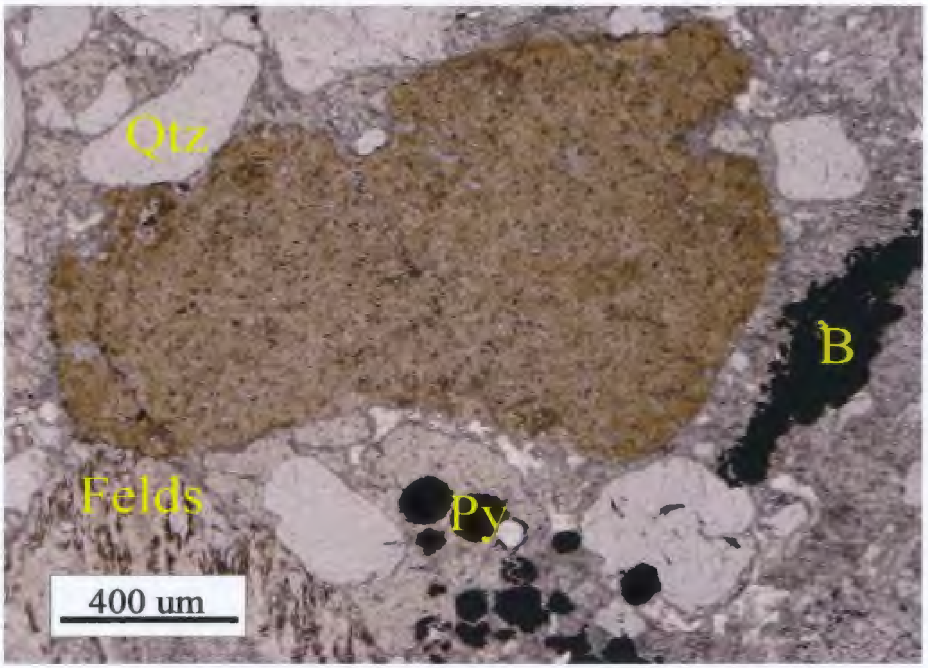


Plate 5.14: Sample EG 168, large shale fragment surrounded by quartz, feldspar and framboidal pyrite grains. Pyrobitumen? (B) is seen to the right of the shale fragment. Plane polarized light.

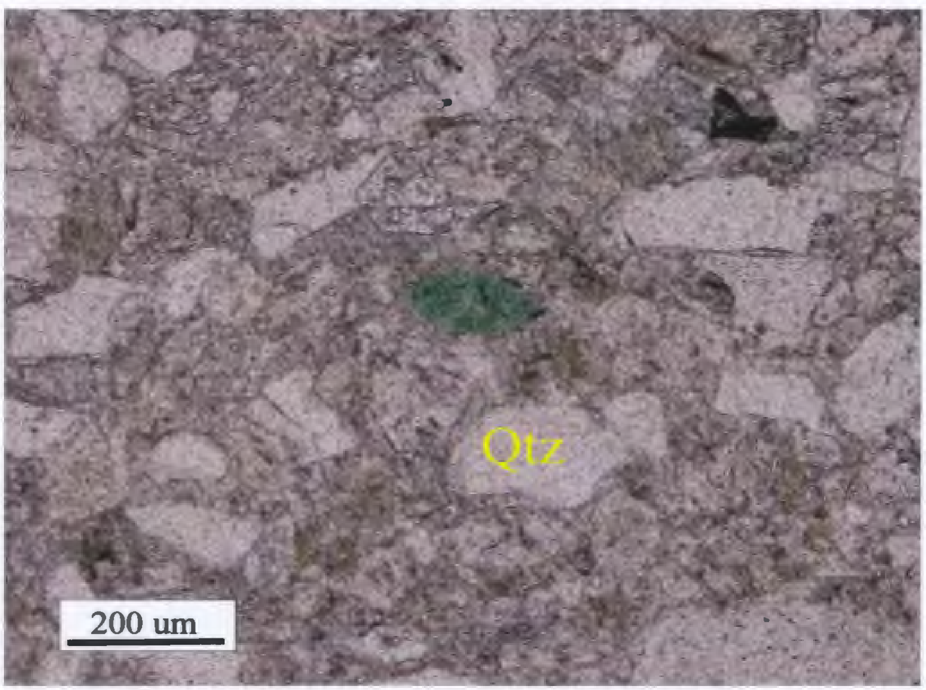


Plate 5.15: Sample EG 05 46 with green, oblate shaped glauconite grain, surrounded by subangular quartz grains. Plane polarized light.

5.2.5 Accessory Minerals

Type 1: Glauconite

Glauconite grains are typically round to oblate in shape, consistant with their possible origins as fecal pellets, and have a distinct bright green color (Plate 5.15).

Type 2: Chlorite

Chlorite has a platy texture and greenish color; these grains are normally detrital in origin and may be compacted.

Type 3: Opaques

Brown to black in color, grain shape can be angular (rhomb) to framboidal (Plate 5.16). The opaques within these samples are commonly 20um to 50um in size and likely consist of pyrite.

Type 4: Mica

Brown to green biotite, and clear colorless muscovite. Grains have a platy texture and display one direction of cleavage. (Plate 5.17)

Type 5: Dolomite

Clear to colorless, with rhombic shape. Dolomite grains within the Blow Me Down Brook formation are rare, and are usually found within carbonate cements.

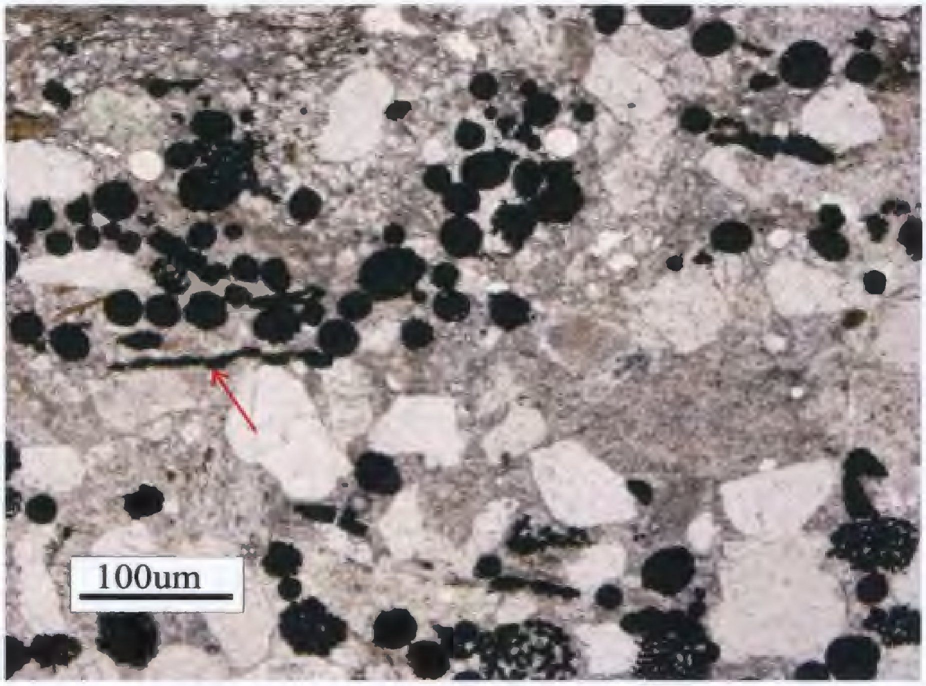


Plate 5.16: Sample EG 170 framboidal pyrite grains from Molly Ann North section. Possible organic tubes also seen in this sample (marked by red arrow). Plane polarized light.

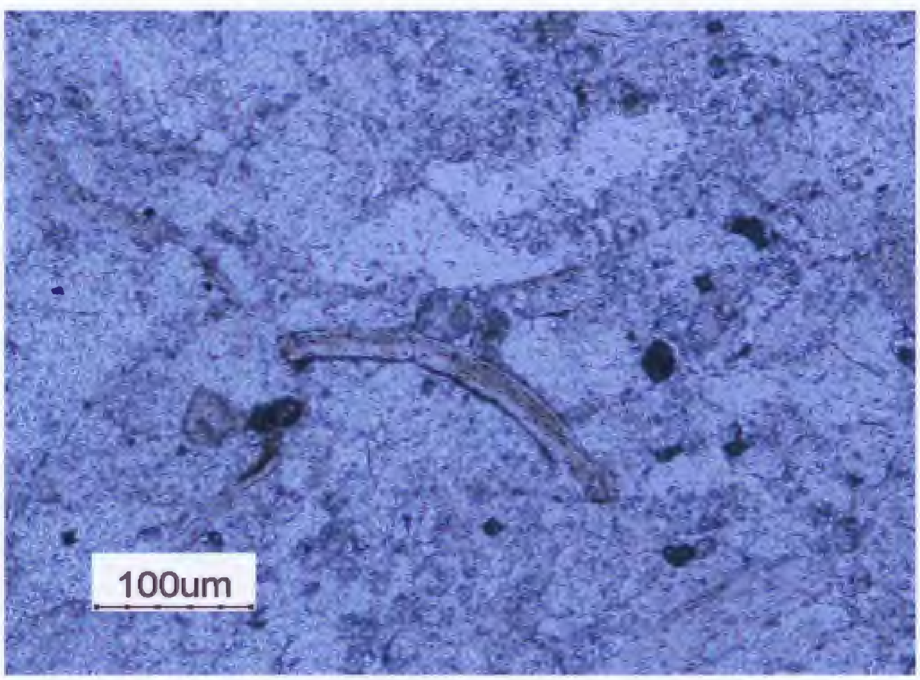


Plate 5.17: Muscovite from sample EG 052. The grain is colorless and has a platy texture, with cleavage clearly visible.

Chapter 6

Stratigraphy of the Blow Me Down Brook formation

6.1 Lithologic Character of the Blow Me Down Brook formation

The Blow Me Down Brook formation is not formally named, and a type locality and other basic information for compliance under the North American Stratigraphic Code (Anonymous, 2005) has not been determined. At Blow Me Down Brook, (the formation's namesake) the strata are incompletely exposed and complexly deformed. Rocks can be described as grey-green, coarse-grained to granular, thickly bedded, subarkosic sandstone. Planar laminations, and calcite veining are common; rarely, soft sediment deformation is observed. Interbedded with the massive sandstone are green, grey and red micaceous shale, with common *Planolites*, and *Gordia*; however, the author in a traverse along Blow Me Down Brook uncovered no *Oldhamia* traces.

For petrographic analysis point counts were taken on samples of the entire formation and plotted following classification by Pettijohn (1975). Samples of Blow Me Down Brook formation straddle several fields: 1) Quartz arenite; 2) Subarkose; and 3) Sublitharenite (Figure 6.1). However, individual sections (i.e. Molly Ann South, Bluff Head) representing different parts of the formation plot in relatively close groupings within the QFL diagram (Pettijohn, 1975).

This petrographic data affirms the field observation that the Blow Me Down Brook formation can be separated into distinctive units based on differences in petrography,

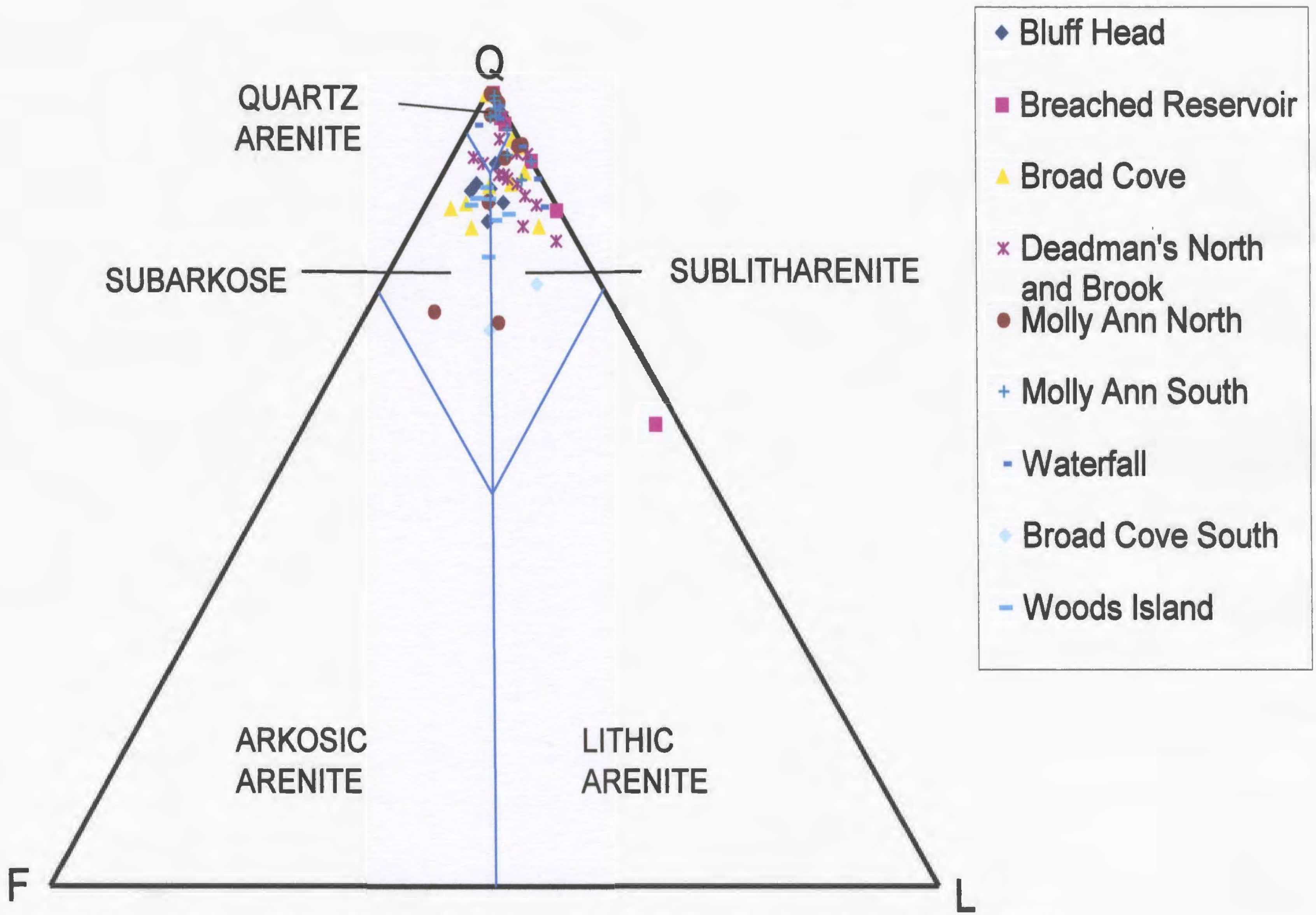


Figure 6.1: Sandstone classification diagram after Pettijohn (1975). QFL plot for the entire Blow Me Down Brook formation.

especially in combination with ichnology and stratigraphic assembly. Six units are recognized and informally named A, B, C, D, E and F (Insert II).

6.1.1 Unit A

Unit A (Figure 6.2) is best exposed in small streams in hills lying in the upper reaches of western Blue Hill Brook. Here, one to two meter thick beds of mostly red colored siliceous shale, with lesser amounts of grey shale and rarely black shale, are interbedded with and conformably overlie 2-5m thick beds of the Fox Island River Volcanics consisting of pillowed basalt (Fowler, 2005).

6.1.2 Unit B

The second unit of the Blow Me Down Brook formation (Figure 6.3) is located at the base of some thrust panels along the coastal sections west of the Lewis Hills. In the Broad Cove South section near Fox Island River the minimum thickness for Unit B is 75m. Strata are dominated by greenish grey and red hematitic colored coarse-grained and granular sandstone beds ranging from 25 cm to 14 m in thickness. Scattered throughout this interval there are successions of 1-2 m beds of red, green and dark grey shale. Shale beds are largely devoid of trace fossils. The first *Oldhamia* trace comes from the uppermost dark grey shale near the contact with Unit C.

In thin section Unit B is a medium to coarse-grained sublitharenite (lower Broad Cove South samples) (Figure 4.21) to subarkosic sandstone (Woods Island and upper

Figure 6.2: Interfingered basal contact between Fox Island Volcanics and red shales of the Blow Me Down Brook formation in upper reaches of western Blue Hill Brook.

Figure 6.3: Red, hematitic, sublitharenite sandstones of Unit B; Broad Cove South section.

Broad Cove South samples) (Figures 4.21 and 4.25) to quartzose sandstone (upper Bluff Head samples) (Figure 4.26) as displayed in (Figure 6.4). Within the sandstones of Unit B the grain size ranges from medium to pebble conglomerate, with moderate to well grain size sorting. Pebble conglomerates tend to be 90% quartz with smaller quantities of feldspar and other rock fragments. Small, patches of calcium carbonate are seen in thin sections, but when tested with hydrochloric acid the hand specimens do not react.

Thin sections are dominated by monocrystalline quartz grains, which are typically sub-rounded to sub-angular in shape. Other common minerals include polycrystalline quartz, alkali feldspar, and mica. Overall, the grains are closely packed with a small quantity of clay matrix infilling small pore spaces, and surrounding most grain boundaries. Planar and point contacts are often observed between grains; sutured grain contacts are rare (Plate 6.1).

6.1.3 Unit C

Where observed, Unit C always lies in sharp contact with Unit B. It is easily recognized by an abrupt shift in grain size from coarse- to granular-grained sandstones and pebble conglomerates of Unit B, to beds of clast and matrix-supported polylithic boulder conglomerate.

One of the more distinctive elements of Unit C is a calcarenite boulder conglomerate horizon up to 12 m thick (Figure 6.5). This calcareous boulder conglomerate, is seen in Broad Cove, Woods Island and up Deadman's Brook, may be a regional marker across the entire formation, akin to the well documented polylithic limestone conglomerates of the Irishtown formation (Stevens, 1965, 1970; James et al.,

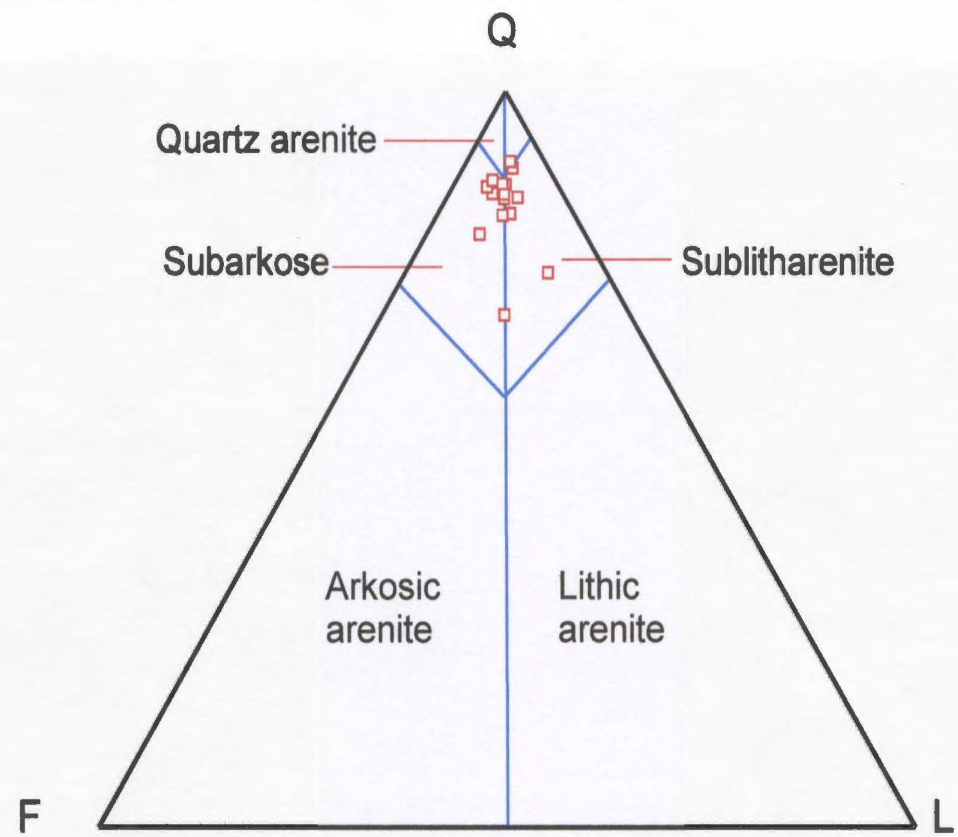


Figure 6.4: Unit B point count data displayed on QFL sandstone classification diagram (after Pettijohn, 1975).

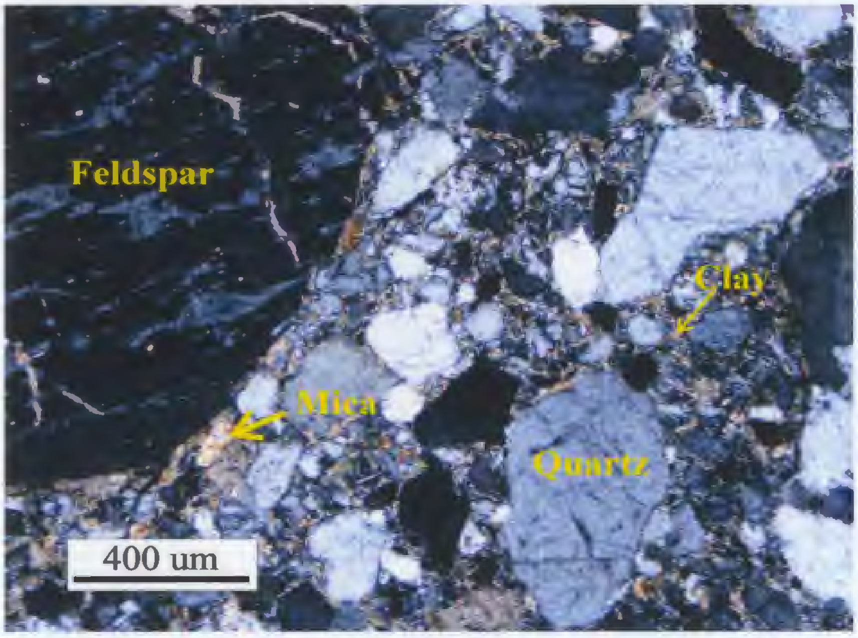


Plate 6.1: Typical texture of a Unit B sample (EG 05 12). Subrounded to subangular monocrystalline quartz grains, with common alkali feldspar and clay matrix. Grains are poorly sorted. Crossed polars.

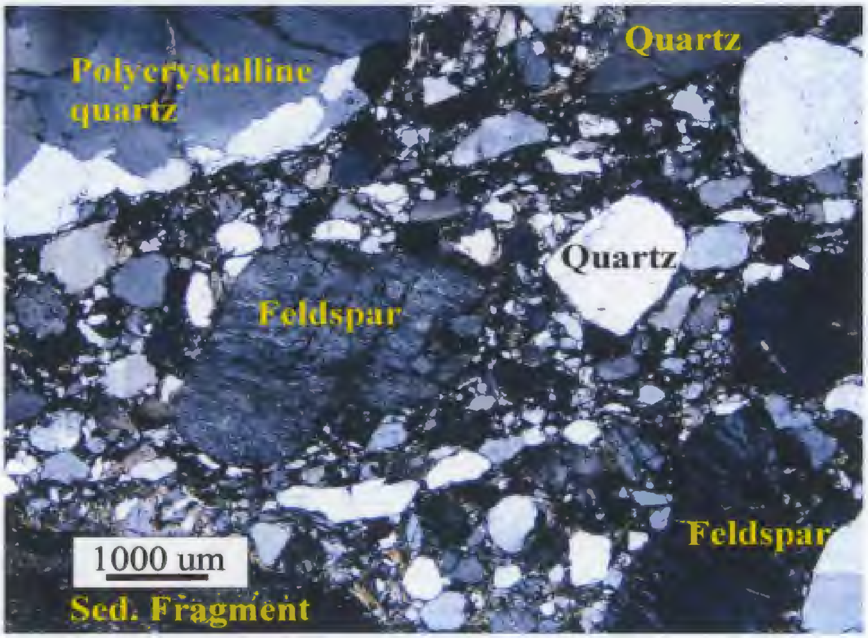


Plate 6.2: Typical texture of a Unit C sample (EG 279). Subrounded to subangular monocrystalline quartz grains with common feldspar and polycrystalline quartz, and rare sedimentary lithic fragments. Moderate grain sorting. Crossed

1988). The calcareous sandstone clasts are 10 to 65 cm in diameter, and rest in a calcite-cemented matrix of quartz and feldspar pebbles. The clasts may be somewhat oblate to discoidal in shape and frequently contain parallel laminations and mud chips.

In outcrop Unit C commonly has an eroded basal contact; overlying strata show variations in thickness. Within the Broad Cove section, near Fox Island River, tight folding and faulting make stratigraphic measurements difficult; here, the conglomerate bed is apparently no more than 12 m thick. Farther north, in the Bay of Islands, parts of the Blow Me Down Brook section measured by Waldron and Palmer (2000) on Woods Island are tentatively correlated with Unit C (Insert II). These beds are 1-4 m thick, with an overall unit thickness of 15 m.

Petrographic analysis of Unit C shows this sandstone as a subarkose to sublitharenite (Figure 6.6). Thin sections of rocks in this unit are dominated by monocrystalline quartz grains, with lesser amounts of mica, alkali feldspar and polycrystalline quartz. Grain size is dominantly medium to coarse, with rare examples of very coarse-grained sedimentary rock fragments. The grain sorting for Unit C is moderate to poor, with clay matrix filling small spaces between grains. Grain contacts within this unit tend to be point or planar. Within the matrix rare calcium carbonate cement is seen in some thin sections, usually in a "patchy" pattern (Plate 6.2).

6.1.4 Unit D

Unit D conformably overlies the conglomeratic Unit C; the contact between these units is gradational, with the feldspar content decreasing upsection until the strata are

Figure 6.5: Calcarenite boulder conglomerate of Unit C, with common imbricate mud chips and planar lamination. Broad Cove section.

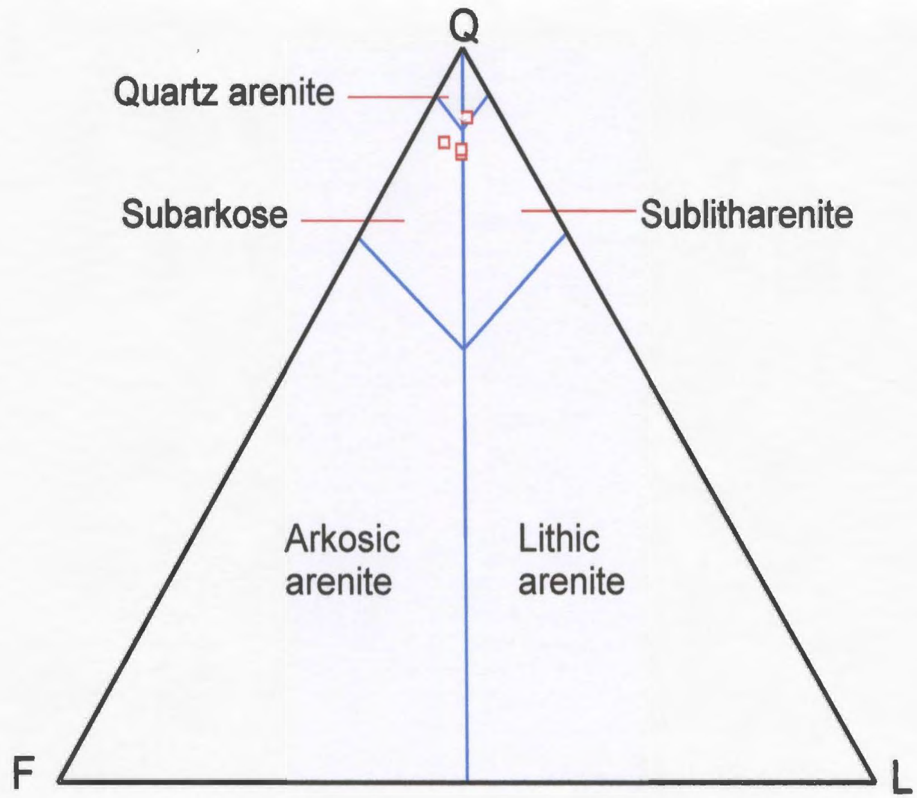


Figure 6.6: Unit C point count data displayed on QFL sandstone classification diagram (after Pettijohn, 1975).

quartzose sandstones. Unit D is seen in the Molly Ann South, Waterfall, Deadman's North, and Breached Reservoir sections. It measures 285 m total thickness. The basal 50 m are dominated by thick-bedded, greenish-grey, massive, subarkosic sandstone, with rare, thin centimeter scale interbeds of dark grey shale (Figure 6.7A). The middle of this unit between 100-200 m marks a transitional zone with a shift in the sediment composition from subarkose to sublitharenite and quartz arenite. Also, across this interval, the thickness of the sandstone beds decreases and fining upward sequences capped with thin shale and siltstone beds become common (Figure 6.7B). Grey shale beds are commonly bioturbated; *Oldhamia* is often found amongst other diverse trace fossils in these muddy successions. The upper 85 m of Unit D is composed of 2 - 17 m thick beds of coarse-grained to granular, grey quartz arenite with minor calcite veining. Dark grey, *Oldhamia* bearing shale beds, no more than 5 m thick, are less common in this part of the succession.

Sedimentary structures in the sandstones include planar lamination, cross lamination, common mud chips, rare ripples, load casts, convolute bedding, flute casts and scours. In thin section, many of these sandstones are seen to be slightly calcareous and rarely dolomitic. Amongst other common lithic minerals, glauconite pellets are common.

Point count analysis show sandstones as mixed subarkose, sublitharenite, and quartzite (Figure 6.8). This varied classification reflects the gradual transition from Unit C to Unit D. Using petrography alone to distinguish the base of Unit D from the top of Unit C proves difficult; therefore, outcrop relations and hand specimens must be considered for features such as, bed thickness, lithology, grainsize and ichnology to aid in

A

B

Figure 6.7: A) Massive thick-bedded subarkosic sandstone, lower Unit D; Broad Cove section. B) Interbedded coarse-grained sandstone and micaceous grey shale, upper Unit D; Broad Cove Section.

separating units C and D. The fundamental difference between these two units lie in the lack of calcarenite boulders in Unit D.

A petrographic shift is evident midway through Unit D, with the sandstone becoming increasingly quartzose, with rare feldspar and mica grains. The upper part of Unit D (Plate 6.3) can be described as quartzose sandstone of medium to coarse grain size, with well to very well sorted and rounded grains. The quartz grains are closely packed with planar to sutured contacts. Very little clay matrix exists in the upper part of Unit D. Calcite cement is commonly seen infilling pore space between grains. It also occurs as small veins in some thin sections. Glauconite is commonly present in thin section; in some samples (ie. EG 059, EG 072) it can be abundant.

6.1.5 Unit E

Unit E is seen in the Molly Ann South, Waterfall, and Deadman's North sections. It consists of massive red siliceous shale with rare thin fine-grained sandstone beds, sharply overlying strata of Unit D (Figure 6.9). Unit E is very deformed, with small scale folding and abundant clevage. The thickest representative section at the Waterfall section is less than 30 m thick.

6.1.6 Unit F

The final and uppermost unit of the Blow Me Down Brook formation is Unit F. This unit is seen in at the headland of the Molly Ann North (Figure 6.10), the headland at Molly Ann South, Deadman's North and the siliciclastic Breached Reservoir section. It is composed of massive, coarse-grained quartz arenite sandstone (Figure 6.11),

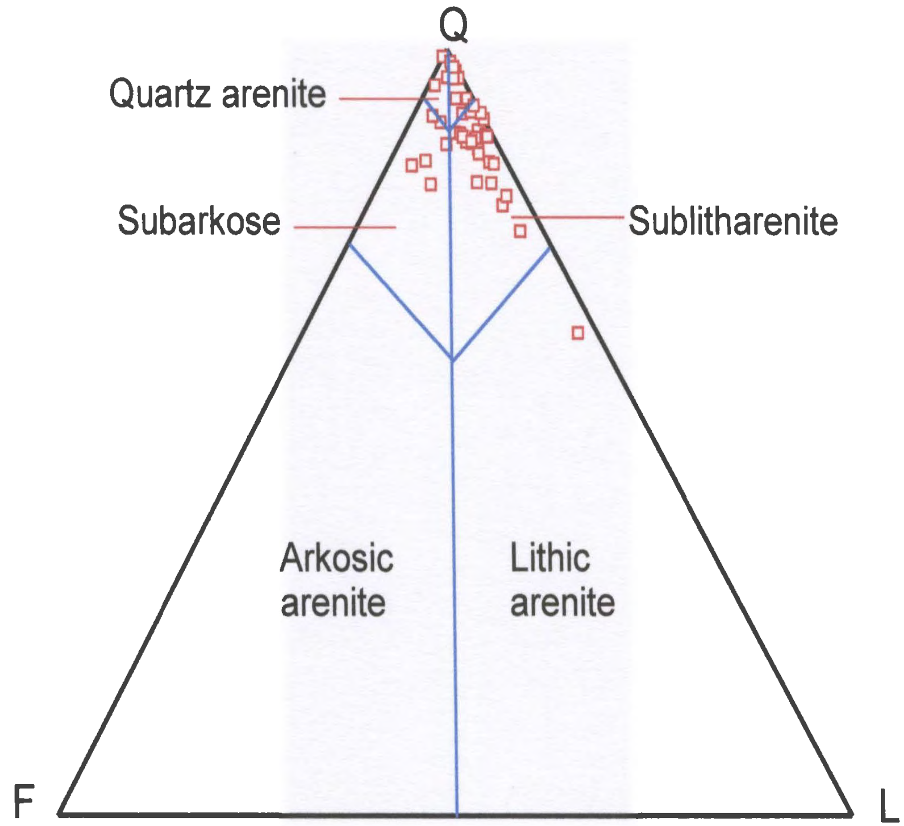


Figure 6.8: Unit D point count data displayed on QFL sandstone classification diagram (after Pettijohn, 1975).

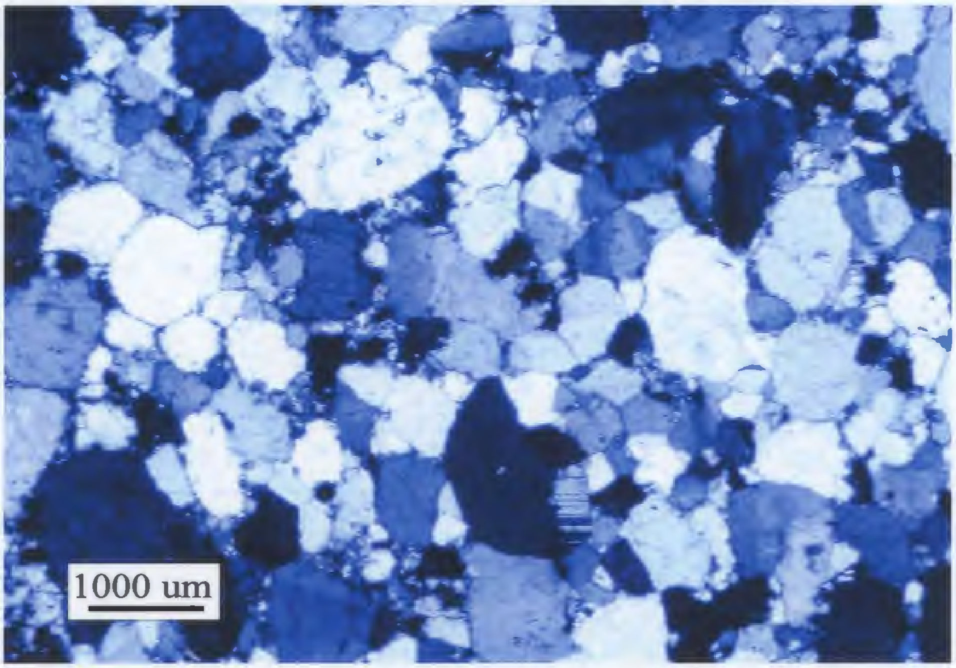


Plate 6.3: Sample EG 224 from the Molly Ann South section, shows the common appearance of upper Unit D. Quartzose sandstone with closely packed, sub-rounded, moderately well-sorted grains. Crossed polars.

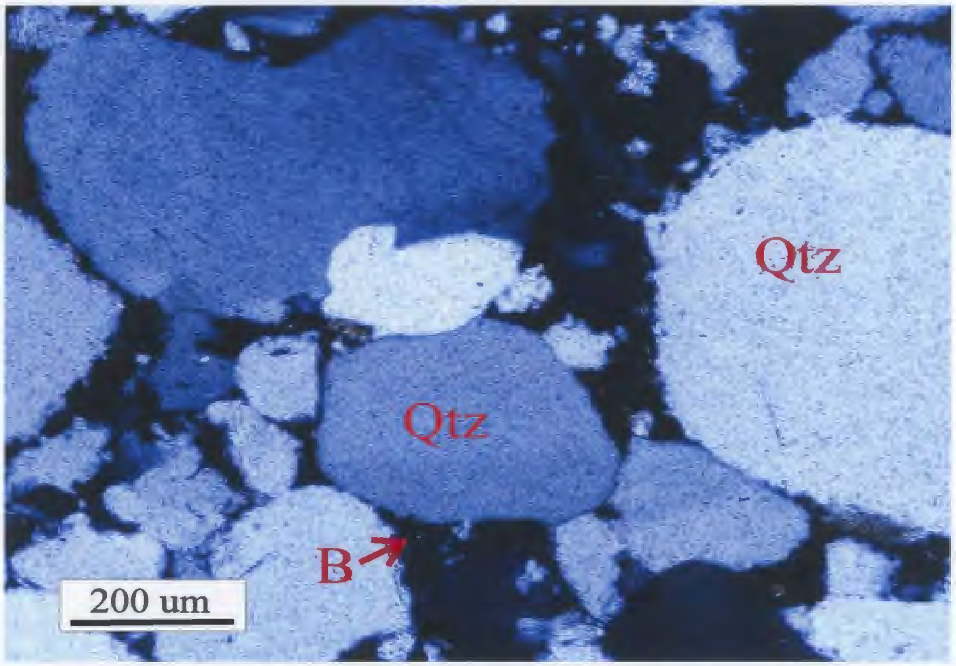


Plate 6.4: Sample EG 099 shows the typical appearance of Unit F, a subrounded monocrystalline quartz (Qtz) with degraded bitumen (B) filling the pore space. Crossed polars.

Figure 6.9: Unit E of Blow Me Down Brook formation at the Waterfall section. The unit consists entirely of deformed, and massive, red and black shale. Cliff approximately 15m high

interbedded with black shale. Commonly the sandstones are petroliferous, and display dewatering features such as sand volcanoes (Figure 6.12). Within the study area there is a common structural relationship with Unit F and the Cooks Brook Formation. Wherever Unit F is found, the Cooks Brook Formation is in close proximity.

In thin section Unit F is a well-sorted, rounded to well-rounded quartzose sandstone. Grain contacts are commonly point-to-point or planar. Pore space between quartz grains is commonly filled by degraded oil. There is no calcite cement within thin sections of Unit F, nor is any matrix visible (Plate 6.4).

Figure 6.10: Unit F, located at Molly Ann North section Thick quartzose sandstone saturated with degraded bitumen.

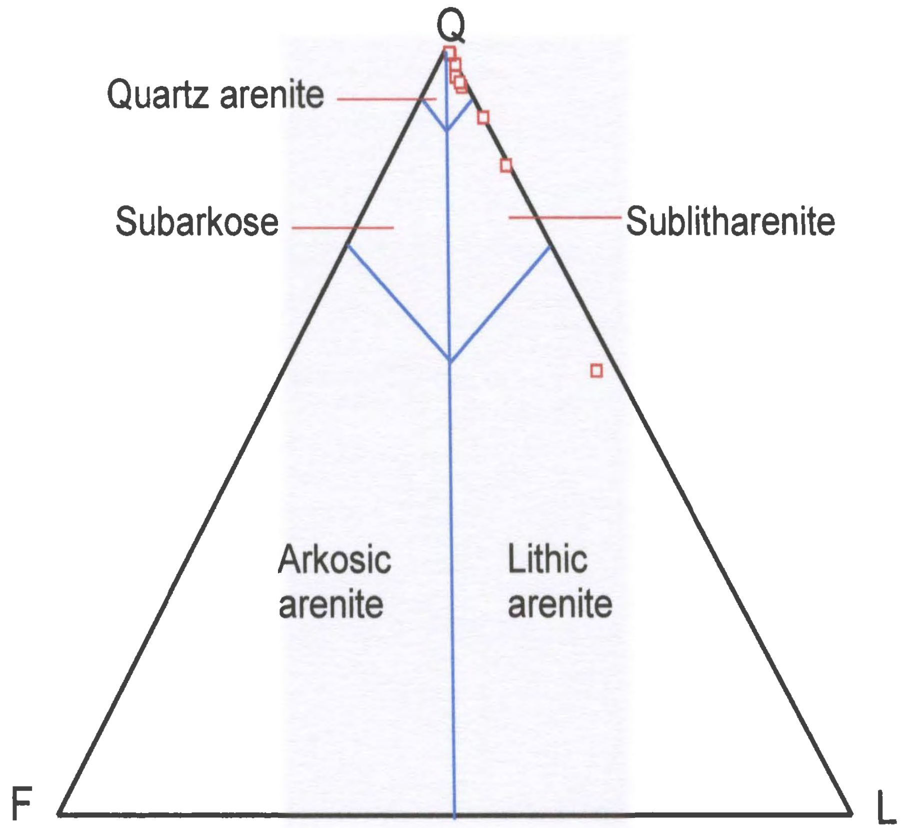


Figure 6.11: Unit F point count data displayed on QFL sandstone classification diagram (after Pettijohn, 1975).

Figure 6.12: Sand volcano observed in Unit F at the Molly Ann South locality.

Chapter 7

Discussion

7.1 Previous interpretation of the Blow Me Down Brook formation

Early work on the geology of the Blow Me Down Brook formation stated that the sediments represented an Ordovician flysch containing ophiolitic detritus (Lily, 1967; Brückner, 1966; Stevens, 1965 and 1970; James and Stevens, 1982). In particular, Stevens (1970) suggested that the Blow Me Down Brook sandstones were derived from a source rich in microcline granite and sodic granophyre, gabbros, volcanic rocks, and chrome spinel-bearing ultramafic rocks and sedimentary rocks. By implication the Blow Me Down Brook formation was derived from the assembled Humber Arm Allochthon including the ophiolite suite. This interpretation was supported by the discovery of Ordovician graptolites in rocks attributed to the Blow Me Down Brook formation (Stevens, 1976). However, questions concerning the nature of the formation began to arise when studies of adjacent allochthon sediments indicated that at least part of the Blow Me Down Brook formation lacked ophiolitic detritus (Quinn, 1985).

The Blow Me Down Brook formation was considered Ordovician in age until the work of Quinn (1985) who suggested that the Blow Me Down Brook formation and the correlative Sellars formation in Bonne Bay, along with Summerside and Irishtown formations represented deep-water Precambrian - Cambrian units, coeval to the more proximal Bradore and Hawkes Bay formations. Quinn's reasoning for placing the Blow Me Down Brook formation at a lower Cambrian age came from her petrographic work on the formation. She noted that the Sellars and Blow Me Down Brook sandstones were petrographically akin to sedimentary rocks within the Appalachians interpreted as older Precambrian - Cambrian rift sediments of the ancient North American margin.

Waldron (1985) suggested informal names including "easterly derived flysch", for the clastics of the Humber Arm allochthon that contain ophiolitic detritus, and "western sandstones" for the rocks exposed near Blow Me Down Brook and which are devoid of ophiolitic detritus. Waldron also suggested that the Cambrian Summerside formation could correlate with the Blow Me Down Brook formation.

Reclassification of the Blow Me Down Brook formation to the lower Cambrian was backed up by the research of Lindholm and Casey (1989) and their report of the Early Cambrian trace fossil *Oldhamia* within shales of the Blow Me Down Brook formation. Previous observations made by Stevens (1970) and James and Stevens (1982) on the importance of chrome spinel as a component of the formation were incorrect. Samples were not collected at the type locality at Blow Me Down Brook, but from a younger lithologically similar flysch succession which is now known as the Eagle Island formation (Botsford, 1988).

7.2 A Deep water facies classification for the Blow Me Down Brook formation

The Blow Me Down Brook formation is classified as a deep-water deposit based upon its large-scale channel complexes, small-scale sedimentary features, and ichnology. Within the coastal outcrops, thick, massive packages of sandstone, with large scour surfaces at their base, have been interpreted as channels. Within some of the surrounding medium to thinly bedded sandstones there are common planar laminations, dewatering structures, soft sediment deformation and flute casts. These features are commonly associated with rapid deposition of sediment. As well, the trace fossil *Oldhamia* found in some Blow Me Down Brook shale belongs within the *Nereites* ichnofacies (Seilacher, 1967). This fossil is considered representative of deep-sea pelagic and turbiditic deposits (Lindholm and Casey, 1989).

When dealing with deep-water siliciclastic deposits, the facies classification of Stow et al. (1996) and Pickering et al. (1986) is commonly used (Table 7.1). Within Pickering et al. (1986) the term 'facies' is used to describe a body of sedimentary rock/sediments with specific physical, chemical and biological characteristics. This classification uses seven 'facies classes', divided into two or more 'facies groups'; these facies groups are then subdivided into 'facies'. Only those facies observed in the Blow Me Down Brook formation will be described here.

7.2.1 Facies Class A – The Gravels

Stow et al (1996) and Pickering et al (1986) describe facies class A as a sandstone which consists of greater than 5% pebble size or coarser material, and includes clast-supported gravel, gravels within a sand-supported matrix, muddy gravels, and gravelly muds. These coarse-grained sediments have been originally deposited in shallow water,

Facies Class
Facies Group
A: Gravels, muddy gravels, gravelly muds, pebbly sands, ≥5% gravel
A1: Disorganized gravels, muddy gravels, gravelly muds and pebbly sands
A1.1 Disorganized gravel
A2: Organized gravels and pebbly sands
A2.3 Normally graded gravel
B: Sands ≥80% sand grade, <5% pebble grade
B1: Disorganized sands
B1.1 Thick/medium-bedded, disorganized sands
B2: Organized sands
B2.1 Parallel/stratified sands
B2.2 Cross-stratified sands
C: Sand-mud couplets and muddy sands. 20-80% sand grade, <80% mud grade (mostly silt)
C1: Disorganized muddy sands
C2: Organized sand-mud couplets
C2.2 Medium-bedded organized sand-mud couplets
C2.3 Thin-bedded organized sand-mud couplets
D: Silts, silty muds, and silt-mud couplets, >80% mud, ≥40% silt, 0-20% sand.
D1: Disorganized silts and silty muds
D1.1 Structureless silt
D1.2 Muddy silts
D2: Organized silts and muddy silts
D2.1 Graded-stratified silt
D2.2 Thick irregular silt and mud laminae
D2.3 Thin regular silt and mud laminae

E: ≥95% mud grade, <40% silt grade, <5% sand and coarser, ≤25% biogenics.

E1: Disorganized muds and clays

E1.1 Structureless mud

E1.2 Varicolored mud

E2: Organized muds

F: Chaotic deposits

F1: Exotic clasts

and then transported into deeper water (Walker, 1975). A model for these coarse-grained materials has been put forth by Walker (1978) (Figure 7.1), in which he speculated that in submarine fans disorganized conglomeratic beds are most proximal, inverse to normal graded conglomerate beds are intermediate, and graded-stratified conglomerate beds are the most distal.

Facies class A (Stow et al. 1996, Pickering et al. 1986) may be used to characterize Unit B and parts of Unit C of the Blow Me Down Brook formation.

In particular, facies A1.1: Disorganized Gravel, best describes the rocks of Unit B at the Bluff Head locality (Figures 4.1 and 4.23), where the sandstones are composed of pebble conglomerates. Facies A1.1 can have beds thicknesses ranging from 0.5 m to tens of meters. Beds may be flat based or have scours; the upper surfaces of beds may be irregular, wavy, or have individual clasts sticking out of the bed. Laterally, the facies may have a pod-like shape. Clast size ranges from pebble to boulder, with poor sorting.

Both angular and well-rounded-clasts are present within this facies; elongate clasts may have a roughly defined imbrication within beds. Also, variously oriented mudstone clasts are common.

The transport process for the sediments of facies A1.1 is high concentration turbidity current. The depositional process, as interpreted by Pickering et al. (1986) is 'freezing' on the decreasing bottom slopes due to intergranular friction and cohesion.

Unit B of the Woods Island locality (Figures 4.1 and 4.26) commonly display scoured bed bases, with thin stringers of pebbly sandstone fining up to granular or coarse-grained sandstone. Therefore, Unit B at Woods Island can best be classified with facies A2.3 Normally graded gravel (Stow et al. 1996, Pickering et al. 1986).

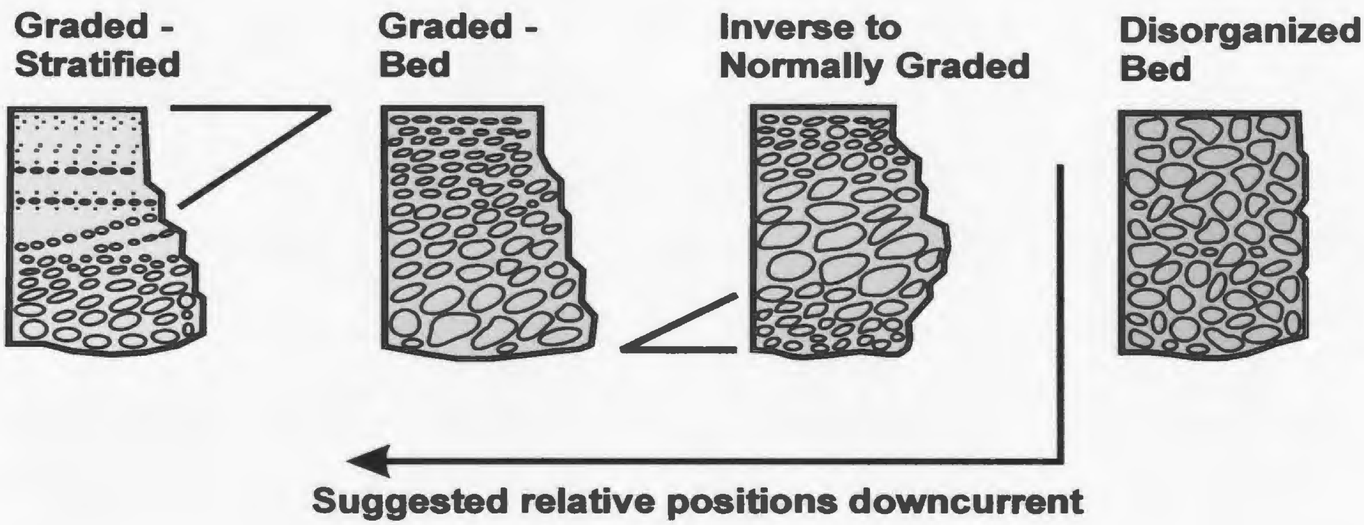


Figure 7.1: Four models for resedimented conglomerates (after Walker, 1978). Unit C of Blow Me Down Brook formation is described as both disorganized (at Broad Cove) and graded stratified (Woods Island).

Facies A2.3: Normally graded gravel, can also be interpreted for Unit C at the Woods Island locality. This facies tends to have similar bed thickness to other gravel facies but is finer-grained than the disorganized beds. Beds commonly have thickness changes due to deep scours and gradational down - cutting into pebbly sands. Several modes of grading occur within this facies; the first show a coarse tail grading, where the coarsest materials are only present in the lowest part of the bed, and then grade up to finer pebbles. The second is less common and consist of grading from cobbles to granular sandstone; this mode of deposition is more commonly found in very thick beds. Imbrication tends to be less well developed in this facies.

The transport process for this facies has been interpreted by Pickering et al. (1986) as a high concentration turbidity current. The depositional model for this facies is explained as "grain-by-grain deposition from suspension. The clasts undergo little or no traction transport after reaching the bed, probably because of relatively rapid deposition." (Pickering et al. 1986, p. 50)

7.2.2 Facies Class B - Sands

Facies class B, (Stow et al. 1996, Pickering et al. 1986), is sandstone beds with <20% mud and silt matrix, and <5% pebble-grade material. This facies (like facies class A) is divided into organized and disorganized facies groups, and then subdivided into independent facies.

Facies B1.1 consists of thick/medium-bedded, disorganized sands which are laterally continuous, and are parallel-sided to highly irregular beds. Sole marks on bed bases tend to be rare. Grading of sediment tends to be rare, or poorly developed as a coarse tail grading with small pebbles and granules concentrated in a thin basal layer. Common fluid escape structures are present within this facies, typically in the upper half of beds, and include sub-vertical sheet structures, dish structures and fluidization pipes and pillars. Dish structures are characteristic of better-sorted sandstones of the facies, while pillars and sheets are common to the less well-sorted sediment. Sediments of Unit D are akin to this facies type of the Blow Me Down Brook formation, especially in the Molly Ann South, Molly Ann North, Deadman's North, Waterfall, and Breached Reservoir sections (Figures 4.1,4.7, 4.11, 4.15, 4.18). Transport process for this facies is described by Pickering et al. (1986) to be a high concentration turbidity current. The depositional process for this facies is interpreted to be a rapid mass deposition due to intergranular friction. During or after deposition grain packing may collapse resulting in escape of surplus pore fluid, thus creating fluid escape structures.

The second facies group within facies class B seen in the Blow Me Down Brook formation is facies B2: the organized sands. This group includes any sandstones with clear, defined sedimentary structures that are not part of the Bouma sequence for sand mud turbidities. This facies group has been split into two facies, B2.1: Parallel/stratified sandstone and B2.2: Cross-stratified sandstone. Both of these facies have been observed by the author within Unit D of the Blow Me Down Brook formation (Insert II).

7.2.3 Facies Class C-Sand mud couplets and muddy sands

Facies Class C is composed of mud couplets and muddy sands (Stow et al. 1996, Pickering et al. 1986). This facies is considered a classic turbidite based on the Bouma sequence. Generally the beds within this class are sheet-like, with graded bedding capped by a mud. This facies class is divided into two facies groups: (C1) disorganized, and (C2) organized. Textural homogeneity is used to characterize the disorganized facies, while bed thickness is the main characteristic used for the organized beds (Pickering et al., 1986). The C1: disorganized muddy sands are not encountered within the studied sections of the Blow Me Down Brook formation.

Facies group C2 is based upon thickness. In particular facies C2.2 is described as medium-bedded sand mud couplets, which generally begin with the Bouma division b (massive sandstones with common flutes and tool marks at bed bases). This facies can be seen at the upper end of the Broad Cove south section (Figures 4.1 and 4. 21). Pickering et al. (1986) have interpreted this type of deposit to originate from turbidity currents of intermediate character.

Unit F of the Molly Ann South and Breached Reservoir sections (Figures 4.1, 4.7 and 4.11) are comprised of the C2.3 facies. This facies consists of thin-bedded sand mud couplets (Pickering et al., 1986). It tends to begin at the Bouma division c, with cross-laminated sandstones and low amplitude ripples with long wavelengths. This facies is deposited from a lower flow regime or current.

7.2.4 Facies Class D – Silts and Silty muds

Facies Class D is composed of silt and clay grade sediments (Pickering et al., 1986). The coarser silts commonly occur in distinct beds with interbedded mud and/or clay. This facies class has been divided into two facies groups: (D1) disorganized, and (D2) organized.

Many of the facies of facies class D are common in the studied sections of the Blow Me Down Brook formation. These include: D1.1 structureless silt, D1.2 muddy silt, D2.1 graded-stratified silt, D2.2 thick irregular silt and mud laminae (Figure 4.10), and D2.3 thin regular silt and mud laminae (Figure 4.24A). One of the most common facies in the Blow Me Down Brook studied sections is D1.2, muddy silt. This facies occurs as thick- or thin-bedded, poorly sorted, structureless muddy silts, with little or no grading. The base of these beds are sharp, while the upper surfaces tend to grade into a finer grained facies. Bioturbation can be common in the upper part of this facies. The finer-grained interbeds of units B, D and F are akin to the D1.2 facies (Insert II).

The transport process offered for the disordered facies groups (D1.1 and D1.2) is turbidity currents or debris flows. The depositional process is rapid mass deposition from a concentrated dispersion due to a combination of increased cohesion and intergranular friction.

For the ordered facies (D2.1, D2.2 and D2.3), transport processes have been described by Pickering et al., (1986) as low concentration turbidity currents, or weak bottom currents. The depositional processes are as follows: (D2.1) grain-by-grain deposition from suspension, followed by traction transport along the bottom to produce laminations, with late stage suspension deposits resulting in clay grade bed tops; (D2.2) fairly rapid grain-by-grain deposition from suspension followed by traction transport of the silt load; (D2.3) slow uniform deposition form suspension, with shear sorting of silt grains and clay.

7.2.5 Facies Class E – Muds

Facies Class E, the muds, include fine-grained deep-water sediments. Beds can vary from very thick to very thin. Internally beds can be structureless, graded, irregularly or finely laminated, and may show variable degrees of bioturbation (Stow et al. 1996, Pickering et al., 1986).

Facies Group E1, disorganized muds and clays, are often thick, uniform, structureless sections. Of this facies group two facies are recognized within the studied sections of the Blow Me Down Brook formation.

Facies E1.1 is a structureless mud. Sediments within this facies are, as the name suggests – structureless. This facies commonly occurs in thick sections (one to ten meters thick), with none or poor bedding (Pickering et al., 1986). This facies is similar to Units A and E, the thick red and black shale successions of the Blow Me Down Brook formation.

The transport process of this facies is largely unknown, but is likely to include thick, mud-rich turbidity currents and lateral transfer of hemipelagic material (Pickering et al., 1986).

Facies E1.2, the varicolored muds is composed of interbedded muds of various colors, which lack sedimentary structures. Sections of this facies may be tens of meters thick, with individual beds based upon color changes (Pickering et al., 1986). Bioturbation, mottling and burrowing can be common within this facies. This facies is commonly associated with fine-grained turbidites (D2 and E2). The red and green shales interbedded within the upper Broad Cove Section (Unit D) may be classed into this facies. As well, Unit E (Insert II) may also be part of this facies in sections showing color change from red to black shale.

The transport process as interpreted by Pickering et al., 1986 is the lateral transport of hemipelagic material by ocean currents or aeolian action. The depositional process has been interpreted as the settling of individual particles.

7.2.6 Facies Class F – Chaotic Deposits

Facies Class F is composed of chaotic mixtures of deep-water sediments, laid down by large scale downslope mass movements. The thickness of this facies is variable; it can consist of a single clast, to hundreds of meters of section (Pickering et al., 1986). The only strata of Facies Group F is subclass F1, Exotic Clasts. This facies generally has a poorly sorted matrix, which is commonly much finer than the clasts, and may have a bimodal to polymodal grain size distribution. The calcareous boulder conglomerate beds at the base of the Broad Cove locality belong to facies F1. There, the matrix material surrounding exotic calcareous clasts is very coarse to conglomeratic feldspar and quartz; however, this is still much finer grained than the boulder size clasts.

7.3 <u>The Blow Me Down Brook formation: A Submarine Fan Complex</u>

Turbidity flow deposits are important and essential elements to the construction of submarine fan complexes. Comparative analysis of modern and ancient facies associations and vertical sequences measured from outcrops and cores are used to recognize ancient submarine fans. As described in Pickering et al., (1986), Mutti and Ricci Lucchi (1972) stated that submarine fans consist of: 1) An inner fan, characterized by conglomerate and coarse-grained sandstone facies in large channels that cut into fine-grained deposits (Facies A and B of the Pickering et al. classification); 2) A middle fan, containing lenses of sandstone and minor amounts of conglomerate in thinning and fining upward sequences (Facies A, B of Pickering et al.), alternating with intervals of finer grained sediment (Facies C, D and E of Pickering et al), and; 3) An outer fan, with few or no channels, and parallel-sided turbidities with thickening and coarsening upward sequences.

The Blow Me Down Brook formation has many of the characteristics described in deep marine depositional environments, and in particular, submarine fan complexes. As outlined earlier in this chapter, six of the seven submarine fan facies of Pickering et al. (1986) occur in the Blow Me Down Brook formation. All are important in naming the general depositional environment of the formation; however, the exotic clast facies (informally named Unit C of the Blow Me Down Brook formation) may be one of the best indicators for determining a general model for the form and architecture of this in the submarine fan complex.

Unit C is a succession that contains disorganized pebble and boulder conglomerates. According to Walker (1978) the depositional process and rate of deposition determine the internal organization and slope of conglomerate deposits. Disorganized conglomerates indicate more proximal deposits within the fan complex. Thus, the informally named Unit C of the Blow Me Down Brook formation, as compared with the submarine model of Mutti and Ricci Lucchi (1972), indicate deposition in the middle fan complex. As well, southerly paleoflow directions taken throughout the map area give a general indication of the depositional trend. Proximal deposits of the Blow Me Down Brook formation should lie to the north, and distal deposits to the south. At the base of Unit C there is always a scoured surface, infilled by calcareous conglomerate. This conglomeratic unit is seen at Broad Cove, Deadman's Brook and Woods Island localities, and maybe considered a regional marker bed, with a possible correlation to the more proximal limestone conglomerates of the Irishtown formation.

A submarine fan complex has variable thickness of sandstone and shale depending where in the fan the strata accumulate. The base of a submarine channel is commonly scoured and infilled with conglomeratic to coarse-grained strata (Unit C of Blow Me Down Brook formation). During turbid flows channels may gradually fill with both coarse and fine-grained sediments (Units D, E and F). Over time the channel is completely filled and strata are deposited as sheets over the infilled channel, levee and levee flanks, placing younger strata (units E and F) in direct contact with older stratigraphic units (A, B and C) while omitting the thick channel fill successions (Unit D). Therefore, in some areas of the submarine fan channel complex, all units of the stratigraphy (A, B, C, D, E and F) will be observed if there is enough vertical relief to see the entire stratigraphy. However, other areas may be missing units of the stratigraphy (i.e. Unit D, channel fill) in an area where channels are absent.

The coastline on which this study has been conducted is severely deformed and broken; therefore it is difficult to map any of the submarine channels laterally. Therefore, the vertical successions through time were the most reliable to realize a depositional environment for the formation.

When studying the stratigraphy of the Blow Me Down Brook formation it has been recognized that units A and B are distinct from units C, D, E and F. Units A and B within the study area tend to have thinner bedding (.25-2 m thickness) with syn-sedimentary faulting, and may indicate shallower water, and deposition during an active rift stage. Units C, D, E and F are commonly thicker bedded (1-10 m thickness) submarine fan deposits, with a high diversity of deep-water ichnofauna (including *Oldhamia*), which were present in a dioxic environment.

Previously, one of the most diagnostic characteristics of the Blow Me Down Brook formation was considered to be the abundance of pink, potassium feldspar (Quinn, 1985). This work shows that this characteristic is not indicative of the entire formation; only the lower sandstones of units B and C have abundant potassium feldspar. Once Unit D is encountered, the feldspar content diminishes, and gradually disappears in the upper sandstone beds of the unit. An explanation for the reduction of feldspar content may be sea level change at time of deposition. During a low stand sediments are being eroded from the craton into submarine canyons that originally formed as grabens and half grabens on the newly formed margin. These sediments are not extensively reworked, and feldspar grains remain within the sands (Figure 7.3). As the sea level rises, sediments must travel farther on a shelf before reaching the shelf edge and basin. During this transport, feldspar grains can be reworked and weathered. Therefore, the quartz-rich sandstone intervals of the Blow Me Down Brook formation may be attributed to the transport over longer distances (Figure 7.4).

Other possible models such as, different sediment source, changes in chemical weathering intensity, and changes in susceptibility to diagenetic replacement may also contribute to a shift from the subarkosic to quartzose lithology of the Blow Me Down Brook formation. However, the simplest model for this shift is considered to be the HST/ LST model put forth in this thesis. Field evidence, such as the consistent southerly paleoflow supports a single source area for these rocks with deposition along the axis of grabens.

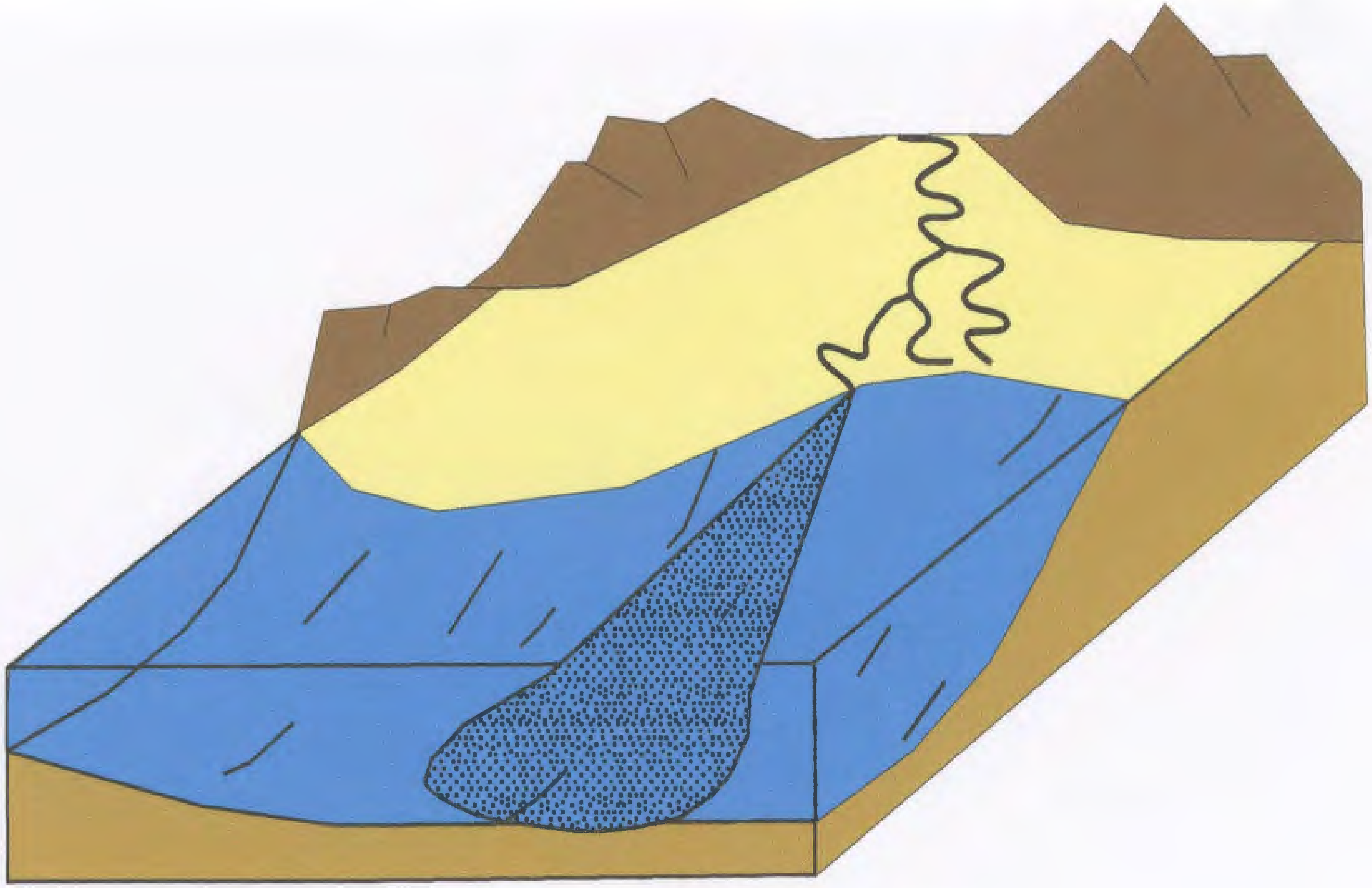


Figure 7.2: Depositional model for the Blow Me Down Brook formation during a low stand systems tract. During this stage sediments shed off the continent are transported short distances to the mouths of feeder canyons and then down into the submarine fan. Therefore, the sediments are not extensively reworked and feldspar grains are preserved.

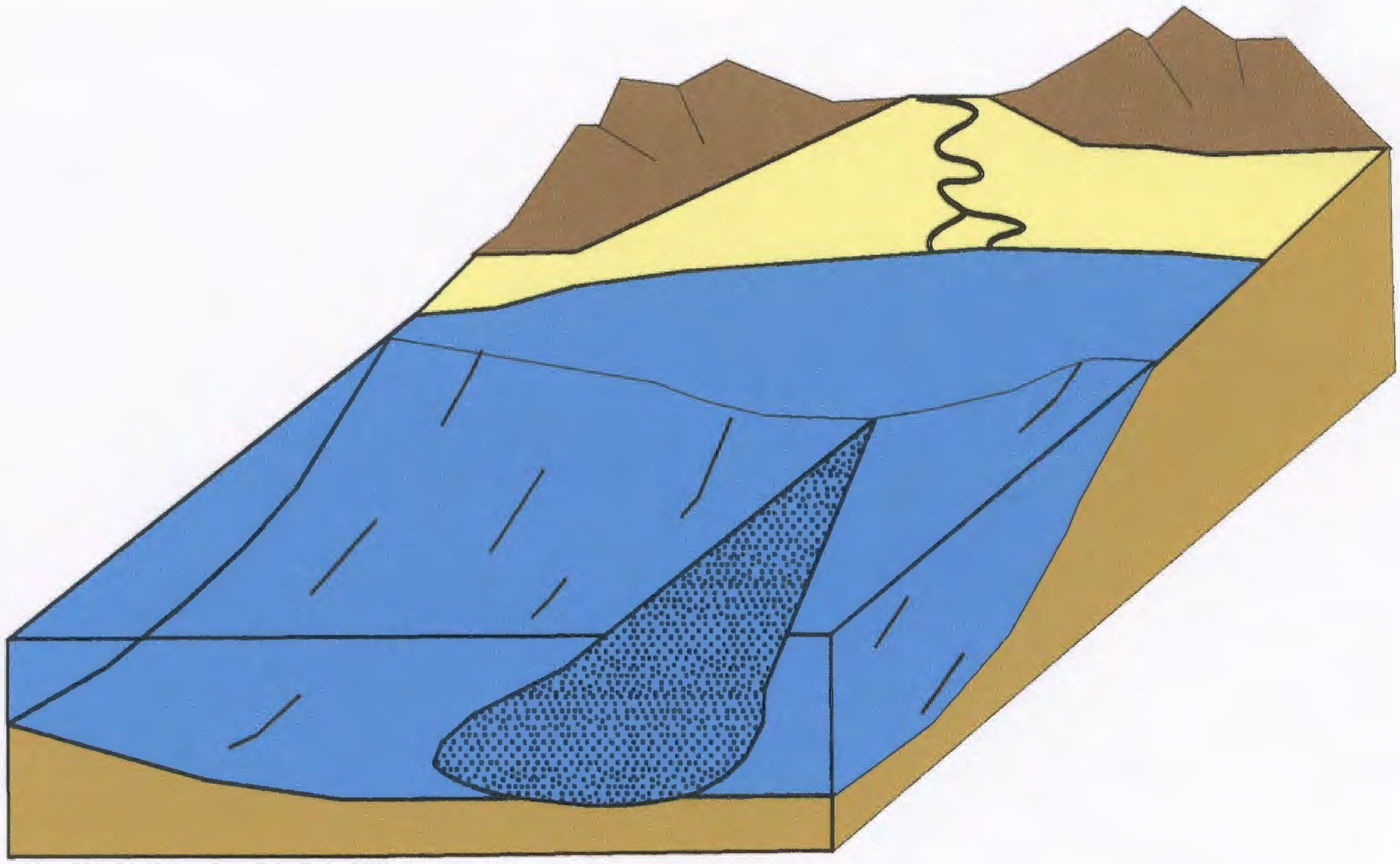


Figure 7.3: Depositional model for the Blow Me Down Brook formation during a transgressive systems tract. During this stage sediments are transported downslope long distances from the nearshore to the deep marine basin. Feldspar grains within these sands tend to be destroyed due to intense reworking of the sediment.

Chapter 8

Conclusions

8.1 Key Conclusions

The Blow Me Down Brook formation is located structurally in the intermediate thrust sheet of the Humber Arm Allochthon. The formation may be conformably underlain by the Fox Island River Volcanics, and overlain by the Northern Head Group. At least part of the Blow Me Down Brook formation is considered lower Cambrian; the trace fossil *Oldhamia* is commonly found in shaly strata from the middle of the formation (Lindholm and Casey, 1989). Based on the similarities in lithology, the lower strata of the Blow Me Down Brook formation may be equivalent to the Summerside formation; the more quartzose upper part of the Blow Me Down Brook formation may be equivalent to the Irishtown formation and possibly to the autochthonous Hawke Bay sandstone (Figure 8.1).

The study of this area has identified a significant extension of Blow Me Down Brook formation around Fox Island River and Cache Valley that was previously mapped as mélange. From mapping and measuring strata 6 subunits are described within the Blow Me Down Brook formation and informally named A, B, C, D, E and F. Unit A is composed of massive red shales overlying the Fox Island River Volcanics. Unit B consists of greenish grey sublitharenites to red hematitic sublitharenites, interbedded with

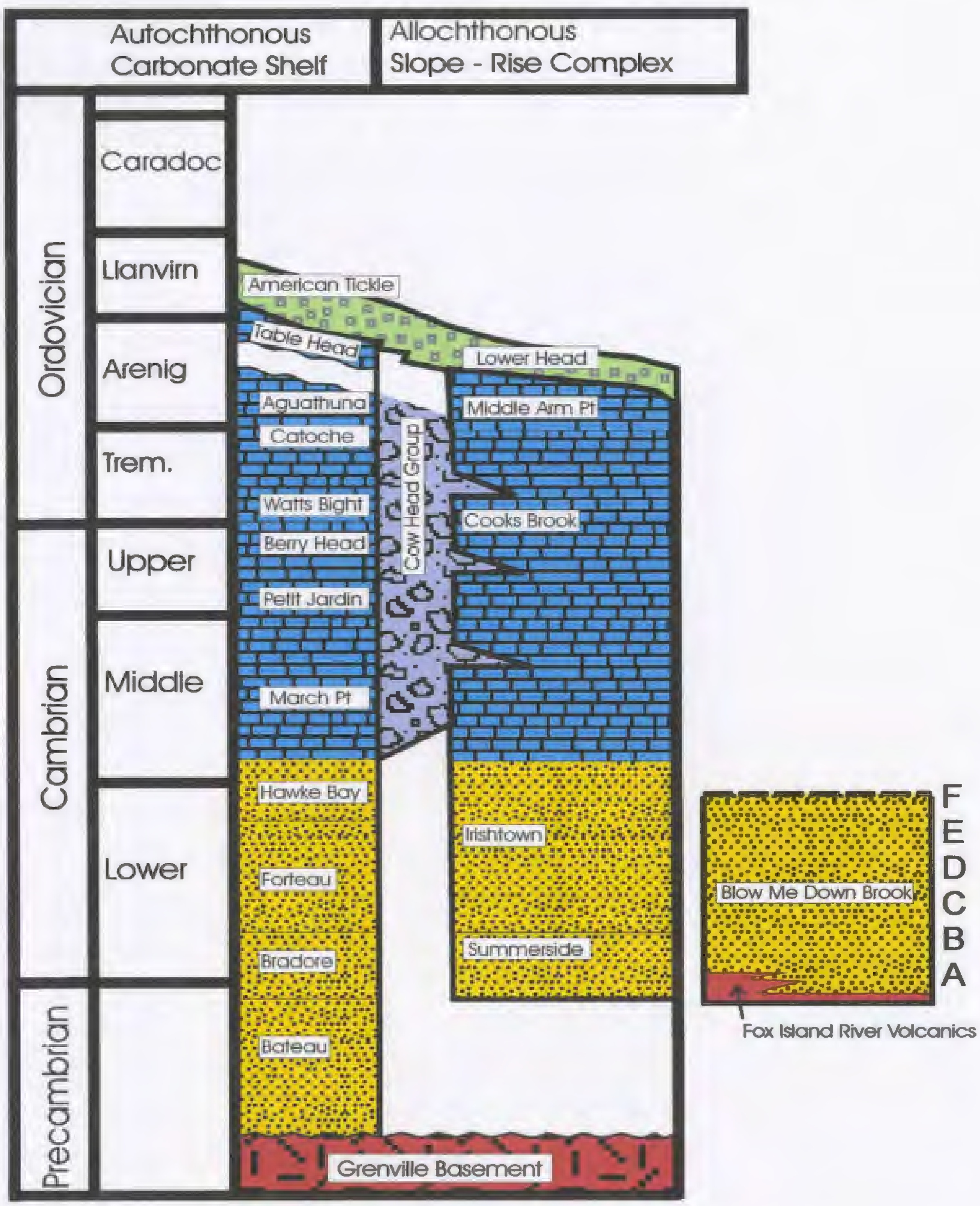


Figure 8.1: Autochthonous and allochthonous stratigraphic columns for the Humber Arm Area, with the Blow Me Down Brook formation as a more distal equivalent to the Summerside and Irishtown formations (modified from Lindholm and Casey, 1990).

thin black, green and red shales. The first *Oldhamia* traces are located in the upper black shales of Unit B. Unit C is a pebble to boulder conglomerate, which shows little to no grading, and tends to be disorganized. Unit D of the formation is greenish grey sandstone which grades from subarkose to quartzose sublitharenite; it is interbedded with intervals of red, green and black shale, that commonly hosts *Oldhamia* traces. Unit E is massive, thick red micaceous shale, similar to Unit A of the formation, but commonly seen over unit D. Unit F is the highest subunit of the Blow Me Down Brook formation. It consists of thick quartzose sandstones interbedded with intervals of black shale, which are devoid of trace fossils.

Unit F has a strong petroliferous odor and abundant hydrocarbon staining; in one case it still hosts live oil. In the coastal sections this unit is always in close proximity with the calcarenite of the Northern Head Group. In the Breached Reservoir section the Northern Head Group contains 'greasy' black shales, which are a likely source for the hydrocarbons in the overlying Blow Me Down Brook formation.

The Breached Reservoir section may be used as a model for plays in the allochthonous strata. A potential source rock within the Northern Head Group was tested to yield a TOC value over 2% and a hydrogen index over 200 (Fowler, M., 2005 pers. comm.). The coarse to granular Unit F sandstone was folded into an antiformal trap, and may well act as reservoir. Structurally overlying these porous Unit F sandstones are the red and black shales of Unit E, which may prove to be an excellent seal.

The Blow Me Down Brook formation is interpreted to be a deep marine deposit, formed on a rifted continental margin. Paleoflow measurements taken at numerous locations suggest a southerly trend, possibly down the axis of a graben. Channels, dewatering structures, conglomeratic units and partial Bouma sequences support the submarine fan interpretation. However, it is likely that the lower units A and B were deposited in a shallower marine setting; less mature rocks and an abundance of feldspar indicate proximity to a granitic source. In contrast, the upper units C, D, E and F contain more mature quartzose sandstones and were likely deposited in a deeper marine setting.

8.2 Recommendations

The exact age of the Blow Me Down Brook formation or underlying Fox Island Volcanics is not well constrained. It is known that the Blow Me Down Brook formation is at least Early Cambrian in age, based on *Oldhamia* occurrences; but it may in fact extend into the Ediacaran. It would be beneficial to date the underlying Fox Island Volcanics to help constrain the formation age. So too, additional geochemistry should be completed on the informal units of the Blow Me Down Brook formation to test their age, and composition to better define the contacts.

The study focused on the Blow Me Down Brook formation along the Gulf of St. Lawrence, southern Bay of Islands, and to the north of Fox Island River. Further study on the north side of the Bay of Islands on correlative sandstones to the Blow Me Down Brook formation may lead to a greater understanding of the regional relationships to with Summerside and Irishtown formations. Is the Blow Me Down Brook formation a distal equivalent of the Summerside and Irishtown formations?

Adjacent to the field study area in Port au Port Bay, seismic data has been collected, and offshore wells have been drilled. Since the Blow Me Down Brook formation is now known to serve as a hydrocarbon reservoir, it may be beneficial to look at seismic data, to explore the extent of this formation in the offshore. Within the study area the Breached Reservoir section near Sluice Brook is an excellent onshore model for a possible offshore play in the area.

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Appendix A

Point Count Data

Waterfall Section

	EG W01	EG 016	EG 019	EG 022A	EG 022A	EG 147
Quartz (Mono)	175	250	255	243	250	240
Quartz (Poly)	0	1	2	0	0	5
Plag	2	1	1	1	1	5
K-Feld	0	0	1	0	0	0
Rock Frag	0	0	0	0	0	0
Volcanic Frag	0	0	0	0	0	0
Sedimentary Frag	0	0	2	0	0	0
Mica	5	10	7	2	3	7
Opaque	0	9	22	0	2	31
Matrix	0	0	3	0	0	0
Cement	120	15	12	32	13	27
Porosity	0	0	0	1	0	0
Chert	0	0	0	0	0	0
Quartz total	175	251	257	243	250	245
Feldspar total	2	1	2	1	1	5
Lithic total	5	19	31	2	5	38
Totals	182	271	290	246	256	288
%Quartz	96.15385	92.61993	88.62069	98.78049	97.65625	85.06944
%Feldspar	1.098901	0.369004	0.689655	0.406504	0.390625	1.736111
%Lithic	2.747253	7.01107	10.68966	0.813008	1.953125	13.19444
Qm	175	250	255	243	250	240
F	0	0	0	1	0	0
Lt	5	20	33	2	5	43
%Qm	96.15385	92.25092	87.93103	98.78049	97.65625	83.33333
%F	0	0	0	0.406504	0	0
%Lt	2.747253	7.380074	11.37931	0.813008	1.953125	14.93056

Deadmans North

	EG 045	EG 046	EG 047	EG 049	EG 052	EG 054b
Quartz (Mono)	213	222	208	235	157	110
Quartz (Poly)	21	12	11	1	0	0
Plag	1	2	3	6	1	0
K-Feld	9	6	2	2	3	0
Rock Frag	0	1	0	0	0	0
Volcanic Frag	0	0	0	0	0	0
Sedimentary Frag	2	0	0	0	0	0
Mica	12	21	8	25	23	8
Opaque	6	2	2	0	0	0
Matrix	16	26	30	29	23	0
Cement	29	11	48	8	101	200
Porosity	0	0	0	2	0	1
Chert	0	0	0	4	0	2
Quartz total	234	234	219	236	157	110
Feldspar total	10	8	5	8	4	0
Lithic total	20	24	10	29	23	10
Totals	264	266	234	273	184	120
%Quartz	88.63636	87.96992	93.58974	86.44689	85.32609	91.66667
%Feldspar	3.787879	3.007519	2.136752	2.930403	2.173913	0
%Lithic	7.575758	9.022556	4.273504	10.62271	12.5	8.333333
Qm	213	222	208	235	157	110
F	0	0	0	6	0	3
Lt	41	36	21	30	23	10
%Qm	80.68182	83.45865	88.88889	86.08059	85.32609	91.66667
%F	0	0	0	2.197802	0	2.5
%Lt	15.5303	13.53383	8.974359	10.98901	12.5	8.333333

Deadman's North

	EG 058	EG 059	EG 068	EG 070	EG 072	EG 073
Quartz (Mono)	147	231	208	205	148	204
Quartz (Poly)	14	4	16	7	5	8
Plag	3	7	1	6	5	2
K-Feld	2	3	1	2	1	7
Rock Frag	0	0	0	0	0	0
Volcanic Frag	0	0	0	0	0	0
Sedimentary Frag	8	0	0	0	0	0
Mica	7	43	24	20	53	20
Opaque	4	1	2	2	6	2
Matrix	0	9	51	14	67	64
Cement	127	5	0	8	0	4
Porosity	0	0	1	6	0	0
Chert	0	6	0	36	25	0
Quartz total	161	235	224	212	153	212
Feldspar total	5	10	2	8	6	9
Lithic total	19	50	26	58	84	22
Totals	185	295	252	278	243	243
%Quartz	87.02703	79.66102	88.88889	76.25899	62.96296	87.2428
%Feldspar	2.702703	3.389831	0.793651	2.877698	2.469136	3.703704
%Lithic	10.27027	16.94915	10.31746	20.86331	34.5679	9.053498
Qm	147	231	208	205	148	204
F	0	6	1	42	25	0
Lt	33	54	42	65	89	30
%Qm	79.45946	78.30508	82.53968	73.74101	60.90535	83.95062
%F	0	2.033898	0.396825	15.10791	10.28807	0
%Lt	17.83784	18.30508	16.66667	23.38129	36.62551	12.34568

Deadman's North

	EG 119	EG 120	EG 121	EG 122	EG 128	EG 130
Quartz (Mono)	200	245	230	236	200	205
Quartz (Poly)	20	12	8	0	3	1
Plag	5	8	6	0	0	0
K-Feld	10	8	6	3	9	1
Rock Frag	0	0	0	0	0	0
Volcanic Frag	0	0	0	0	0	0
Sedimentary Frag	0	0	0	0	0	0
Mica	2	11	15	16	16	5
Opaque	4	0	2	2	0	2
Matrix	1	9	22	33	95	47
Cement	80	21	10	9	0	50
Porosity	9	2	3	4	2	0
Chert	0	0	0	0	0	0
Quartz total	220	257	238	236	203	206
Feldspar total	15	16	12	3	9	1
Lithic total	6	11	17	18	16	7
Totals	241	284	267	257	228	214
%Quartz	91.28631	90.49296	89.13858	91.82879	89.03509	96.26168
%Feldspar	6.224066	5.633803	4.494382	1.167315	3.947368	0.46729
%Lithic	2.489627	3.873239	6.367041	7.003891	7.017544	3.271028
Qm	200	245	230	236	200	205
F	9	2	3	4	2	0
Lt	26	23	25	18	19	8
%Qm	82.98755	86.26761	86.14232	91.82879	87.7193	95.79439
%F	3.73444	0.704225	1.123596	1.55642	0.877193	0
%Lt	10.78838	8.098592	9.363296	7.003891	8.333333	3.738318

Deadman's North

	EG 131	EG 136
Quartz (Mono)	170	195
Quartz (Poly)	7	0
Plag	5	6
K-Feld	0	6
Rock Frag	0	0
Volcanic Frag	0	0
Sedimentary Frag	1	0
Mica	34	21
Opaque	2	5
Matrix	75	68
Cement	2	3
Porosity	16	0
Chert	0	3
Quartz total	177	195
Feldspar total	5	12
Lithic total	37	29
Totals	219	236
%Quartz	80.82192	82.62712
%Feldspar	2.283105	5.084746
%Lithic	16.89498	12.28814
Qm	170	195
F	16	3
Lt	44	29
%Qm	77.62557	82.62712
%F	7.305936	1.271186
%Lt	20.09132	12.28814

Molly Ann North

	EG 150	EG 157	EG 163	EG 166B	EG 168	EG 170
Quartz (Mono)	95	130	258	270	112	131
Quartz (Poly)	0	0	1	10	11	1
Plag	0	0	0	1	5	6
K-Feld	0	0	0	4	30	20
Rock Frag	0	0	0	0	0	0
Volcanic Frag	0	0	0	0	0	0
Sedimentary Frag	0	0	0	0	8	1
Mica	0	10	2	2	0	1
Opaque	0	0	1	3	3	27
Matrix	0	0	50	1	9	12
Cement	205	160	1	2	123	106
Porosity	0	0	4	10	2	0
Chert	0	0	0	0	2	0
Quartz total	95	130	259	280	123	132
Feldspar total	0	0	0	5	35	26
Lithic total	0	10	3	5	13	29
Totals	95	140	262	290	171	187
%Quartz	100	92.85714	98.85496	96.55172	71.92982	70.58824
%Feldspar	0	0	0	1.724138	20.46784	13.90374
%Lithic	0	7.142857	1.145038	1.724138	7.602339	15.50802
Qm	95	130	258	270	112	131
F	0	0	4	10	4	0
Lt	0	10	4	15	24	30
%Qm	100	92.85714	98.47328	93.10345	65.49708	70.05348
%F	0	0	1.526718	3.448276	2.339181	0
%Lt	0	7.142857	1.526718	5.172414	14.03509	16.04278

Molly Ann North

	EG 171	EG 175	EG 180	EG 181	EG 184	EG 186	EG 188
Quartz (Mono)	255	233	152	165	228	256	288
Quartz (Poly)	3	0	0	1	0	1	9
Plag	0	1	1	1	3	0	0
K-Feld	0	0	0	0	4	1	0
Rock Frag	0	0	0	0	0	1	0
Volcanic Frag	0	0	0	0	0	0	0
Sedimentary Frag	0	0	0	1	2	0	0
Mica	5	2	6	7	13	0	3
Opaque	0	1	5	2	0	0	0
Matrix	21	16	0	0	41	14	0
Cement	26	84	146	140	15	1	6
Porosity	1	1	0	0	0	32	6
Chert	0	0	0	0	0	0	0
Quartz total	258	233	152	166	228	257	297
Feldspar total	0	1	1	1	7	1	0
Lithic total	5	3	11	10	15	1	3
Totals	263	237	164	177	250	259	300
%Quartz	98.09886	98.3122	92.68293	93.78531	91.2	99.2278	99
%Feldspar	0	0.42194	0.609756	0.564972	2.8	0.3861	0
%Lithic	1.901141	1.26582	6.707317	5.649718	6	0.3861	1
Qm	255	233	152	165	228	256	288
F	1	1	0	0	0	32	6
Lt	8	3	11	11	15	2	12
%Qm	96.95817	98.3122	92.68293	93.22034	91.2	98.8417	96
%F	0.380228	0.42194	0	0	0	12.35521	2
%Lt	3.041825	1.26582	6.707317	6.214689	6	0.772201	4

Molly Ann North

	EG 193
Quartz (Mono)	251
Quartz (Poly)	0
Plag	0
K-Feld	0
Rock Frag	0
Volcanic Frag	0
Sedimentary Frag	0
Mica	2
Opaque	0
Matrix	3
Cement	16
Porosity	41
Chert	0
Quartz total	251
Feldspar total	0
Lithic total	2
Totals	253
%Quartz	99.20949
%Feldspar	0
%Lithic	0.790514
Qm	251
F	41
Lt	2
%Qm	99.20949
%F	16.20553
%Lt	0.790514

Molly Ann South

	EG 117	EG 210	EG 211	EG 214	EG 215	EG 218
Quartz (Mono)	103	258	230	196	261	262
Quartz (Poly)	26	0	0	0	3	1
Plag	0	0	3	4	1	1
K-Feld	0	3	3	1	4	1
Rock Frag	0	0	0	0	0	0
Volcanic Frag	0	0	0	0	0	0
Sedimentary Frag	9	0	2	1	1	0
Mica	4	10	20	11	4	3
Opaque	0	0	2	1	0	2
Matrix	0	6	35	92	11	15
Cement	37	0	12	4	6	18
Porosity	31	35	11	1	9	1
Chert	0	0	0	0	0	0
Quartz total	129	258	230	196	264	263
Feldspar total	0	3	6	5	5	2
Lithic total	13	10	24	13	5	5
Totals	142	271	260	214	274	270
%Quartz	90.84507	95.20295	88.46154	91.58879	96.35036	97.40741
%Feldspar	0	1.107011	2.307692	2.336449	1.824818	0.740741
%Lithic	9.15493	3.690037	9.230769	6.074766	1.824818	1.851852
Qm	103	258	230	196	261	262
F	31	35	11	1	9	1
Lt	39	10	24	13	8	6
%Qm	72.53521	95.20295	88.46154	91.58879	95.25547	97.03704
%F	21.83099	12.91513	4.230769	0.46729	3.284672	0.37037
%Lt	27.46479	3.690037	9.230769	6.074766	2.919708	2.222222

Molly Ann South

	EG 219	EG 222	EG 224	EG 226	EG 230
Quartz (Mono)	274	238	305	299	274
Quartz (Poly)	0	0	1	1	0
Plag	0	1	0	0	1
K-Feld	1	0	0	0	1
Rock Frag	0	0	0	0	0
Volcanic Frag	0	0	0	0	0
Sedimentary Frag	0	0	0	0	0
Mica	7	2	4	3	11
Opaque	0	1	0	0	1
Matrix	11	3	3	1	4
Cement	12	24	2	3	5
Porosity	2	40	0	9	12
Chert	0	0	3	0	1
Quartz total	274	238	306	300	274
Feldspar total	1	1	0	0	2
Lithic total	7	3	7	3	13
Totals	282	242	313	303	289
%Quartz	97.1631	98.3471	97.76358	99.0099	94.80969
%Feldspar	0.35461	0.41322	0	0	0.692042
%Lithic	2.48227	1.23967	2.236422	0.990099	4.49827
Qm	274	238	305	299	274
F	2	40	3	9	13
Lt	7	3	8	4	13
%Qm	97.1631	98.3471	97.44409	98.67987	94.80969
%F	0.70922	16.5289	0.958466	2.970297	4.49827
%Lt	2.48227	1.23967	2.555911	1.320132	4.49827

Broad Cove

	EG 264	EG 267	EG 268	EG 269	EG 271	EG 274
Quartz (Mono)	118	167	177	227	201	98
Quartz (Poly)	0	8	9	4	5	1
Plag	2	0	1	2	2	3
K-Feld	0	1	0	0	0	1
Rock Frag	1	0	0	1	0	1
Volcanic Frag	0	0	0	0	0	0
Sedimentary Frag	0	0	0	1	0	0
Mica	8	33	7	11	5	7
Opaque	3	3	2	1	0	2
Matrix	8	25	42	28	29	1
Cement	160	79	47	22	71	201
Porosity	14	1	23	13	4	0
Chert	0	0	5	0	2	7
Quartz total	118	175	186	231	206	99
Feldspar total	2	1	1	2	2	4
Lithic total	12	36	14	14	7	17
Totals	132	212	201	247	215	120
%Quartz	89.39394	82.54717	92.53731	93.52227	95.81395	82.5
%Feldspar	1.515152	0.471698	0.497512	0.809717	0.930233	3.333333
%Lithic	9.090909	16.98113	6.965174	5.668016	3.255814	14.16667
Qm	118	167	177	227	201	98
F	14	1	28	13	6	7
Lt	12	44	23	18	12	18
%Qm	89.39394	78.77358	88.0597	91.90283	93.48837	81.66667
%F	10.60606	0.471698	13.93035	5.263158	2.790698	5.833333
%Lt	9.090909	20.75472	11.44279	7.287449	5.581395	15

Broad Cove

	EG 275	EG 276	EG 279	EG 280	EG 281
Quartz (Mono)	203	201	162	191	229
Quartz (Poly)	8	28	25	5	5
Plag	2	6	2	9	1
K-Feld	7	21	23	19	16
Rock Frag	0	0	0	0	0
Volcanic Frag	0	0	0	0	0
Sedimentary Frag	0	0	2	0	0
Mica	18	7	12	4	10
Opaque	2	2	0	1	0
Matrix	33	29	47	3	13
Cement	24	12	25	84	30
Porosity	12	9	5	5	5
Chert	0	3	1	2	4
Quartz total	211	229	187	196	234
Feldspar total	9	27	25	28	17
Lithic total	20	12	15	7	14
Totals	240	268	227	231	265
%Quartz	87.9167	85.4478	82.37885	84.84848	88.30189
%Feldspar	3.75	10.0746	11.01322	12.12121	6.415094
%Lithic	8.33333	4.47761	6.60793	3.030303	5.283019
Qm	203	201	162	191	229
F	12	12	6	7	9
Lt	28	40	40	12	19
%Qm	84.5833	75	71.36564	82.68398	86.41509
%F	5	4.47761	2.643172	3.030303	3.396226
%Lt	11.6667	14.9254	17.62115	5.194805	7.169811

Bluff Head

	EG 255	EG 257	EG 258	EG 05 60	EG 05 62	EG 05 65
Quartz (Mono)	237	210	194	238	234	236
Quartz (Poly)	1	25	26	4	4	3
Plag	6	3	3	10	4	4
K-Feld	19	14	16	11	7	12
Rock Frag	0	0	0	0	1	0
Volcanic Frag	0	0	0	0	0	0
Sedimentary Frag	0	1	0	0	0	0
Mica	17	16	10	16	10	11
Opaque	1	0	1	2	3	1
Matrix	14	18	42	11	38	39
Cement	7	0	0	4	0	6
Porosity	3	24	12	10	0	0
Chert	5	0	0	2	0	0
Quartz total	238	235	220	242	238	239
Feldspar total	25	17	19	21	11	16
Lithic total	23	17	11	20	14	12
Totals	286	269	250	283	263	267
%Quartz	83.21678	87.36059	88	85.51237	90.4943	89.51311
%Feldspar	8.741259	6.319703	7.6	7.420495	4.18251	5.992509
%Lithic	8.041958	6.319703	4.4	7.067138	5.323194	4.494382
Qm	237	210	194	238	234	236
F	8	24	12	12	0	0
Lt	24	42	37	24	18	15
%Qm	82.86713	78.06691	77.6	84.09894	88.97338	88.38951
%F	2.797203	8.921933	4.8	4.240283	0	0
%Lt	8.391608	15.61338	14.8	8.480565	6.844106	5.617978

Bluff Head

	EG 05 66	EG 05 67	EG 05 68
Quartz (Mono)	216	240	235
Quartz (Poly)	13	1	3
Plag	7	11	4
K-Feld	16	2	12
Rock Frag	0	0	0
Volcanic Frag	0	0	0
Sedimentary Frag	0	1	0
Mica	9	10	18
Opaque	2	1	6
Matrix	30	24	23
Cement	12	17	12
Porosity	0	3	1
Chert	0	0	0
Quartz total	229	241	238
Feldspar total	23	13	16
Lithic total	11	12	24
Totals	263	266	278
%Quartz	87.072243	90.6015	85.61151
%Feldspar	8.7452471	4.887218	5.755396
%Lithic	4.1825095	4.511278	8.633094
Qm	216	240	235
F	0	3	1
Lt	24	13	27
%Qm	82.129278	90.22556	84.53237
%F	0	1.12782	0.359712
%Lt	9.1254753	4.887218	9.71223

Broad Cove South

	ESG 007	ESG 008
Quartz (Mono)	181	196
Quartz (Poly)	5	3
Plag	7	2
K-Feld	34	17
Rock Frag	0	0
Volcanic Frag	0	0
Sedimentary Frag	3	0
Mica	34	42
Opaque	3	4
Matrix	34	33
Cement	1	4
Porosity	9	0
Chert	0	0
Quartz total	186	199
Feldspar total	41	19
Lithic total	40	46
Totals	267	264
%Quartz	69.66292	75.37879
%Feldspar	15.35581	7.19697
%Lithic	14.98127	17.42424
Qm	181	196
F	9	0
Lt	45	49
%Qm	67.79026	74.24242
%F	3.370787	0
Lt	16.85393	18.56061

Woods Island

	EG 05 12	EG05 16	EG 05 17	EG 05 19	EG 05 21	EG 05 22	EG 05 27
Quartz (Mono)	210		24	211	236	200	249
Quartz (Poly)	15		1	5	6	7	1
Plag	0		0	0	0	5	2
K-Feld	21		4	18	24	8	26
Rock Frag	0		0	0	0	0	0
Volcanic Frag	0		0	0	0	0	0
Sedimentary Frag	1		1	0	1	2	0
Mica	21		1	12	10	17	12
Opaque	2		0	5	3	4	3
Matrix	34		2	46	23	7	13
Cement	1		2	4	2	17	3
Porosity	0		0	0	0	3	0
Chert	0		0	0	1	0	0
Quartz total	225		25	216	242	207	250
Feldspar total	21		4	18	24	13	28
Lithic total	24		2	17	15	23	15
Totals	270		31	251	281	243	293
%Quartz	83.3333		80.6452	86.0558	86.121	85.1852	85.3242
%Feldspar	7.77778		12.9032	7.17131	8.54093	5.34979	9.55631
%Lithic	8.88889		6.45161	6.77291	5.33808	9.46502	5.11945
Qm	210		24	211	236	200	249
F	21		4	18	24	13	28
Lt	39		3	22	21	30	16
%Qm	77.7778		77.4194	84.0637	83.9858	82.3045	84.9829
%F	7.77778		12.9032	7.17131	8.54093	5.34979	9.55631
Lt	14.4444		9.67742	8.76494	7.47331	12.3457	5.46075

Woods Island

	EG 05 28	EG 05 31
Quartz (Mono)	115	227
Quartz (Poly)	8	1
Plag	2	2
K-Feld	15	14
Rock Frag	0	0
Volcanic Frag	0	0
Sedimentary Frag	2	0
Mica	11	25
Opaque	3	2
Matrix	45	39
Cement	3	3
Porosity	0	0
Chert	0	0
Quartz total	123	228
Feldspar total	17	16
Lithic total	16	27
Totals	156	271
%Quartz	78.84615	84.1328
%Feldspar	10.89744	5.90406
%Lithic	10.25641	9.9631
Qm	115	227
F	17	16
Lt	24	28
%Qm	73.71795	83.7638
%F	10.89744	5.90406
Lt	15.38462	10.3321

Breached Reservoir

	EG 091	EG 092	EG 097	EG 099	EG 100	EG 102
Quartz (Mono)	103	22	147	269	255	248
Quartz (Poly)	26	0	0	3	3	6
Plag	0	1	1	0	1	1
K-Feld	0	0	0	0	0	1
Rock Frag	0	0	0	0	33	0
Volcanic Frag	0	0	0	0	0	0
Sedimentary Frag	9	0	2	0	0	0
Mica	4	1	2	2	13	8
Opaque	0	14	2	0	0	0
Matrix	0	0	1	0	0	40
Cement	37	166	160	0	2	1
Porosity	31	5	0	37	0	2
Chert	0	0	0	0	0	0
Quartz total	129	22	147	272	258	254
Feldspar total	0	1	1	0	1	2
Lithic total	13	15	6	2	46	8
Totals	142	38	154	274	305	264
%Quartz	90.84507	57.89474	95.45455	99.27007	84.59016	96.21212
%Feldspar	0	2.631579	0.649351	0	0.327869	0.757576
%Lithic	9.15493	39.47368	3.896104	0.729927	15.08197	3.030303
Qm	103	22	147	269	255	248
F	31	5	0	37	0	2
Lt	39	15	6	5	49	14
%Qm	72.53521	57.89474	95.45455	98.17518	83.60656	93.93939
%F	21.83099	13.15789	0	13.50365	0	0.757576
Lt	27.46479	39.47368	3.896104	1.824818	16.06557	5.30303