PALEOENVIRONMENTAL AND TECTONOSTRATIGRAPHIC EVOLUTION OF THE WEST CUMBERLAND BASIN OF NOVA SCOTIA AND NEW BRUNSWICK DURING THE UPPER MISSISSIPPIAN

By

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May 19, 2010

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Dedicated to my parents, Rejane and Reid McLeod and my grandmother Ina McLeod for their never ending love, support and encouragement

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ABSTRACT

Jason R. McLeod

Paleoenvironmental and tectonostratigraphic evolution of the west Cumberland Basin of Nova Scotia and New Brunswick during the Upper Mississippian

May, 2010

The Cumberland Basin, which spans the provinces of Nova Scotia and New Brunswick, contains one of the most complete stratigraphic records of upper Mississippian (Viséan – Namurian) strata within the Maritimes Basin. The paleoenvironmental and tectonostratigraphic evolution of these units is here assessed, as well as lateral variations and stratigraphic relationships between upper Mississippian units in the western half of the basin. This exercise resulted in necessary petrographic and stratigraphic correlations across the study area, and several redundancies and inconsistencies in the pre-existing stratigraphic nomenclature were identified and informally amended based on equivalencies and precedence. Three source areas were identified in the west Cumberland Basin during the upper Mississippian, and a paleogeographic model was created for that interval based on geophysical, paleocurrent, provenance and facies distribution data.

ACKNOWLEDGMENTS

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1.0 INTRODUCTION

The Cumberland Basin is one of several sub-basins of the composite Maritimes Basin of Atlantic Canada (van de Poll and Ryan, 1985; Ryan and Boehner, 1994; St. Peter, 1993). The Maritimes Basin extends from southwestern New Brunswick to the continental margin of the eastern Grand Banks and from offshore Labrador to the southern Grand Banks, encompassing much of New Brunswick and Nova Scotia (Gibling et al., 2008) (Figure 1.1).

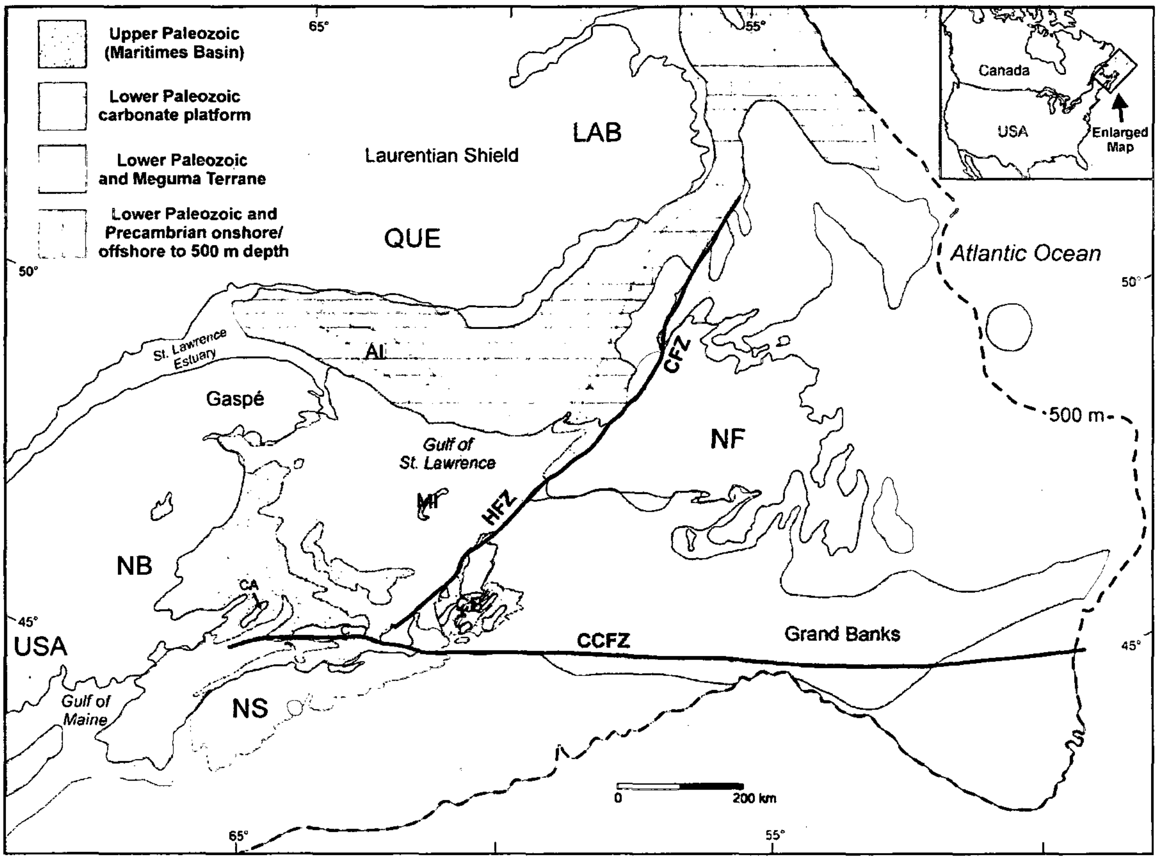


Figure 1.1 Lateral extent of the Maritimes Basin (in red) with associated structures: CCFZ – Cobequid/Chedabucto Fault Zone; CFZ – Cabot Fault Zone; HFZ – Hollow Fault Zone; CA – Caledonia Highlands; C – Cobequid Highlands. Modified from Gibling et al., 2008).

Like all sub-basins of the Maritimes Basin, the origins of the Cumberland Basin are associated with transtensional tectonics in the aftermath of the Middle Devonian Acadian Orogeny, and during the ongoing closure of the Rheic Ocean in Late Devonian to Carboniferous times (Calder, 1998; Jutras et al., 2003, Gibling et al., 2008). It includes rocks that are exposed along the Bay of Fundy shores of New Brunswick and Nova Scotia, and it covers an area of approximately 3,600 km^2 (Figure 1.2) (Ryan et al., 1987). It is one of the only sub-basins of the Maritimes Basin that shows a fairly complete and preserved stratigraphic succession of sedimentation through the entire period of basin evolution (Ryan and Boehner, 1994). However, most studies in the basin have focused on Pennsylvanian strata, the fossiliferous Joggins Formation especially, whereas the underlying Mississippian strata had never been thoroughly studied prior to this study. As they bear all the elements to provide petroleum reservoirs (Tournaisian oil shales, Viséan carbonates and evaporites, several thick, coarse clastic units, and post-sedimentary brittle faulting), a more detailed study of this interval is warranted, especially given the fact that petroleum resources are currently being exploited from similar Mississippian strata in the nearby Moncton Basin.

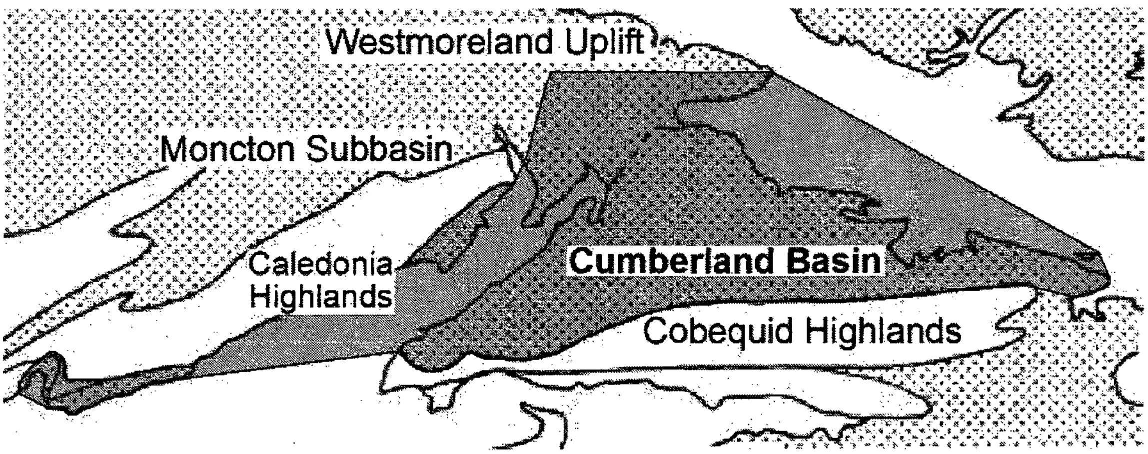


Figure 1.2 Lateral extent of the Cumberland Basin. Modified from Ryan and Boehner (1994).

1.1 Objectives

The primary focus of this research project is to determine the evolution of the upper Viséan to early Namurian units in the Cumberland Basin, which include the Windsor (Bell 1929), Percé (Jutras and Prichonnet, 2005) and Mabou (Belt, 1964) groups, and to generate a paleogeographical and paleoenvironmental model for this area at the time, between 340 and 323 million years ago. This study also includes an effort at rationalizing the stratigraphic subdivisions and nomenclatures by looking at how the stratigraphy of Nova Scotia for this interval correlates with that of New Brunswick. Any redundancies and inconsistencies between Nova Scotia and New Brunswick are pointed out and amended by correlating units based on petrographic and stratigraphic equivalence, and based on precedence of formational names.

2.0 METHODS

2.1 Stratigraphic and petrographic data collection from field sites

Stratigraphic and petrographic data from Viséan to Namurian rocks were compiled from ten sites distributed within the Cumberland Basin to determine the lateral continuity and variations of the rocks of interest within the basin. The data included granulometry, colour, contact types, bed thicknesses, sedimentary structures, the presence or absence of floral and/or faunal fossilized remains, as well as post-depositional features such as pedogenic overprints, groundwater calcrete lenses, and karst. This data set was later compiled in stratigraphic columns.

2.2 Paleocurrent analysis

The collection of the majority of paleocurrent data was done using trough cross-bed orientations, where exposures allowed the three dimensions of the troughs to be assessed. Clast imbrication data were also collected, but proved to be not nearly as consistent as trough cross-bed data, and were therefore abandoned in favour of the latter.

2.3 Spore sampling

Samples of dark grey mudrocks that are rich in organic matter were collected to ascertain the age of sedimentary units through palynology. These samples were then catalogued and sent to the Geological Survey of Canada in Calgary, Alberta, to be processed and analysed by Dr. John Utting.

2.4 Thin section microscopy

Rock samples were collected from units of interest. Samples of sandstones were collected from different intervals of various units. The majority of the samples were taken from or near the centre of the basin. The samples were cut at Saint Mary's University, and sent to Gordon Brown at Dalhousie University, who prepared them for thin section microscopy analysis. The thin sections were observed using a Nikon Labophot-pol microscope.

2.5 Geophysical analysis

Gravity and magnetic data were used to help identify structures and basement highs in the study area. The geophysical data were obtained from the Geoscience Data Repository of the Geological Survey of Canada (GSC) (Canadian Geodetic Information System, 2006a,b). The data are compiled into a 200m spacing grid and are viewable using the Generic Mapping Tools of Wessel and Smith (1991).

2.6 Air photo analysis

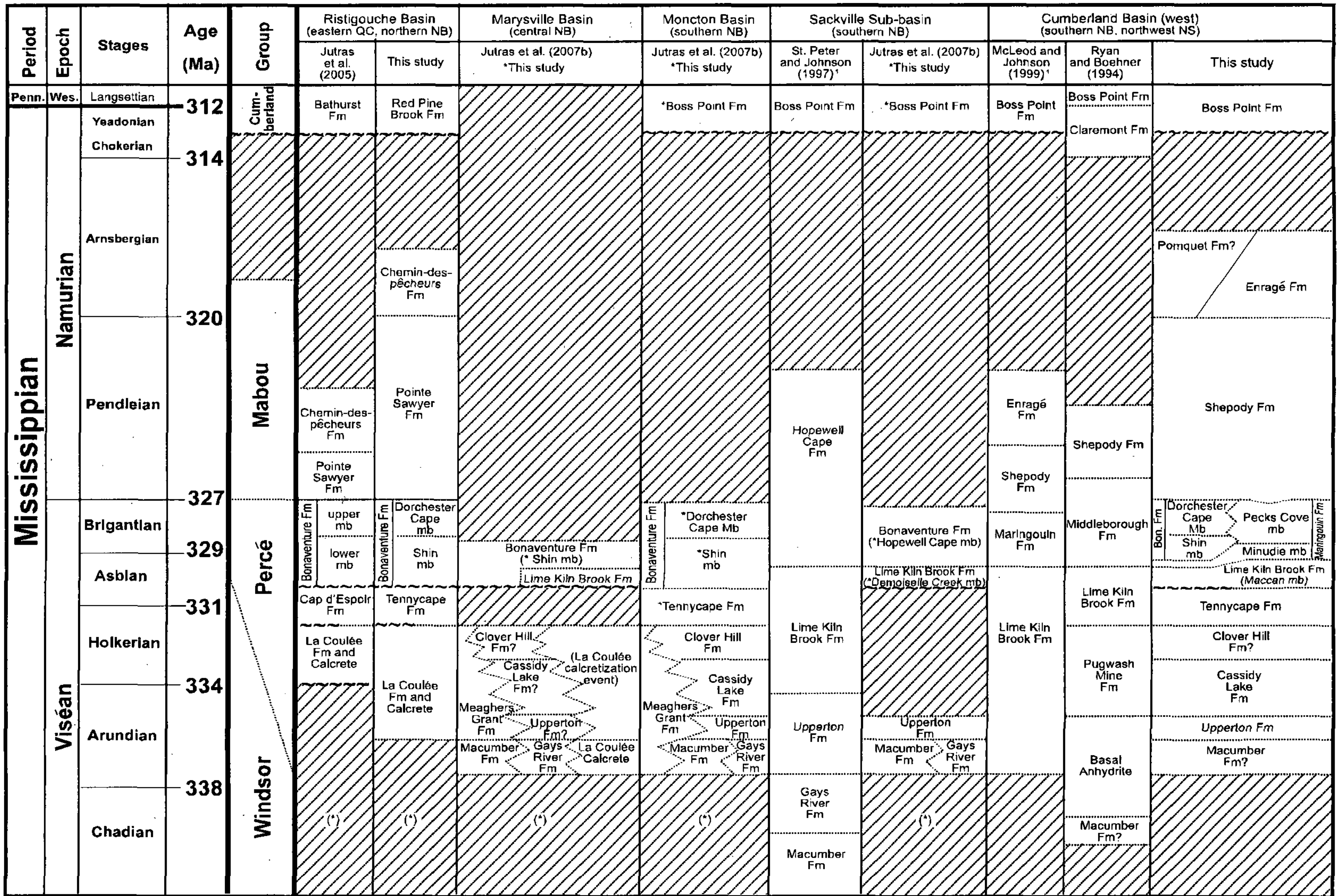
To obtain better control on the lateral continuity of units and lateral evolution of contacts, air photo analysis was performed in a zone of particular interest within the general study area.

3.0 STRATIGRAPHIC NOMENCLATURE

The Cumberland Basin succession has been subdivided into six distinct groups by Ryan and Boehner (1994), which are the Fountain Lake Group, the Horton Group, the Windsor Group, the Mabou Group, the Cumberland Group and the Pictou Group, moving up stratigraphy. In this study, a seventh group is added, the Percé Group of Jutras and Prichonnet (2005), which was formerly included within the Mabou Group by Ryan and Boehner (1994). Moreover, the base of the Cumberland Group (sensu Ryan and Boehner, 1994) is here correlated with the upper part of the Mabou Group of Belt (1964).

Various stratigraphic frameworks have been proposed for the Cumberland Basin and other sub-basins of the composite Maritimes Basin. The following figure illustrates some of the most recent frameworks proposed, as well as the framework proposed in this study (Figure 3.1). Note that the proposed framework is currently not applied by other workers in the study area, and please refer to Figure 3.1 for the correlative nomenclatures. Also, note that the introduction of new units and the abandonment of existing units in this thesis are to be formalized in an upcoming publication and are presently used only in order to facilitate the reading. In the meanwhile, the revisions should be considered informal.

The remaining chapter discusses the geological characteristics of the retained and informally introduced members and formations in the Windsor, Percé and Mabou groups, as well as their bounding units. A historical summary of each unit and equivalent units is provided for each item of stratigraphic nomenclature.



¹Age ranges based on St. Peter (2001)

Figure 3.1 Recent evolution of the stratigraphic nomenclature in selected sub-basins of the Maritimes Basin.

3.1 Units Underlying the Viséan to Namurian Successions

The basal units of the Cumberland Basin are the Middle to Upper Devonian interbedded volcanics and continental red beds of the Fountain Lake Group (Donohoe and Wallace, 1980), and the uppermost Devonian to Tournaisian fluvio-lacustrine deposits of the Horton Group (Bell, 1929) (Ryan and Boehner (1994).

3.2 Viséan to Early Namurian Successions

3.2.1 Lower Windsor Group

The Windsor Group was deposited during multiple transgression/regression cycles caused by the waxing and waning of a Gondwanan ice sheet in response to orbital forcing (Giles, 2009). The first transgression happened to be the largest in terms of inland extent. It reached as far north as Gaspé, Quebec (Jutras and Schroeder, 1999; Jutras et al., 2007b). When dealing with the deposition of the Windsor Group, it is unfortunate that there are no close modern analogues. Floral and faunal specimens collected show that the depositional environment was stressed, most likely due to a hypersaline environment. The evaporites of the Windsor Group were deposited in a relatively large epicontinental sea (Jutras et al., 2006).

Giles (1981) subdivided the marine Windsor Group into three subgroups, namely the Lower, Middle and Upper, which are characterized by a macrofaunal assemblage corresponding to respectively the A, B and C-D-E subzones of Bell (1929). According to

Utting and Giles (2004), based on macrofossils, spores and conodonts, the Lower Windsor Group is Chadian to Holkerian in age, whereas the Middle Windsor Group is Asbian, and the Upper Windsor Group is Brigantian.

According to Ryan and Boehner (1994), the Cumberland Basin of Nova Scotia includes subzones A, B, and possibly the base of C (Ryan and Boehner, 1994). Moving northward through New Brunswick, the upper sections of the Windsor Group begin to pinch out quite rapidly. In southern New Brunswick, only the Lower Windsor and the base of the Middle Windsor are present. Only the Lower Windsor is recorded in central New Brunswick, and there is no record of the Windsor Group in northern New Brunswick, although the Windsor Sea is inferred to have reached that far (Jutras et al., 2007b).

The Windsor Group within the Cumberland Basin is stratigraphically quite complex. Abrupt lateral facies changes occur frequently, and data are severely lacking in the lower portion of the Windsor due to the dearth of drill holes and outcrops (Ryan and Boehner, 1994). The Windsor Group in the Cumberland Basin consists mainly of evaporites, namely anhydrite, gypsum, halite and lesser amounts of potash, with interbedded red beds and carbonates (Boehner, 1984; Ryan and Boehner, 1994). Waldron and Rygel (2005) estimated that the original thickness of the evaporitic layers was greater than 2.5 km in the Cumberland Basin. However, due to faulting, erosion, salt migration and karst effects, evaporite successions as thin as 500 m have been recorded and are not believed to reflect true original thicknesses (Ryan and Boehner, 1994).

The Windsor Group of the Cumberland Basin is here subdivided into seven formations: the Gays River, Macumber, Upperton, Cassidy Lake, Clover Hill and

Tennycape formations, which belong to the Lower Windsor, and the Lime-kiln Brook Formation, which belongs to the Middle Windsor.

3.2.1.1 Gays River and Macumber formations (Chadian to Arundian)

The Gays River and Macumber formations (Giles et al., 1979) are the products of the first Carboniferous marine transgression to have invaded the Maritimes Basin. They are the basal unit of the Windsor Group. The Gays River Formation consists mainly of dolomitized carbonates in the Minas Basin (*sensu* Jutras et al., 2006) of Nova Scotia, including algal boundstones and bafflestones with some skeletal packstones and wackestones (Giles et al., 1979). Conversely, in the Moncton and Marysville basins of New Brunswick, the Gays River Formation is characterized by non-dolomitized carbonates that include fossiliferous algal boundstones with some bioclastic wackestones and packstones (Giles et al., 1979; McCutcheon, 1981). In the Cumberland Basin, the only exposure of the Gays River Formation is at Quaco Head, New Brunswick, at the south westernmost edge of the basin, where it is comprised of stromatolitic bindstone (Jutras et al., 2007b).

Boehner (1977) and Giles and Boehner (1982) determined that the Gays River Formation is laterally equivalent to the deeper water laminites of the Macumber Formation of Weeks (1948). The Macumber Formation is not directly observed in the Cumberland Basin (Ryan and Boehner, 1994), but it is inferred to be there based on its persistent existence throughout the Maritimes Basin and on excellent seismic reflectors seen in shot lines that were recorded within the Cumberland Basin. The unit is mainly a laminar limestone or dolostone that ranges from 1-18 m in thickness (Ryan and Boehner, 1994).

3.2.1.2 Upperton Formation (Arundian)

The Upperton beds were originally designated as the upper member (Anderle et al., 1979) of the now abandoned Upham Formation of Alcock (1938) before being upgraded to formation status by McCutcheon (1981). The Upperton Formation is characterized by stratiform nodular or mosaic anhydrite, although it is difficult at best to determine the original nature of the anhydrite since all exposed outcrops have undergone, to some degree, gypsification (McCutcheon, 1981; Ryan and Boehner, 1994). The anhydrite is interbedded with wackestone, greenish grey mudstone and fine-grained sandstone (Anderle et al., 1979; McCutcheon, 1981), as well as with some minor carbonate and possibly halite beds (Ryan and Boehner, 1994).

The overall thickness and distribution of the Upperton Formation is variable. Ryan and Boehner (1994) describe the equivalent Basal Anhydrite as ranging between 100-300 m in thickness and having a distribution that covers much of the Maritimes Basin.

3.2.1.2.1 Equivalent units

In their stratigraphic nomenclature, Ryan and Boehner (1994) place an informal Basal Anhydrite section conformably and transitionally above the Macumber Formation.

This Basal Anhydrite is correlative to the Carrolls Corner Formation (Giles and Boehner, 1982) of central Nova Scotia and the Upperton Formation (McCutcheon 1981) of New Brunswick, which has precedence.

3.2.1.3 Cassidy Lake Formation (Arundian)

The Cassidy Lake Formation (Anderle et al., 1979) is a halite-dominated unit with interbedded layers of anhydrite and lesser amounts of potash. There is also sparse grey mudstone and red beds present throughout the formation. Anderle et al. (1979) divided the Cassidy Lake Formation into four distinct members: the Basal Halite Member, the Middle Halite Member, the Potash Member and the Upper Salt Member.

The original thickness of the formation is at best difficult to ascertain due to deformation. Anderle et al. (1979) measured the maximum thickness of the Cassidy Lake Formation to be ~350m from data derived from 46 exploration holes.

3.2.1.3.1 Equivalent units

The Cassidy Lake Formation of southern New Brunswick is equivalent to the Pugwash Mine Formation of Ryan and Boehner (1994) within the Nova Scotian portion of the Cumberland Basin, and to the Stewiacke Formation (Giles and Boehner, 1982) of central Nova Scotia.

3.2.1.4 Clover Hill Formation (Arundian to Holkerian)

The Clover Hill Formation was first introduced by Anderle et al. (1979). It consists primarily of a lower anhydrite unit and an upper claystone unit. This was revised by McCutcheon (1981) who stated that an intermediate unit of salt be included within the Clover Hill Formation based on findings from the Plumweseep potash deposit, which had a substantial amount of halite separating the lower anhydrite unit from the overlying claystone unit (Figure 3.2). The anhydrite unit, according to McCutcheon (1981), is very similar to that of the Upperton Formation with the exception that the unit itself is considerably thinner (only 7-8m) than the Upperton Formation, and that it may be partially or entirely brecciated.

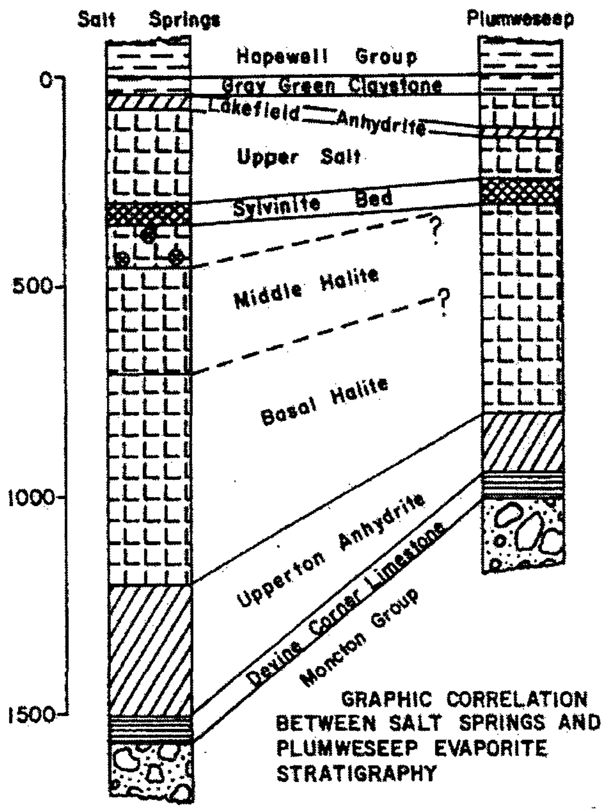


Figure 3.2 The Clover Hill Formation - Plumweseep potash deposit. Modified from Anderle et al. (1979).

Gradationally overlying the anhydrite is the halite of the Plumweseep area that reaches a maximum thickness of 25m and contains anhydrite and argillaceous interbeds (McCutcheon 1981). The claystone unit ranges from 3 to 13m in thickness, and is of a grey-green colour (Anderle et al. 1979).

3.2.1.4.1 Equivalent units

The Clover Hill Formation is probably correlative to the upper part of the Pugwash Mine Formation of Ryan and Boehner (1994), as the latter authors state that mudstone is abundant near the top of this unit.

3.2.1.5 The Tennycape Formation (Holkerian to early Asbian)

The Tennycape Formation was introduced by Weeks (1948) to designate a succession of fine red beds of varying thickness separating the Lower Windsor evaporites from the basal Middle Windsor carbonate in the Minas Basin of central Nova Scotia. Although noting that they are probably equivalent to the Tennycape Formation, Ryan and Boehner (1994) did not give formation status to that poorly constrained red bed interval. In concurrence with Weeks (1948), this interval is here assigned to the Tennycape Formation and to the top of the Lower Windsor Group as it is in part unconformable with the overlying Middle Windsor Group (Giles, 1981). An estimated 250 m of that unit underlie the basal Middle Windsor carbonate in the Cumberland Basin at the Lime-kiln Brook Quarry of Nova Scotia.

3.2.1.5.1 Equivalent units

Jutras et al. (2007b) determined that the fine red beds of the Cap d'Espoir Formation of eastern Quebec occurred as the result of an erosion event that preceded deposition of the Middle Windsor Group and correlated that unit with the Poodiac Formation (Anderle et al., 1979) of the Moncton Basin, southern New Brunswick. Both of these units are probable correlatives of the Tennycape Formation. However, what Anderle et al. (1979) referred to as the Poodiac Formation may include younger strata as well, and more work is necessary on the Viséan successions of the Moncton Basin to determine precise stratigraphic relationships with Nova Scotia and eastern Quebec for this interval. In any case, the Tennycape Formation has precedence.

3.2.2 The Middle Windsor Group

3.2.2.1 Lime-kiln Brook Formation (upper Asbian)

The Lime-kiln Brook Formation (Ryan and Boehner, 1994) is characterized by the interstratification of up to eight successions of red beds and carbonates, with lesser amounts of anhydrite, gypsum and salt (Ryan and Boehner, 1994). The fossils contained within the marine carbonates include bivalves, brachiopods, algae, cephalopods (Bell, 1944, 1958) and unidentified hollow tube fossils, as well as locally well developed oncolites and columnar algal stromatolites (Ryan and Boehner, 1994).

The thickness of the Lime-kiln Brook Formation varies greatly over the Cumberland Basin. Values range from 384 m within the Pacific Fox Harbour C-96V drill hole near Wallace, Nova Scotia, to 110 m ~50 km to the west, in the LMA88-1 drill hole at Lower Maccan, with individual carbonate intervals also thinning rapidly from east to west (Ryan and Boehner, 1994).

3.2.2.1.1 Maccan member

The informally proposed Maccan member is a succession of red mudstone (mainly) interbedded with micritic and stromatolitic limestone, anhydrite and minor red sandstone. It corresponds to the Lime-kiln Brook Formation in its type-area.

3.2.2.1.2 Demoiselle Creek member

Originally referred to as the Demoiselle Creek Beds by McCutcheon (1981), but mapped as Lime-kiln Brook Formation in recent times (eg., McLeod and Johnson, 1999b), the Middle Windsor Group succession at Hopewell Cape, NB, is characterized by much coarser red beds than in the type-area of that formation. This contrasting facies is herein informally referred to as the Demoiselle Creek member of the Lime-kiln Brook Formation. This unit is characterized and distinguished from the Maccan member by carbonates that are interbedded with red conglomerate, as opposed to red mudrock.

3.2.3 Percé Group

The Percé Group (Jutras and Prichonnet, 2005) is time-equivalent to the entire Windsor Group, but includes only continental sedimentary rocks. The type area at Percé, Quebec, includes three formations, but only the uppermost unit, the Bonaventure Formation of Logan (1846) and the finer, time-equivalent Maringouin Formation of Norman (1941) are represented in the Cumberland Basin, where they overlie Lower and Middle Windsor Group rocks.

3.2.3.1 Bonaventure Formation (Asbian to Brigantian)

The Bonaventure Formation is a thick succession of predominantly continental red beds that include red conglomerate, red breccia, red sandstone, red mudstone, pedogenic calcretes and phreatic calcrete lenses (Jutras et al., 2001, 2007a). It is virtually devoid of organic matter. In the Cumberland Basin, the Bonaventure Formation sits above the Demoiselle Creek member of the Lime-kiln Brook Formation, and a thin occurrence of Maringouin Formation mudrock separates it from the Maccan member of the Lime-kiln Brook Formation at Dorchester Cape, New Brunswick. It sits below thin lenses of grey Pendleian mudrock at Dorchester Cape, and disconformably below grey Pendleian conglomerates of the Pointe Sawyer Formation (Mabou Group) in the Gaspé area of Quebec (Jutras et al., 2001). The Bonaventure Formation in the Cumberland Basin is here informally subdivided as the Hopewell Cape, Shin and Dorchester Cape members.

3.2.3.1.1 Hopewell Cape member

The informally proposed Hopewell Cape member is a monotonous planar-bedded succession of red, polymictic, poorly-sorted, pebble to cobble conglomerate with occasional small boulders and rare quartz pebbles (~1%). This particular facies has only been observed in the Hopewell Cape region of New Brunswick. It is time-equivalent to the herein informal Shin member (i.e., Shin Formation in the literature), possibly to the Dorchester Cape Member, and to at least the base of the Maringouin Formation.

3.2.3.1.1.1 Equivalent units

The herein informal Hopewell Cape member of the Bonaventure Formation corresponds to the Hopewell Cape Formation of Ami (1902) in its type-section, which was abandoned by Jutras et al. (2007b) based on its petrographic and stratigraphic equivalency with the Bonaventure Formation of Logan (1846). Note that coarse red beds that were mapped as Hopewell Cape Formation at Alma and Dorchester Cape are here assigned to the informal Shin member of the Bonaventure Formation.

3.2.3.1.2 Shin member

Corresponding to the informal lower member of the Bonaventure Formation of Jutras and Prichonnet (2005), the still informal Shin member is the most ubiquitous facies of that formation. It is mainly characterized by a red, polymictic, trough cross-stratified pebble conglomerate that typically includes 1 to 20% distally derived quartz pebbles among more locally derived lithic clasts (Jutras and Prichonnet, 2005; Jutras et al., 2001; 2005; 2007a,b). This conglomerate is typically interstratified with red sandstone and minor mudstone. It is time-equivalent to at least the base of the herein informal Hopewell Cape member, in part time-equivalent to the Maringouin Formation, and it lies below the Dorchester Cape Member.

3.2.3.1.2.1 Equivalent units

The herein informal Shin member is stratigraphically and petrographically equivalent to the Lower Member of the abandoned Cannes-de-Roches Formation (Alcock, 1935; revised by Rust, 1981) in the Cannes-de-Roches Basin of eastern Quebec (Jutras et al., 2001); to the informal lower member of the Bonaventure Formation in the Ristigouche Basin of the circum-Chaleur Bay area (Jutras and Prichonnet, 2005); to the Mississippian portion of what was referred to as the Bathurst Formation by Alcock, (1935) in the northern part of the Central Basin in New Brunswick (Davies, 1977), (the Bathurst Formation is now referred to as the Red Pine Brook Formation (Wilson, 2006), and should be restricted to lowermost Pennsylvanian red beds (Jutras et al., 2005)); to the McKinley Formation (Anderson and Poole, 1959) in the Fredericton area; to the Newcastle Creek Formation (Muller, 1951) in the Minto area; to the Shin Formation (van de Poll, 1967) in the Marysville Basin of central New Brunswick; to the Wanamaher Formation (Anderle et al. 1979) in the Moncton Basin of southern New Brunswick; and to part of the Hopewell Cape Formation (Ami, 1902) in the New Brunswick portion of the Cumberland Basin. Jutras et al. (2001) proposed to abandon the Cannes-de-Roches formation, and Jutras et al. (2007b) proposed to abandon the Shin, Hopewell Cape, McKinley and Wanamaker formations, as these units were petrographically and stratigraphically correlated with the Bonaventure Formation of Logan (1846).

3.2.3.1.3 Dorchester Cape Member

The Dorchester Cape Member was introduced by McLeod and Johnson (1999b) in reference to relatively fine red beds with abundant calcretes in the upper half of what they mapped as Hopewell Cape Formation at Dorchester Cape, New Brunswick, which were originally mapped as Maringouin Formation by Sutherland and van de Poll (1976). This unit is here informally included within the Bonaventure Formation.

3.2.3.1.3.1 Equivalent units

The Dorchester Cape Member is stratigraphically and petrographically equivalent to the Middle Member of the abandoned Cannes-de-Roches Formation (Alcock, 1935; revised by Rust, 1981) in the Cannes-de-Roches Basin of eastern Quebec (Jutras et al., 2001); to the informal upper member of the Bonaventure Formation in the Ristigouche Basin of the circum-Chaleur Bay area (Jutras and Prichonnet, 2005); and to the Scoodic Brook Formation (Anderle et al., 1979) in the Moncton Basin of southern New Brunswick, which Jutras et al. (2007b) proposed to abandon based on their petrographic and stratigraphic equivalence with the Bonaventure Formation of Logan (1846).

3.2.3.2 Maringouin Formation (Asbian to Brigantian)

Introduced by Norman (1941) in the Maringouin Peninsula of south-eastern New Brunswick, the Maringouin Formation is a monotonous succession of planar-bedded red mudstone and fine- to medium-grained red sandstone with no calcretes and very limited pedogenic overprints, which distinguishes it from the finer-grained fraction of the Bonaventure Formation. The conformable contact of this unit with carbonates of the Lime-kiln Brook Formation at Minudie, Nova Scotia, indicates that it is at least in part laterally equivalent to the herein informal Hopewell Cape member of the Bonaventure Formation. It is here informally subdivided as the Minudie and Pecks Cove members.

3.2.3.2.1 Equivalent unit

The Maringouin Formation is equivalent to the Middleborough Formation (Bell and Norman, 1938) of Nova Scotia. Although the latter has precedence, it was agreed at a formal meeting between geologists of the Geological Survey of Canada and of the New Brunswick and Nova Scotia departments of Natural Resources and Energy that the name Maringouin would be retained due to its dominant usage.

3.2.3.2.2 Minudie member

The informally proposed Minudie member is composed predominantly of laminar red mudstone, with rare thin beds of fine sandstone. It shows the same facies as the red beds in the Maccan member of the Lime-kiln Brook Formation, but occurs above the uppermost marine carbonate, which by convention forms the upper limit of the Windsor Group. It is transitionally overlain by the sandier Pecks Cove member, which is also much thicker (~210 m at the nearby Downing Cove section, compared with ~30 m for the Minudie member at Minudie).

3.2.3.2.3 Pecks Cove member

The informally proposed Pecks Cove member makes up the bulk of the Maringouin Formation within the Cumberland Basin. It consists of predominately thin (less than 2m thick) beds of alternating fine to medium sandstone and red mudstone. Pedogenic overprinting is present, but not penetrative.

3.2.4 Mabou Group (Pendleian to Arnsbergian)

The Mabou Group, originally designated as the Canso Group (Bell, 1944), consists of the Shepody and Enragé formations of Norman (1941) in the Cumberland Basin. Note that this definition differs from that of Ryan and Boehner (1994), who included the Middleborough (Maringouin equivalent) Formation within the Mabou, and the Claremont Formation (Enragé equivalent) within the Cumberland Group. It also differs from St. Peter (2001), who included the Hopewell Cape and Maringouin formations within the Mabou. It is here argued that the Shepody and Enragé formations are the coarse equivalents of the two units in the Mabou type-section, which are the Hastings and Pomquet formations, whereas the underlying Viséan red beds are the coarser equivalents of the red beds that alternate with marine carbonates of the Upper Windsor Group below the Mabou type-section. The continental Mabou Group is herein constrained to sub-humid and semi-arid Pendleian to Arsnbergian beds, whereas the hyper-arid Viséan continental clastics are assigned to the Percé Group. Therefore, the base of the Mabou Group is here placed at the first occurrence of grey to greyish continental clastic rocks with plant remains above the Windsor Group, or above Viséan red beds.

3.2.4.1 Shepody Formation (Pendleian)

Conformably overlying the Maringouin Formation is the Shepody Formation of Norman (1941). Although it includes thick successions of red mudstone and fine to medium sandstone that strongly resemble those of the Maringouin Formation, the Shepody Formation is characterized by thick occurrences of coarse grey to greyish sandstone with grey mud clasts and plant remains, which are increasingly abundant up stratigraphy. It is a coarser equivalent of the Hastings Formation (Rostokek, 1960) in the type section of the Mabou Group, and a finer equivalent of the Pointe Sawyer Formation (Jutras et al., 2001) in the Ristigouche and Cannes-de-Roches basins of Quebec.

3.2.4.2 Enragé Formation (Arnsbergian)

Sharply to disconformably overlying the Shepody Formation is the coarser and exclusively red Enragé Formation (Norman, 1941) in the Cumberland Basin. It consists primarily of coarse and granular red sandstone and granular to pebble red conglomerate. It is a coarser equivalent of the muddy Pomquet Formation (Belt, 1965) in the type section of the Mabou Group, and of the sandier Chemin-des-Pêcheurs Formation (Jutras et al., 2001) in the Cannes-de-Roches Basin of Quebec.

3.2.4.2.1 Equivalent units

The Enragé Formation is stratigraphically and petrographically equivalent to the Claremont Formation (Bell, 1944) of Nova Scotia.

3.3 Overlying Carboniferous Units

Disconformably and unconformably overlying the Mabou Group is the dominantly grey Cumberland Group (Bell, 1944), which includes numerous coal seams. The base of this unit is the grey sandstone-dominated Boss Point Formation in the Cumberland Basin. Stratigraphically above the Cumberland Group is the uppermost group of the Cumberland Basin, the Pictou Group (Bell, 1944), which predominantly consists of red beds (Ryan et al., 1991). Coal seams are also present within the Pictou Group, but are infrequent. This is the most prevalent group in the Maritimes Basin and it occurs through most of its extent. Maximum thickness of the Pictou Group is approximately 1650 m within the Cumberland Basin, but can reach much thicker values in other sections of the Maritimes Basin. An example of this is noted near Prince Edward Island, where thicknesses of up to 3000 m have been recorded (Howie and Barss, 1975b), although these estimates included beds that are now assigned to the Cumberland Group (*sensu* Ryan et al., 1991).

4.0 PALYNOLOGY

Samples from grey mudstone beds or mud clasts were collected throughout each section at specific intervals, when present, to ascertain the approximate age of the sediment from spore assemblages. The samples were analyzed by John Utting at the Geological Survey of Canada in Calgary, and the data are compiled in Appendix 1.

The Subzone B fossil assemblage of the Lime-kiln Brook Formation (McCutcheon, 1981; Ryan and Boehner, 1994) was recently dated as late Asbian (Giles, 2004). Its spore assemblage corresponds to the *K. stephanephorus* Concurrent Range Zone of Utting and Giles (2004), which spans the entire Asbian. The Bonaventure and Maringouin formations are barren in terms of fossils, but as can be seen on Figure 5.2 (in pocket), the diachronous base of the overlying Shepody Formation straddles the *acadiensis - K. triradiatus* and *G. spinosa-I. magnificus* concurrent range zones, which are respectively Brigantian and Pendleian (Utting and Giles, 2004). The laterally equivalent Bonaventure and Maringouin formations are therefore considered to be latest Asbian to earliest Pendleian, and possibly entirely Brigantian.

The Enragé Formation is also devoid of fossils, but the spore assemblage of grey beds from the uppermost Shepody Formation still corresponds to the Pendleian *G. spinosa-I. magnificus* Concurrent Range Zone (Figure 5.2, in pocket). A similar transition between grey beds of the Hastings Formation and red beds of the Pomquet Formation in northern Nova Scotia is marked by an abrupt transition from the Pendleian *G. spinosa-I. magnificus* Concurrent Range Zone to the Arnsbergian *R. carnosorus* Concurrent Range

Zone (Utting and Giles, 2008), which strongly suggests that the Enragé Formation is Arnsbergian at the oldest.

The spore assemblage at the very base of the Boss Point Formation indicates that this unit starts in the Yeadonian or the Langsettian. Hence, if the Enragé Formation is indeed Arnsbergian, this would imply a hiatus spanning the Cholkerian, Alportian, Kinderscoutian, Marsdenian and perhaps the Yeadonian. Although air-photo analysis suggests that the Enragé/Boss Point disconformity does not involve deep downcutting, a mature regolith that marks the top of the Enragé Formation (see next chapter) may account for the implied large hiatus, which is observed throughout the Maritimes just below the Mississippian-Pennsylvanian boundary (Utting and Giles, 2008). However, in the light of its deep downcutting into the Shepody Formation (see chapter 10), the possibility must be considered that the laterally limited Enragé Formation may be slightly younger than the Arnsbergian Pomquet Formation and the depositional product of an erosion event that affected most of the Maritimes Basin in middle to late Namurian times.

5.0 REGIONAL SEDIMENTOLOGY AND STRATIGRAPHY

Ten coastal sections of upper Viséan to early Namurian successions were measured across the Cumberland Basin at Minudie, Downing Cove, Downing Head East and Downing Head West, Nova Scotia, and at Maringouin East, Maringouin West, Dorchester Cape, Hopewell Cape, Cape Enragé and Alma, New Brunswick (Figure 5.1). Vertical and lateral variations were studied along two transects, oriented SW-E (from Alma to Minudie) (Figure 5.2, in pocket) and NW-E (from Hopewell Cape to Minudie) (Figure 5.3, in pocket). The sections are positioned based on the herein estimated Viséan-Namurian boundary according to available spore dates. The Minudie section was placed by extrapolating the contact between the Minudie and Pecks Cove members at Downing Cove, although this contact is possibly diachronous. The Alma exposure is a floating section that has no tangible correlative features and is thus placed arbitrarily between the stratigraphic levels of the Lime-kiln Brook and Shepody formations.

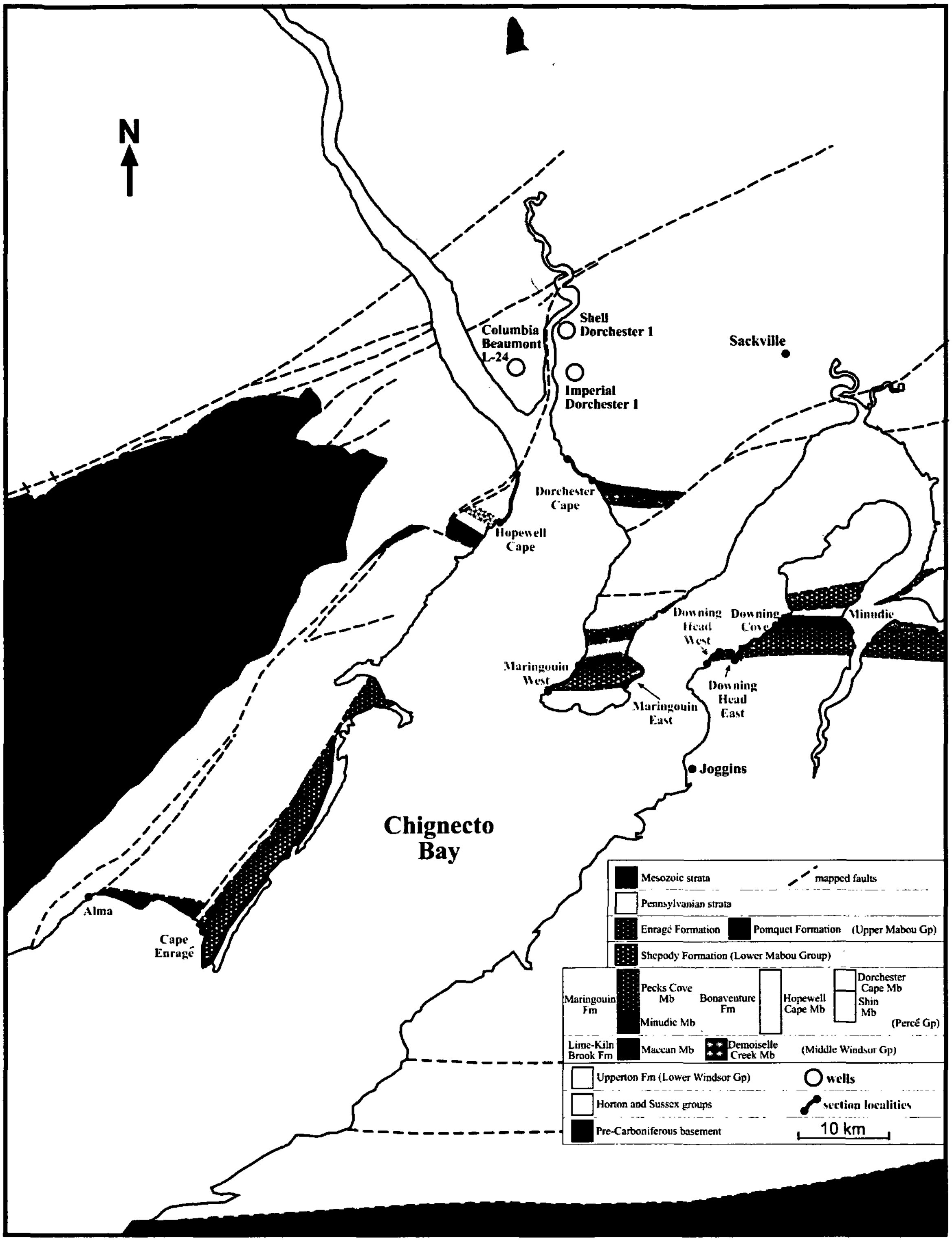


Figure 5.1 Geology of the study area (modified from St. Peter, 2001) and studied localities.

5.1 Vertical and lateral variations along a SW-E transect between Alma and Minudie

5.1.1 Lower Windsor Group

Sulphate of the Upperton Formation is present below a ~300m gap that separates it from the lowermost exposure of Maringouin Formation red beds at Maringouin West (Figure 5.2, in pocket), although it should appear at least 940m below this unit according to wells of the Joggins areas, where a minimum of 300m of salt and 640m of Lime-kiln Brook Formation beds separate the two units (Ryan and Boehner, 1994); or at least 1135m below according to the Imperial Dorchester #1 Well of the Dorchester Cape area, where 795m of salt and 340m of Lime-kiln Brook Formation beds separate the two units. Salt withdrawal may explain the thin gap, which would then be encompassed by Lime-kiln Brook Formation beds only. Moreover, the sulphate is probably ongoing modern diapirism, allowing it to maintain a cliff exposure (Figure 5.4), which may have caused it to break through the remaining stratigraphy (i.e. the succession that was left after salt withdrawal).

Figure 5.4 Sulphate cliff exposure at Maringouin West, NB (~7 m high at the highest point).

5.1.2 Lime-kiln Brook Formation (Maccan member)

The upper 63m of the newly assigned Maccan member of the Lime-kiln Brook Formation was measured along the exposed wave-cut platform at Minudie (Figure 5.2, in pocket). This section is characterized by interbedded carbonates and red mudrocks. The carbonates include grey stromatolitic banks, grey nodular limestone, and massive black limestone that occasionally houses cephalopods and algal tubes. Thickness of the carbonate intervals ranges from one to four metres, whereas that of the red beds ranges from 1.5 to 25 metres. Although the red bed intervals are largely dominated by red mudrock, they also include minor green mudrock, and red or green fine sandstone. Below the uppermost limestone, there are also some severely brecciated muddy to sandy red beds that exhibit hummocky cross-stratification in areas that are less disturbed. West of the Minudie section, stratigraphic control of the Maccan member is lost due to lack of outcropping with the exception of the stratigraphic and time equivalent Demoiselle Creek member of the Hopewell Cape section, which will be discussed in the next sub-chapter.

5.1.3 Maringouin Formation

Above the uppermost limestone at Minudie is a ~30m succession of laminated red mudrock (green in the first few metres) with only minor thin (less than 25cm thick) intervals of fine sandstone that is here informally assigned to the Minudie member of the Maringouin Formation (Figure 5.2, in pocket). This unit is strikingly similar to the Maccan member in that it is largely dominated by laminated red mudrock, but it lacks any carbonate intervals besides occasional limestone laminae, which are present throughout. Many instances of calcite-cement-supported sands are also noted, but no fossils were identified. A 3m thick sandstone bed occurs ~30m above the last Windsor Group limestone and marks the base of the Pecks Cove member of the Maringouin Formation, which is a tightly interbedded succession of mildly mottled red mudrock and fine to medium sandstone with rare occurrences of coarse red sandstone.

Moving southwest into Downing Cove, below the Pecks Cove member, the Minudie member becomes slightly sandier, although the sandstone intervals are still thin and comprise less than 10% of the succession. It is also much thicker (~63m) than at Minudie, although incomplete, which suggests that the uppermost carbonate beds of the

Lime-kiln Brook Formation pinch-out to the west in less than 5 km. Continuing into the Maringouin East and West sections, the Minudie member becomes significantly sandier, but again laminated mudrock is strongly dominant, and sandstone occurrences are still less than 0.5m thick for the most part. Sandstone becomes rare again in the Minudie member of the Cape Enragé section, where only a lone, thin (~ 1m) bed of sandstone is present among laminated red mudrock. The Minudie member therefore shows increasingly higher energy inputs moving towards the centre of the Cumberland Basin, with trough cross-stratification and ripple marks becoming present in the more frequent sandy intervals at Maringouin East and West. Although only the Minudie section includes a complete succession of this member, it is up to three times thicker in the incomplete sections that lie to the west.

Gradationally overlying the laminar red mudrock of the Minudie member at Downing Cove is the Pecks Cove member, a ~210m succession of tightly alternating, trough cross-stratified red sandstone and mildly mottled red mudrock. A few relatively thick intervals of coarse red sandstone also occur, but are restricted to the Downing Cove section with the exception of a single lens of coarse sandstone present near the base of the Pecks Cove member at Maringouin West. The overall characteristics of the Pecks Cove member stay relatively similar moving west, throughout the Cumberland Basin. Ripple marks are common, and overhang exposures indicate that many of them are the result of interference ripples (Figure 5.5). Downcutting is limited throughout the Pecks Cove member, and this succession is for the most part planar-bedded.

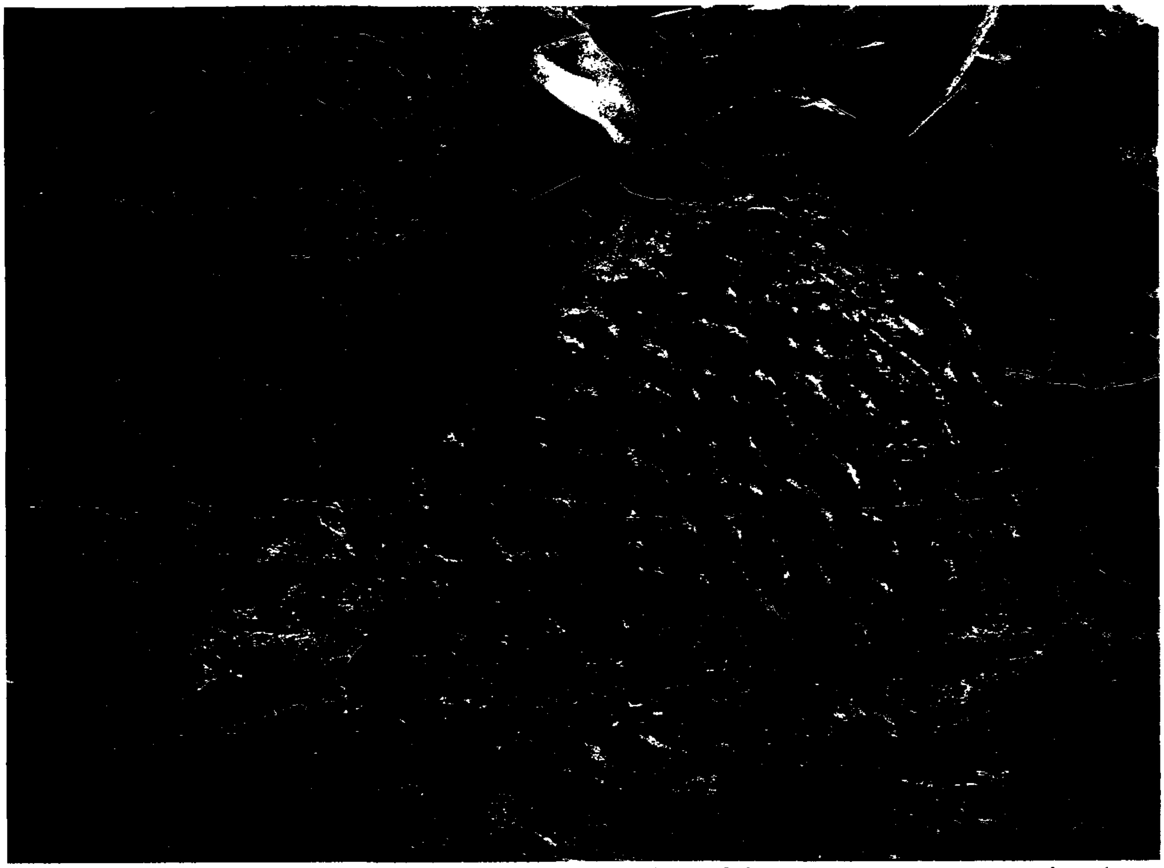


Figure 5.5 Interference Ripples, Pecks Cove member of the Bonaventure Formation (pen for scale).

Pedogenic overprinting is present in both the mudrock and sandstone, but very poorly developed. Occasionally, red mudrock clasts can also be observed at the base of some sandstone units.

Overall thickness of the Pecks Cove member increases to the west, and maximum thickness is attained at the Cape Enragé section, which is nearly twice as thick as the Downing Cove section (~407m). The first occurrence of grey to greyish sandstone with fossilized plant remains marks the transition into the overlying Shepody Formation.

5.1.4 The Bonaventure Formation

A floating ~110m section of heavily trough cross-stratified pebble and cobble conglomerate with coarse sandstone lenses at Alma is assigned to the Shin member of the Bonaventure Formation (Figure 5.2, in pocket). Based on correlations along a NW-E transect from Hopewell Cape to Minudie (Figure 5.3, in pocket), this unit is considered time-equivalent to the Pecks Cove member of the Maringouin Formation (see next chapter).

5.1.5 Shepody Formation

The contact between the Maringouin and Shepody formations is sharp and disconformable throughout the Cumberland Basin. The lowermost coarse grey sandstone bed of the Shepody Formation is observed to deeply downcut into the underlying red beds of the Pecks Cove member, especially at Cape Enragé (Figure 5.6) and at Maringouin West.

The Shepody Formation at Downing Cove consists of a repetitive, ~280m succession of fining-upward cyclic sequences that commence with grey or red, coarse to granular sandstone with plant remains and grey or red mud clasts, followed by fine to tightly interbedded red mudrock and fine sandstone, or simply mudrock. The coarse sandstone beds that begin each fining-upward sequence become more notable in both thickness and frequency of occurrence moving up stratigraphy, which is the case in all of the sections,

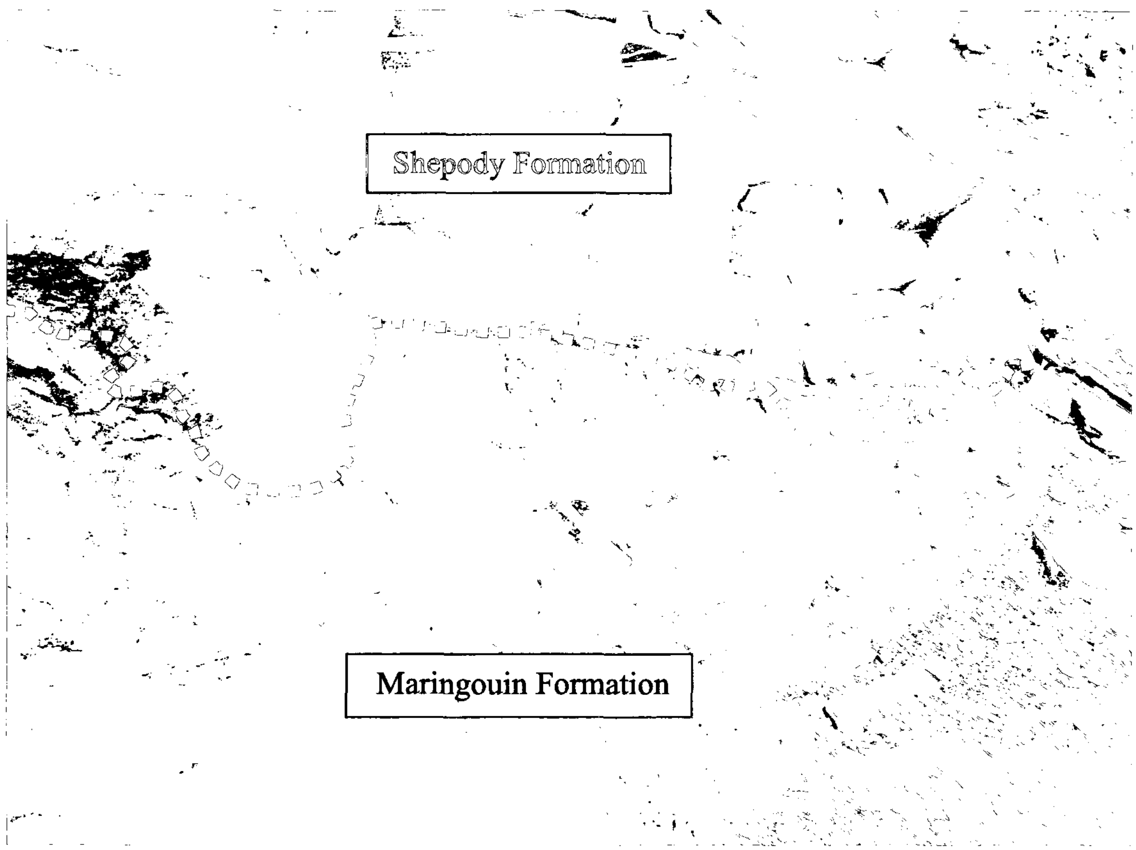


Figure 5.6 Erosional contact between the Maringouin and Shepody formations at Cape Enragé, NB (hammer for scale).

and are more often thoroughly grey moving up stratigraphy as well. At all localities, these grey sandstone beds occasionally contain thin lenses of grey intraformational pebble conglomerate. The sandstone beds are mostly trough-cross stratified, whereas the red intervals are planar-bedded and display moderate pedogenic overprinting in the form of mottling, root traces and minor calcitic nodules. The intraformational conglomeratic lenses and fossilized plant remains become increasingly more abundant, moving west towards the Cape Enragé section.

The thickness of the Shepody Formation is much more consistent than that of underlying units. A maximum thickness of 392m is reached at Cape Enragé. This is only a 40% increase from that of its most thin occurrence at Downing Cove, which is much less of a variation than in the underlying units. However, it should be noted that the Cape Enragé section is offset by numerous faults, with displacement along these faults on the order of potentially tens of metres. With displacements exceeding the depth of the cliff face, and due to the high degree of lateral variability in many of the beds, correlation is at best difficult. Error in thickness estimation is probable, but mainly a risk in terms of underestimation. Hence, the measured section at Cape Enragé is here regarded as reflecting minimum thickness.

The Shepody Formation at Maringouin West is ~ 60m thinner than at Maringouin East, although only 5 km separate the two sections. This is explained by earlier occurrences of the Shepody Formation facies at Maringouin East, which occurs in uppermost Brigantian times, whereas the first occurrence of that facies is Pendleian at Maringouin West.

5.1.6 Enragé Formation

The contact between the uppermost coarse grey sandstone bed of the Shepody Formation and red beds of the overlying Enragé Formation is well exposed at both Downing Cove and Downing Head East and South. The basal bed of each section is an intraclastic conglomerate composed of red or grey mudstone clasts and red or grey fine sandstone clasts. These conglomeratic units at the contact between the Shepody and Enragé formations were scavenged from deep downcutting into the underlying Shepody Formation (Figure 5.7). The Enragé Formation is the coarsest unit along the SW-E

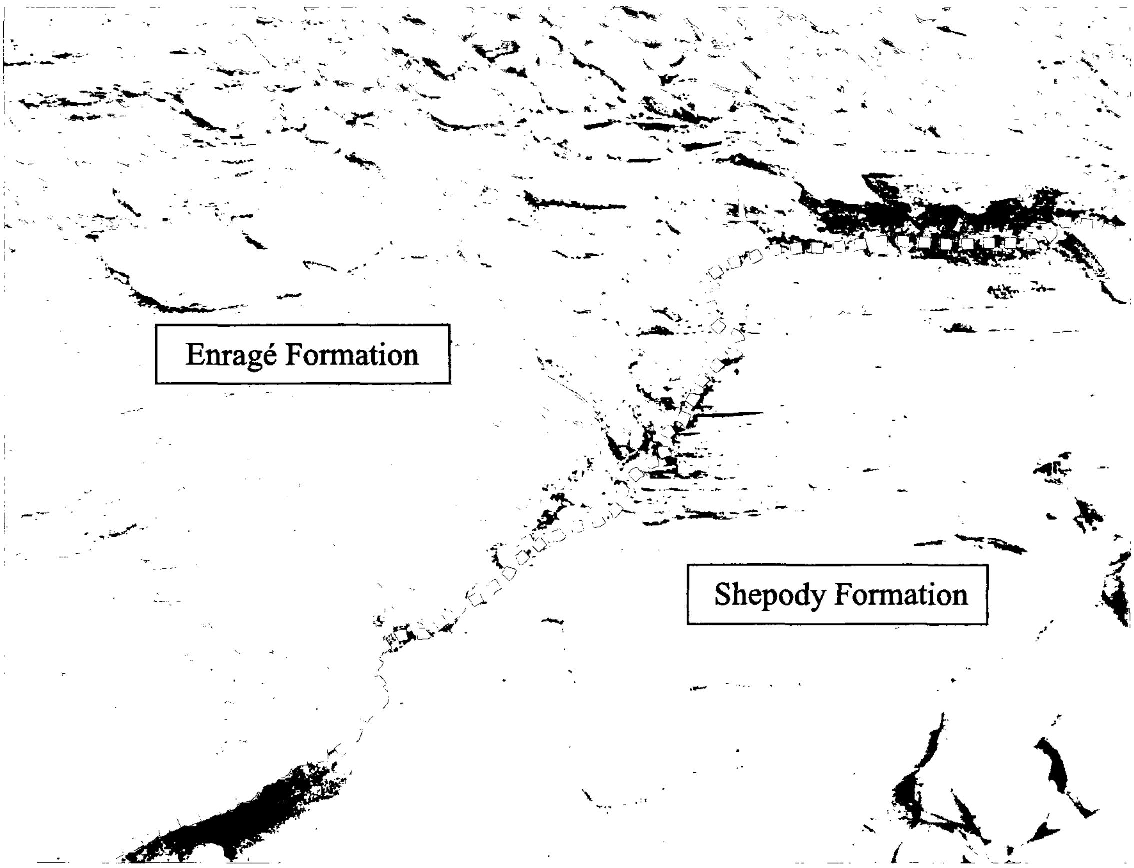


Figure 5.7 Erosional contact between a coarse grey sandstone bed at the top of the Shepody Formation and an intraclastic conglomerate bed at the base of the Enragé Formation. (hammer for scale).

transect. This unit is only accounted for in the last 50m of the Downing Cove section before the outcrop is lost.

The Downing Head East and West sections display a minimum thickness of ~180m for the Enragé Formation, but are incomplete due to the presence of 62 and 92 m gaps in the stratigraphy, respectively. These sections consist mainly of red, trough cross-bedded, coarse to granular sandstone, along with pebble conglomerate, fine to medium sandstone and mudstone. The first few occurrences of conglomerate are intraclastic, whereas the other occurrences are polymictic and rich in quartz, the granular fraction especially, which is almost exclusively composed of quartz granules. A feature that distinguishes the Enragé Formation of the Downing Head West section from the East is the numerous and large occurrences of karst infills in the upper half of the section, present in coarse to pebbly sandstone (Figures 5.8 and 5.9). Despite the absence of karst infills in the Enragé Formation of Downing Head East, deep weathering is observed in the upper section of that unit. The overall trend of the Downing Head East section is one that gradually fines upward from the base and coarsens again near the top before terminating with a ~5 meter thick muddy red paleosol that is disconformably downcut into by the overlying basal bed of the Boss Point Formation, which is an intraclastic grey conglomerate (Figure 5.10).

Figure 5.8 Karst structure within pebbly sandstone of the upper part of the Enragé Formation at Downing Head West, NS (hammer for scale).

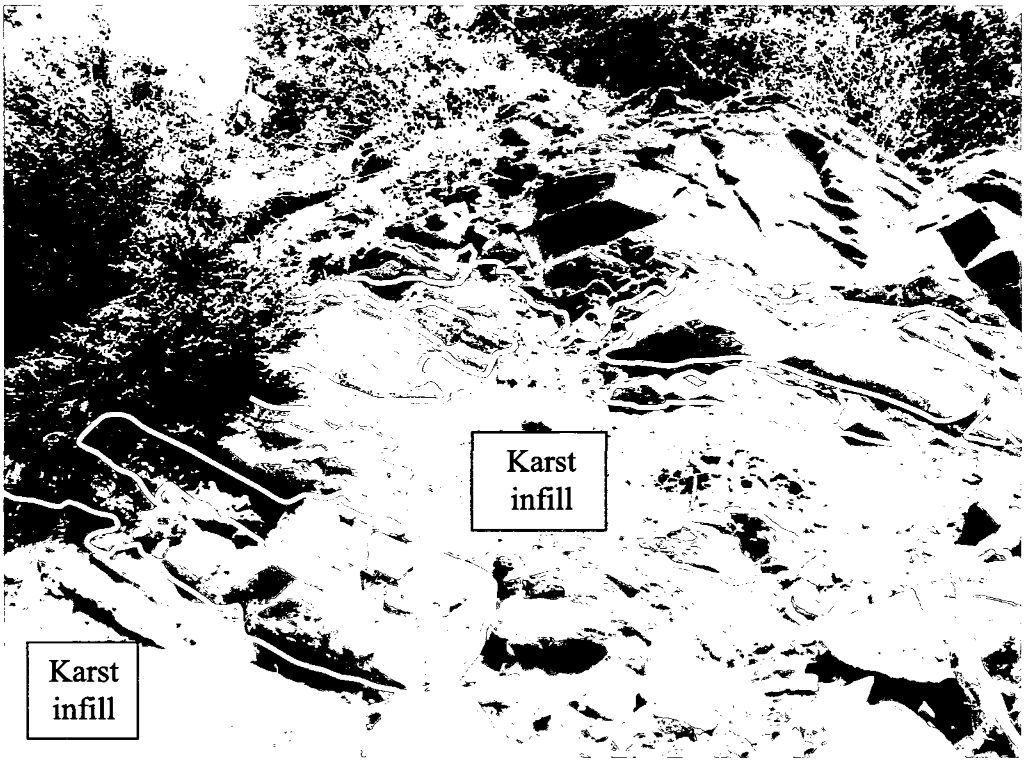


Figure 5.9 Collapsed karst structure within pebbly sandstone of the Enragé Formation at Downing Head West, NS (hammer for scale).

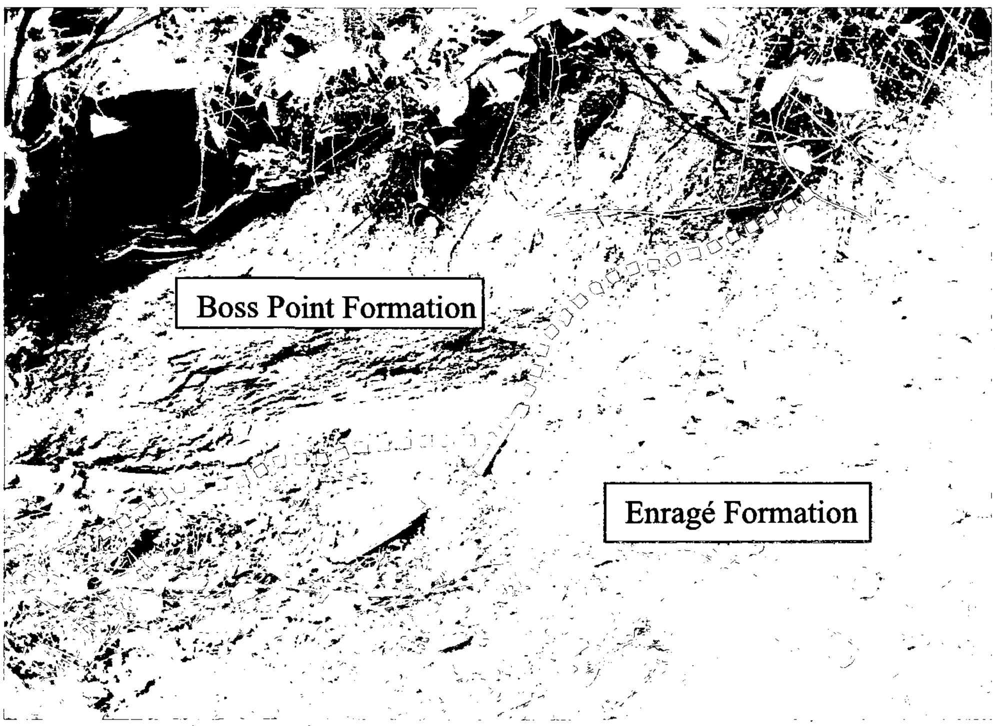


Figure 5.10 Erosional contact between the Boss Point and Enragé formations at Downing Head West, NS (hammer for scale).

The Downing Head West sections fines upward towards the centre of the available Enragé stratigraphy, and then coarsens to terminate with a very thick (41.5m) interval of granular conglomerate.

The Enragé Formation at Maringouin East is similar to that of both Downing Head sections in that there is a gradual fining towards the centre of the succession and then coarsening towards the top of the formation. As in the case of the Downing Head sections, the conglomerates evolve upward from intraformational to polymictic, but they eventually become quartzitic, a trait that was not found at the other sections.

The Maringouin West section displays an incomplete stratigraphy of the Enragé Formation due to several gaps, of which two are very notable: a 66 m gap present near the centre of the formation, and a 44 m gap at the top of the formation, obscuring the contact between the Enragé and Boss Point formations. The exposed segments show a similar petrography than at Maringouin East.

5.1.7 Pomquet Formation?

Overlying the uppermost sandstone unit of the Shepody Formation at the Cape Enragé section is a large ~345m gap in the stratigraphy that is inferred to be the stratigraphic position of the Enragé Formation (McLeod and Johnson, 1999a). This inference is based on the presence of coarse grey sandstone beds of the Boss Point Formation overlying the gap, which are typically separated from the Shepody Formation by the Enragé Formation. However, this very well-defined and laterally persistent differential erosional gap suggests that the Enragé Formation is finer at this locality than in the Maringouin and Downing areas. It is more likely a finer (i.e., weaker) equivalent of the Enragé Formation, such as the Pomquet Formation of northern Nova Scotia, which occurs at the same stratigraphic level above Pendleian grey beds (Belt, 1964).

5.2 Vertical and lateral variations along a NW-E transect between Hopewell Cape and Minudie

5.2.1 Lime-kiln Brook Formation (Demoiselle Creek and Maccan members)

As previously stated, the Maccan member of the Lime-kiln Brook Formation at Downing Cove is predominantly a red mudrock succession with various types of interbedded carbonate lenses and beds. Time-equivalent to at least the base of the Maccan member is the coarser Demoiselle Creek member in the lower ~115m of the Hopewell Cape section. It should also be noted that based on cuttings from the Imperial Dorchester #1 Well, located ~4 km to the north (Figure 5.1), the Lime-kiln Brook Formation occurs 69m below the base of the Bonaventure Formation conglomerates at Dorchester Cape. The mix of red mudrock and minor limestone that characterizes the Lime-kiln Brook Formation is approximately 76m thick below the Minudie member and directly above a ~209m succession of salty red and grey mudrock that characterizes the Tennycape Formation, which is underlain by clearer salt of the Cassidy Lake Formation. In the nearby Minudie-Maccan area, ~37 kilometres to the southwest, the Lime-kiln Brook Formation is 110m thick according to logs from the LMA88-1 hole, and 384m thick in the Pacific Fox Harbour C-96V drill hole near Wallace, another ~50 kilometres to the west (Ryan and Boehner, 1994). This unit therefore thins from east to west in the

Cumberland Basin, as suggested by the rapid pinch-out of carbonate beds in the 5km that separate the Minudie and Downing Cove sections (Figure 5.2 in pocket).

The lower ~65% of the Demoiselle Creek member is entirely composed of cobble conglomerate with abundant pebbles and sparse boulders. Most of it is only observable during low-tide as it is part of a wave-cut platform. The clasts range from sub-rounded to sub-angular, and the conglomerate itself is polymictic and matrix- to clast-supported. The conglomerates of the Demoiselle Creek member are characterized by planar-bedded sheetflood deposits that show no significant downcutting and channelling (Figure 5.11). The conglomerate transitions into finer beds of sandstone and mudstone and the Demoiselle Creek member terminates with three distinct limestone successions separated by conglomerate and sandstone, analogous to the underlying red beds.

The lower limestone succession occurs above a 1m thick grey mudrock and starts with 1m of grainstone followed by 1m of dark grey marl and another 4m of grainstone wrapping around stromatolitic mounds laterally (Figure 5.12 and 5.13). The middle occurrence of limestone is a thin (0.25m) lens of grainstone. The uppermost limestone succession is the thickest of the three. The lower 2m of this interval is a dark grey marl followed by 2m of thin alternations of dark grey marl and nodular limestone, two additional metres of fine


Figure 5.11 Planar-bedded sheetflood conglomerates of the Demoiselle Creek member at Hopewell Cape, NB (metre ruler for scale).

grainstone with minor stromatolites, 3m of thin alternations of dark grey marl and nodular limestone, 0.5m of grainstone, 0.25m of grey granular conglomerate, and 1m of karstified grainstone (the karst infill is red and grey mudrock) with columnar stromatolites. This uppermost limestone succession also contains large ripple marks. It is sharply overlain by red conglomerate of the Hopewell Cape member of the Bonaventure Formation, which is petrographically similar to those that underlie and separate the limestone intervals below (to be discussed in more detail later in this chapter).

Figure 5.12 Stromatolites near the top of the Lime-kiln Brook Formation (Demoiselle Creek member) at Hopewell Cape, NB (hammer for scale).

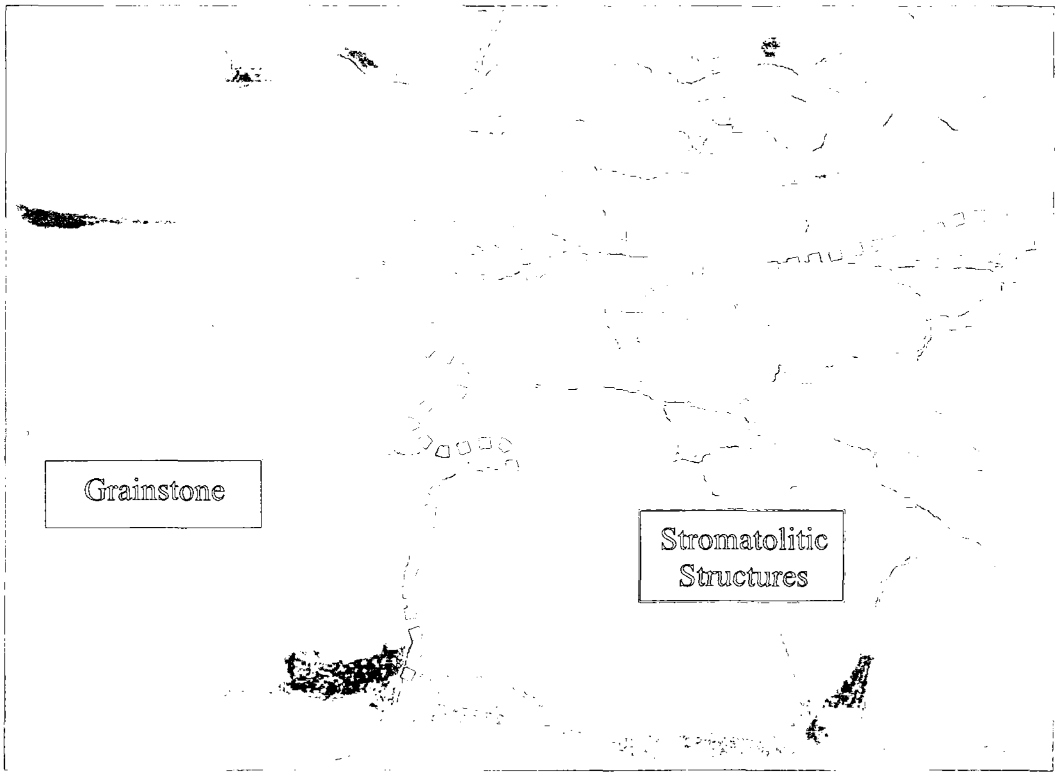


Figure 5.13 Stromatolites (right) buried by grainstone (the width of the photo is ~2 m).

5.2.2 Minudie member of the Maringouin Formation

As mentioned earlier, the Maccan member at Minudie is overlain by the Minudie member, which is dominantly composed of laminar red mudrock. A thin (~9m) exposure of the uppermost Minudie member is also present at Dorchester Cape, exhibiting the same laminar bedding in red mudrock, and small exposures on the adjacent wave-cut platform suggests that it is at least a few tens of metres thick. According to the Imperial Dorchester #1 well, it is ~69m thick in this area, but it is absent from the Hopewell Cape section, where coarse conglomerate of the Bonaventure Formation directly overlies the uppermost carbonate of the Lime-kiln Brook Formation. At Dorchester Cape, it is sharply overlain by downcutting conglomerate of the Shin member of the Bonaventure Formation.

5.2.3 Shin and Dorchester Cape members of the Bonaventure Formation

The contact between the red mudrock of the Minudie member of the Maringouin Formation and the pebbly conglomerate of the Shin member of the Bonaventure Formation at Dorchester Cape is erosional, with a pebbly conglomerate bed, locally affected by karst, and downcutting into the underlying mudrock by up to one metre (Figure 5.14). The Shin member is a ~90m thick succession of poorly sorted, trough cross-bedded red beds ranging in grain-size between mudrock and pebble conglomerate.

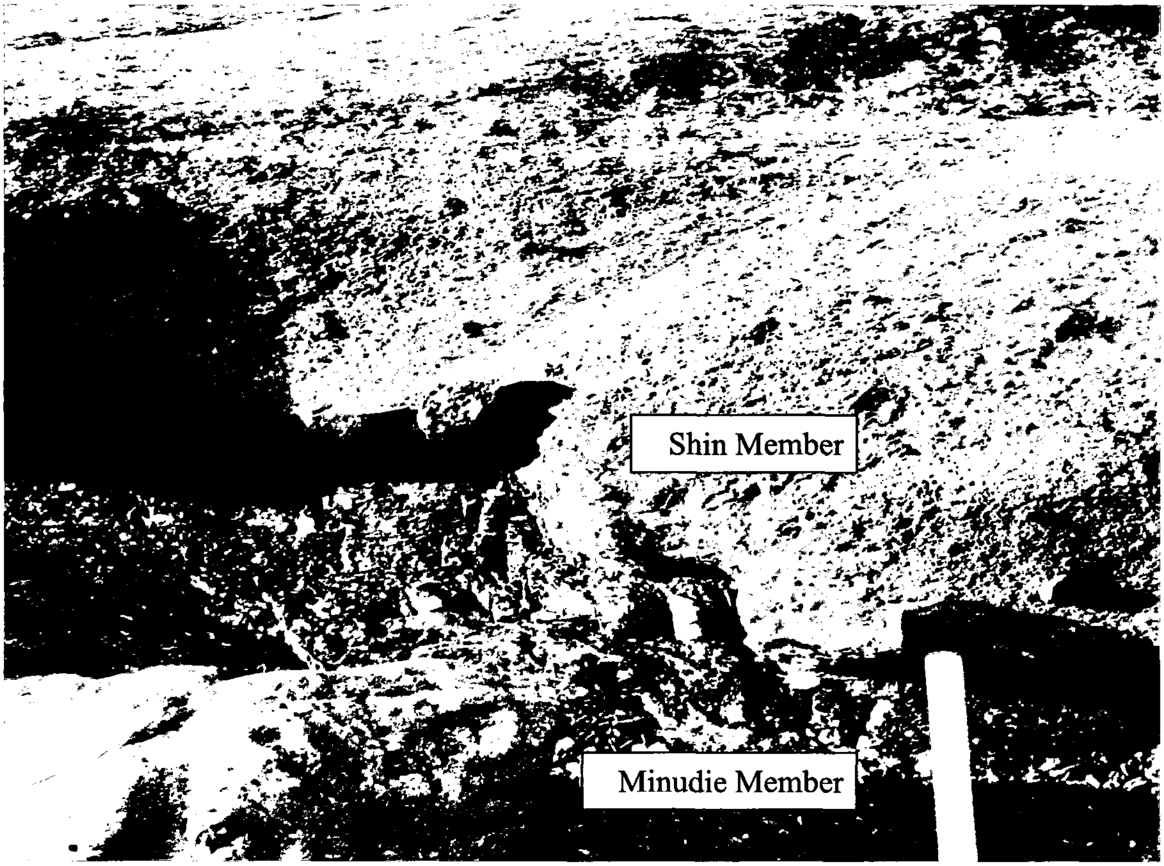


Figure 5.14 Erosional contact between the Minudie member of the Maringouin Formation and the Shin member of the Bonaventure Formation, Dorchester Cape, NB (hammer for scale).

The red to reddish-brown mudrock beds resemble those of the underlying Maringouin Formation, except that pedogenic overprinting is much more penetrative in the form of mottling and abundant reduced root traces. Although mainly observed in the muddy fraction of the succession, pedogenic overprints are also observed in sandstone and conglomeratic beds, often in association with reduction spheres (Figure 5.15). These reduction spots at Dorchester Cape were studied by van de Poll and Sutherland (1976), and were observed to contain highly concentrated levels of copper (cuprite, native copper) as well as silver, mercury (schachnerite) and vanadium (roscoelite), but they are

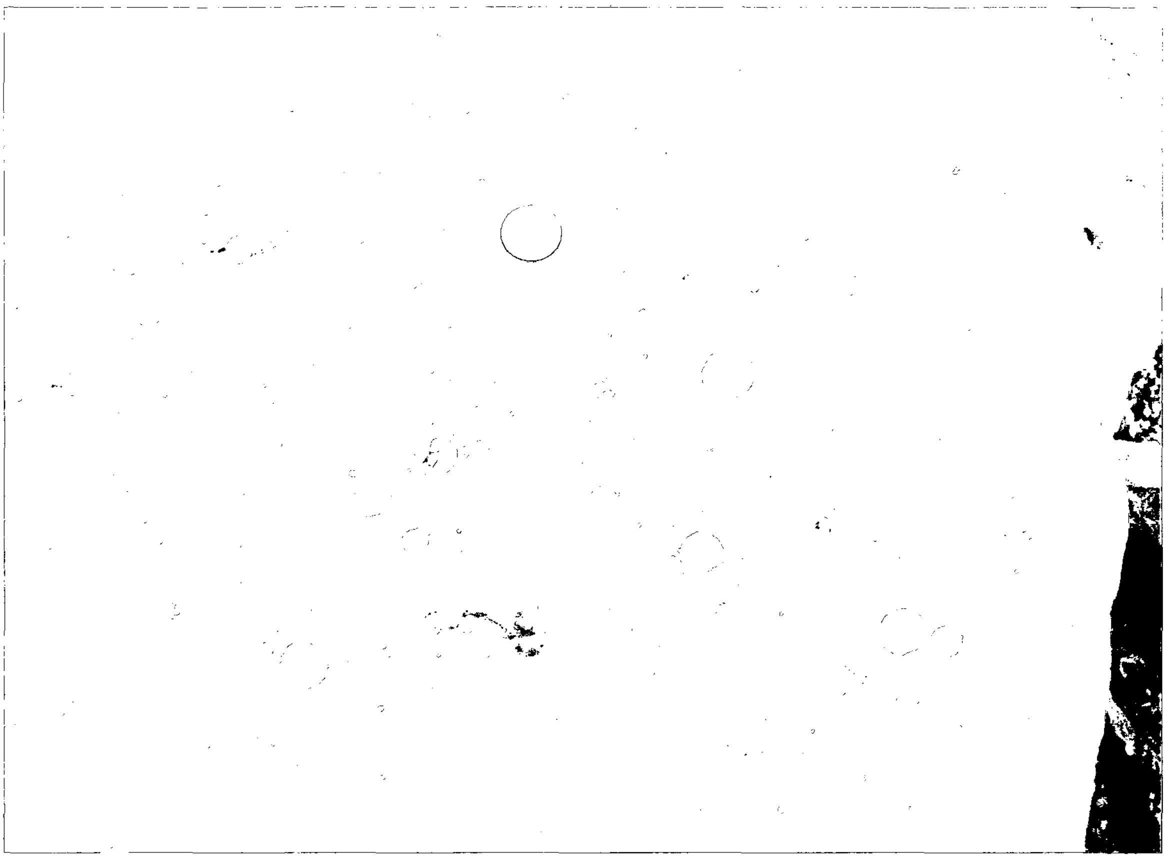


Figure 5.15 Reduction spheres with dark, mineralized centres within the Shin member of the Bonaventure Formation, Dorchester Cape, NB (Canadian dollar coin for scale: 2.7cm).

devoid of any organic content. According to these authors, some of the larger reduction spots that contain mineralized centers show copper concentrations reaching 17%. Polymictic gravels are an important component of the Shin member at Dorchester Cape, but they are mostly part of beds that are dominated by sand. In instances where a pebble conglomerate or pebbly sandstone overlies sandy mudrock, a very irregular contact may be seen due to the effect of loading.

The subjective contact between the Shin member and overlying Dorchester Cape Member is marked by a transition from a succession that is dominated by pebbly sandstone with non-calcretic paleosols to a finer succession with abundant calcretes. The calcrete horizons are in the form of thick nodular calcrete beds, thin calcrete hardpans (Figure 5.16) or phreatic calcrete lenses (Figure 5.17) that become increasingly ubiquitous moving up stratigraphy. These calcrete horizons reach thicknesses of up to 1.5m but can be as thin as a few centimetres. In terms of granulometry, the Dorchester Cape Member is a fining-upward succession of interbedded mudrock and sandstone. Polymictic gravels are also found in the lower half, but in lesser abundance than in the underlying Shin member. The gravels become increasingly dominated by calcrete intraclasts going-up the succession, and the uppermost conglomerate is entirely intraclastic.

Near the top of the succession, the presence of silcrete nodules (Figure 5.18) is noted within one of the large lenses of phreatic calcrete that occur within the uppermost 30m of the Dorchester Cape Member. They are diagnosed as phreatic due to the observation that they follow tightly the internal structures of the sandstone lenses, suggesting gradual precipitation by the lateral movement of groundwater between muddy aquicludes.

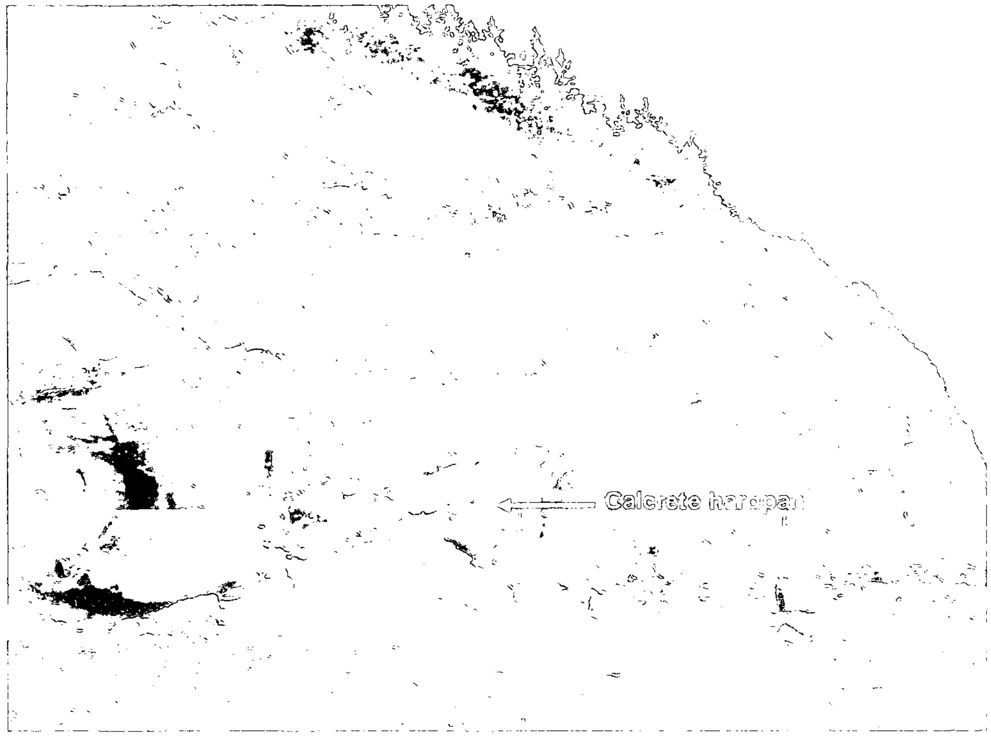


Figure 5.16 A reduced calcrete hardpan horizon (~25 cm thick) within the Dorchester Cape Member of the Bonaventure Formation, Dorchester Cape, NB.

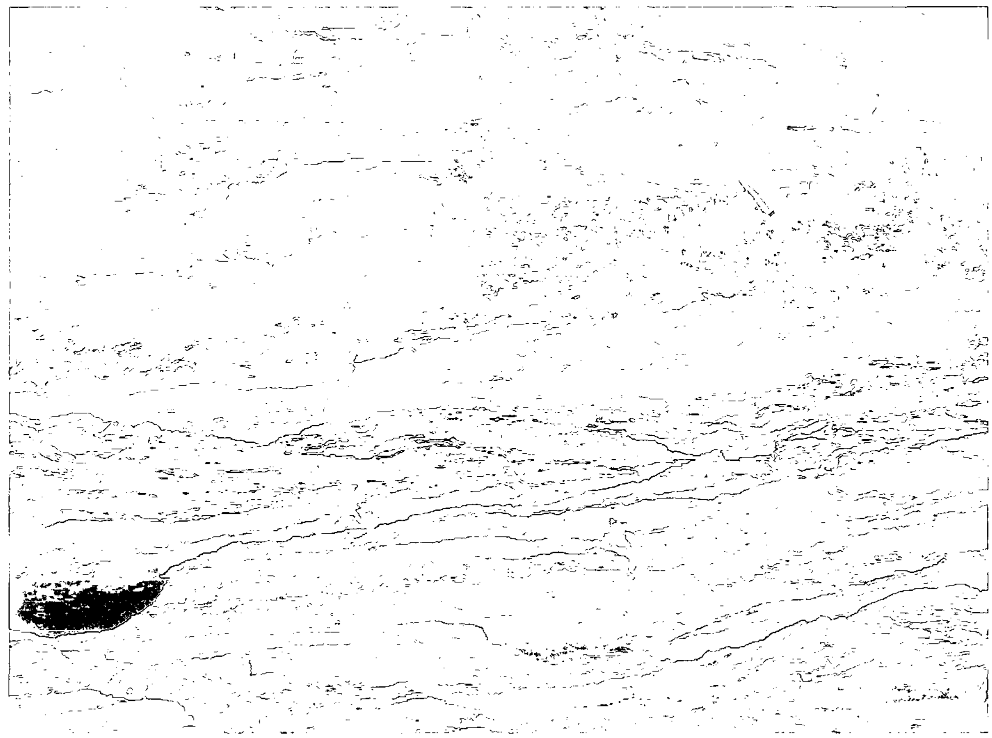


Figure 5.17 Phreatic calcrete lens within the Dorchester Cape Member of the Bonaventure Formation, Dorchester Cape, NB (the width of this photo is ~3m).

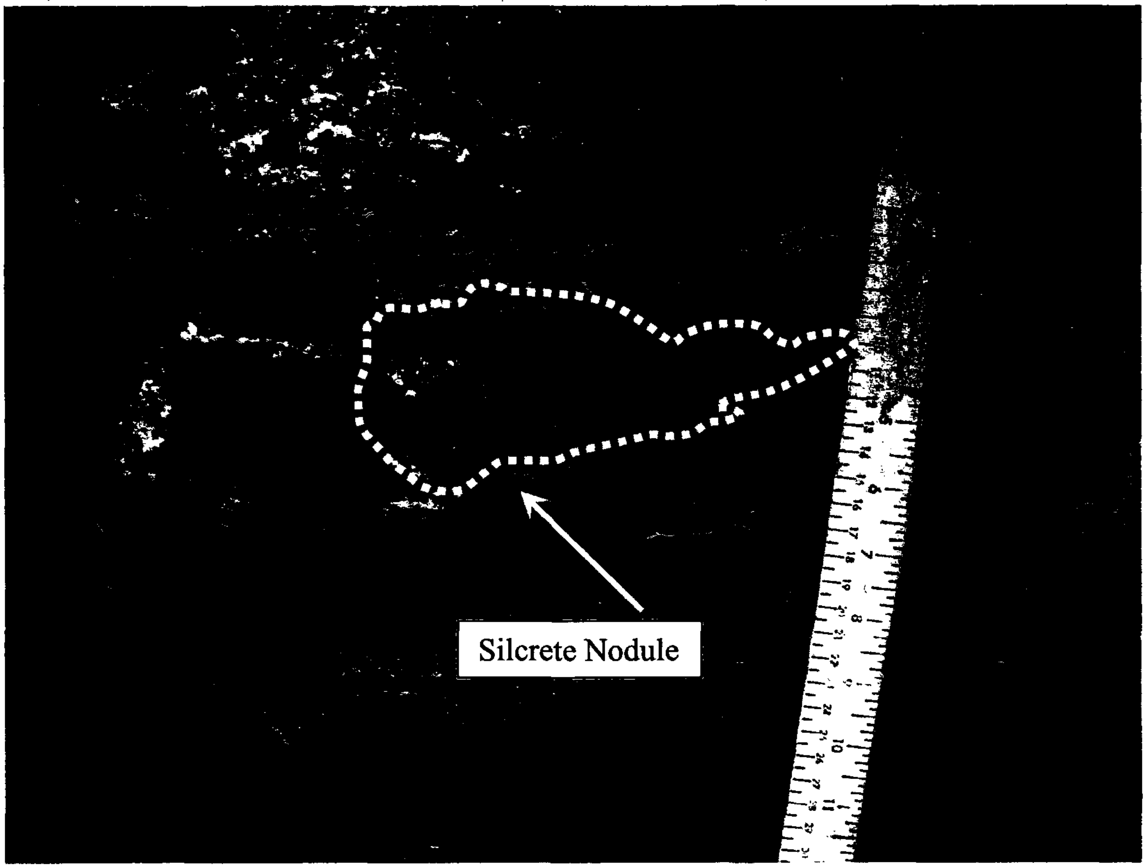


Figure 5.18 Silcrete nodule located within a phreatic calcrete lens within the Dorchester Cape Member of the Bonaventure Formation, Dorchester Cape, NB.

A very low-angle unconformity marks the sharp contact between the Bonaventure Formation and the basal grey sandstones of the Boss Point Formation. A few small lenses of grey mudrock, less than 30cm thick and 1m wide, are found at the contact between the two units. The mudrocks contain a Pendleian spore assemblage (Appendix 1) and are interpreted to represent small remnants of the Shepody Formation, which was largely eroded from that area and incorporated within the Boss Point Formation, as suggested by the high amount of reworked Pendleian spores in the basal beds of that unit at Dorchester Cape according to reports by Graham Dolby in the NBDNRE database. This interpretation is also supported by the abundance of grey mudclasts in the basal beds of the Boss Point. It is possible that the Shepody Formation was originally very thin in that area, which was potentially mainly characterized by non-deposition during the Pendleian. The Shin and Dorchester Cape members of the Bonaventure Formation at Dorchester Cape, which seemingly evolve into the finer Minudie and Pecks Cove members of the Maringouin Formation to the southeast, transition into the very coarse Hopewell Cape member of the Bonaventure Formation to the southeast, at Hopewell Cape.

5.2.4 Hopewell Cape member of the Bonaventure Formation

The Hopewell Cape member of the Bonaventure Formation is a monotonous succession of very poorly-sorted coarse sedimentary rocks that can be almost entirely categorized as planar-bedded cobble conglomerate with abundant pebbles and occasional small boulders, and very thin and wide lenses of medium to coarse sandstone. Common throughout the succession are large karst structures that range from less than one metre to several metres in diameter, and that were subsequently infilled by sands. These karstic structures are elongated parallel to bedding, suggesting that they occurred prior to the tilting of the succession. Their distribution along several hundred metres in succession thickness suggests that they are syn-sedimentary and the record of water-table fluctuations in a succession that was cemented early by pedogenic calcite (Figure 5.19).

Figure 5.19 Karst infills elongated parallel to bedding planes in the Hopewell Cape member at Hopewell Cape, NB (the width of this photo is ~20m).

Most conglomerates at Hopewell Cape, although very coarse and poorly-sorted, are clast-supported and show clear evidence of vertical aggradation, suggesting that they are flash flood deposits. They show no significant downcutting and trough cross-stratification, suggesting that they were deposited quite close to the water-table by sheet floods (Figure 5.20). In the uppermost 30 m of the succession, there are two thin occurrences of chaotic, matrix-supported conglomerates that are interpreted as debris flows (at -30 m and -12 m; Figure 5.21). The debris flow conglomerates are reworked by subsequent flash flood deposits at the top, and their remnant thicknesses vary between 0.5 and 1m.

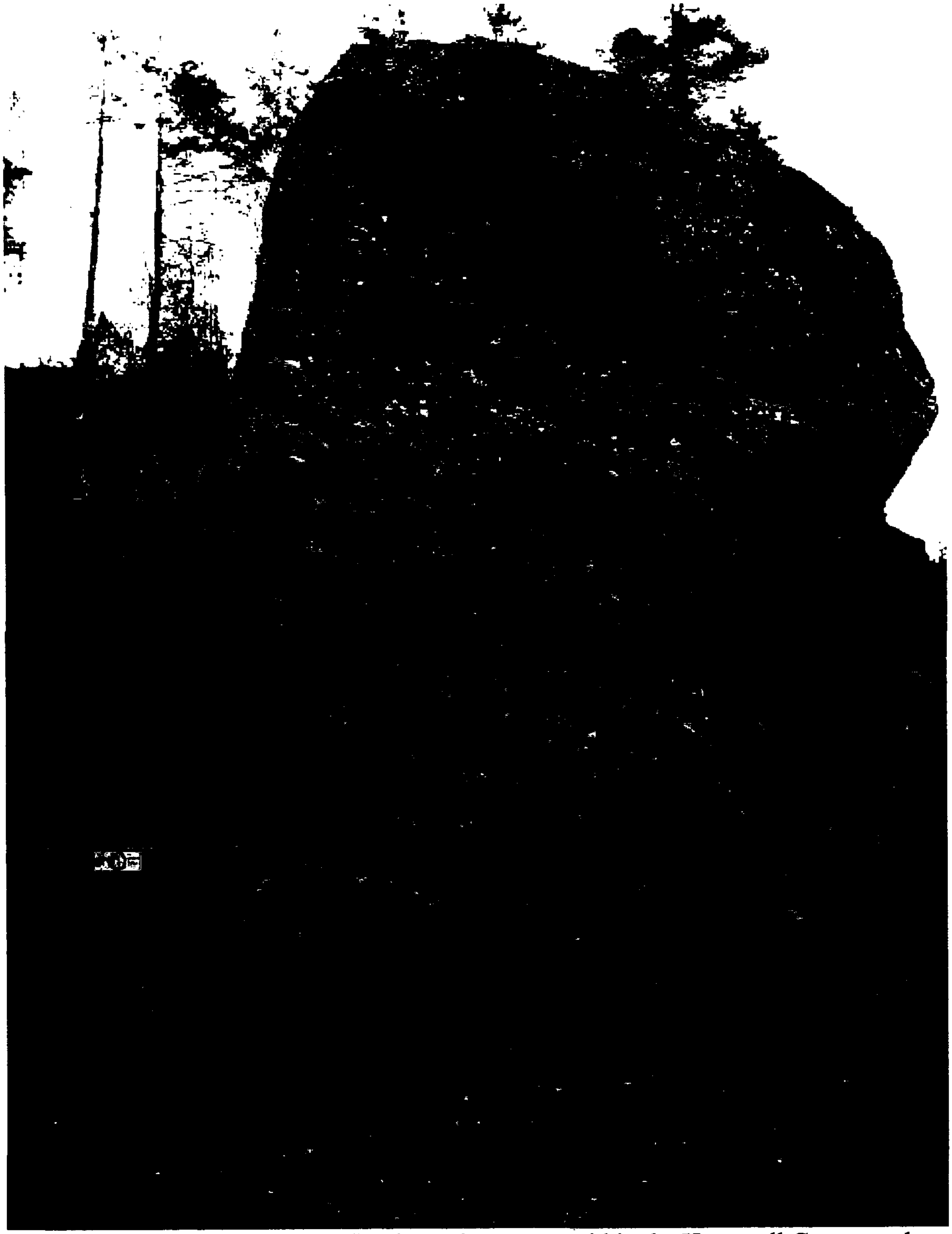


Figure 5.20 Planar bedded sheetflood conglomerates within the Hopewell Cape member of the Bonaventure Formation, Hopewell Cape, NB (flower pot structure is ~12 m high).

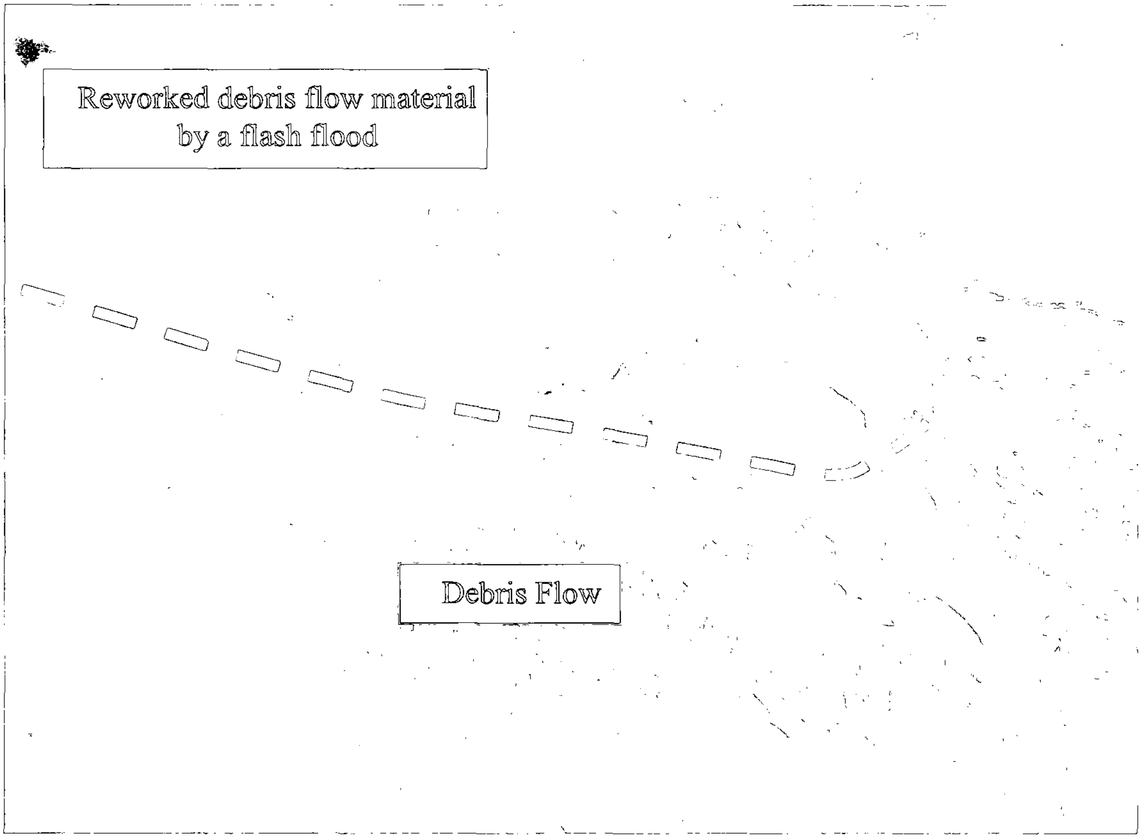


Figure 5.21 Chaotic conglomerate interpreted as a debris flow deposit that was partly reworked by a flash flood within the Hopewell Cape member of the Bonaventure Formation at Hopewell Cape, NB (the width of this photo is ~3m).

6.0 PETROGRAPHY

The following petrographic descriptions were made via thin section microscopy on sandstones and carbonates (detailed descriptions are found in Appendix 2), and petrographic counts on conglomeratic units within the west Cumberland Basin study area. The samples herein are organized relative to their stratigraphic position, moving up stratigraphy from the most basal sample.

6.1. Lime-kiln Brook Formation

Samples collected and analyzed from the Lime-kiln Brook Formation were dominantly limestone, specifically boundstones, with the exception of samples collected near the contact boundary between that unit and the overlying Bonaventure Formation at Hopewell Cape, which are classified as grainstones, sandy limestones and lithic arenites.

6.1.1 Demoiselle Creek member

Many of the samples collected in the Demoiselle Creek member contain extensively recrystallized bioclasts. A detailed work on the fossil assemblages of the Demoiselle Creek member (then Demoiselle Creek Beds) was performed by McCutcheon (1981), who identified nine distinct marine organisms, including brachiopoda, cephalopoda, conodonts, conularida, crustacea, gastropoda, pelecypoda, pelmatozoa and protozoa. Petrographic findings from the thin sections can be observed in tables 6.1 to 6.3 (in Appendix 2).

The significant percentages of carbonate cement in all of these samples, either spar or micrite, accompanied with bioclasts, intraclasts, peloids and ooids, along with abundant siliciclastic material, altogether suggest a proximal marine environment adjacent to a source area.

6.1.2 Maccan member

The carbonate intervals of the Maccan member were studied by Bell (1944, 1958) and by Ryan and Boehner (1994), who describe a marine assemblage of bivalves, brachiopods, algae, cephalopods as well as unidentified hollow tubes (tube worms according to P. von Bitter (pers. comm. 2004). The interbedded red mudrocks, although slightly dominated by silts, are highly calcareous and include a few recrystallized rudaceous bioclasts, suggesting that the environment was still marine, although engorged with siliciclastics (Table 6.4 in Appendix 2).

6.2 Bonaventure Formation

6.2.1 Hopewell Cape member

Rocks of the Hopewell Cape member at the Hopewell Cape section of New Brunswick can be classified as predominantly red, angular to sub-angular, pebble to cobble conglomerates that are polymictic and matrix- to clast-supported. Due to the very coarse nature of the sediments of the Hopewell Cape member, petrographic counts were done in the field. They show that the dominant clast types, accounting for 55% of the total, are metasandstone clasts exhibiting one cleavage plane (i.e., attributable to rocks that were deformed by the Middle Devonian Acadian Orogeny only). Granitic clasts that are rich in potassium feldspar (monzogranite and syenite) account for 40%, while metasandstones with more than one cleavage plane (i.e., attributable to rocks that were deformed by both the Middle Ordovician Taconian Orogeny and the Middle Devonian Acadian Orogeny) account for 4%. The remaining 1% consisted of quartz and chert clasts. The limy and granular sandstone matrix encompasses about 45% of the conglomerate.

6.2.2 Shin member

In petrographic counts conducted in conglomerate of the Shin member at Dorchester Cape, granite clasts account for 50-70% of all clast types, quartz ranges between 5 and 25%, weathered basalts between 10 and 15%, schist between 3 and 10%, and sandstone clasts between 1 and 5%. Again, the matrix is a limy and granular sandstone.

6.3 Maringouin Formation

6.3.1 Minudie member

The presence of pelsparite laminae in fine red lithic wacke that was sampled 5 m above the uppermost carbonate bed of the Lime-kiln Brook Formation at Minudie, along with the calcite-supported nature of the sediment (Table 6.5 in Appendix 2), suggest that the environment in basal beds of the Minudie member was still marine, although engorged with siliciclastic sediments. The abundance of calcitic cement in the fine laminated beds of the Minudie member at Maringouin West also suggests a marginal marine environment, as the calcite is unlikely to be pedogenic due to the undisturbed laminated texture of the deposit (Table 6.6 in Appendix 2). The deposits gradually coarsen higher up, with well-rounded clast-supported grains, but the presence of pelmicrite intraclasts still suggests a nearshore environment, albeit with higher energy (Table 6.7 in Appendix 2).

These petrographic analyses show that the sediment is more mature than that of the underlying Maccan member. The percentage of quartz clasts within the sediment gradually increases moving up stratigraphy, accounting for 32-50% respectively of the total. Spar cement is still present in the Minudie member, but shows a gradual decrease in total percentage moving up stratigraphy (40-13% respectively) towards the overlying Pecks Cove member.

6.3.2 Pecks Cove member

Sediments of the Pecks Cove member show a decreasing percentage of calcitic cement and carbonate components compared with the underlying Lime-kiln Brook Formation, suggesting an evolution in the depositional environment, moving from a shallow marine to a terrestrial setting. Calcite is still the dominant cement, but more amorphous silica is observed than in the underlying units (Table 6.8 in Appendix 2). Although slightly more mature than underlying units, sands of the Pecks Cove member are still rich in lithic fragments (see Chapter 9 on Provenance), and therefore still classify as lithic wackes.

6.4 Shepody and Enragé formations

The percentage of carbonate cement continued to decrease on average moving up stratigraphy into the lithic arenites of the Namurian Shepody and Enragé formations (tables 6.9 to 6.19 in Appendix 2), which is compatible with the transition to a more purely terrestrial environment, and with the transition to less arid beds. Although the Enragé Formation shows more arid features than the Shepody Formation, it includes even less calcite, which suggests a substantially less arid environment than in the Viséan red beds. A similar gradual decrease in calcite contents from Viséan red beds to Namurian grey and red beds was noted by Jutras et al. (2001) in the Gaspé area of eastern Quebec.

The Enragé Formation conglomerates are dominantly intraclastic at the base, and evolve upward into a polymictic composition. At all localities, the granular fraction of the conglomerate tends to be quartzitic.

A petrographic count was performed 85m from the base of the Enragé Formation on the thickest of the sub-angular to sub-rounded pebble conglomerate beds at Downing Head, which has a clast composition of 50% quartz, 45% sandstone, 2% basalt, 2% granite, and 1% schist. Another count was done approximately 65m above the Shepody/Enragé contact at Maringouin East. The pebble portion of the conglomerate is dominated by 87% quartz, 5% chert, 5% grey sandstone, 2% red sandstone and 1% schist clasts. Conglomerates of the Enragé Formation are therefore substantially more quartzitic than those of the Bonaventure Formation, which typically only include 1 to 20% quartz pebbles, never exceeding 50% (Jutras et al., 2007b).

7.0 GEOPHYSICS

Analytical data collected from the Geological Survey of Canada via geophysical surveying was used in rendering an image of first vertical magnetic data overlapped with Bouguer anomaly data in the Cumberland Basin (Figure 7.1a). Positive gravity anomalies are imaged as warmer colours. The image displays three prominent basement highs within the study area, which are characterized by prominent positive anomalies and complex magnetic signatures: the Cobequid Highlands to the south, the Caledonia Highlands to the west and the Westmorland Highlands to the north. The latter basement high is presently buried beneath Pennsylvanian strata, but is nonetheless quite prominent on the composite geophysical image.

Based on this image, as well as on mapping and borehole data from the NBDNRE (McLeod and Johnson, 1999a,b; St. Peter, 2001) and the NSDNRE (Donohoe and Wallace, 1982; Ryan and Boehner, 1994), different generations of faults can be illustrated with a fair degree of certainty (Figure 7.1b). Faults that figure on the above-mentioned geological maps are indicated by a full line on Figure 7.1b, and in some cases extended beyond the limits of exposure based on the continuation of the magnetic lineament. Currently unmapped lineaments that correspond well with the magnetic signatures of mapped faults are indicated with a dashed line (Figure 7.1b). Many of those unmapped lineaments correspond to Mississippian or early Pennsylvanian faults that affect the Westmorland Highlands but that are buried below Pennsylvanian strata.

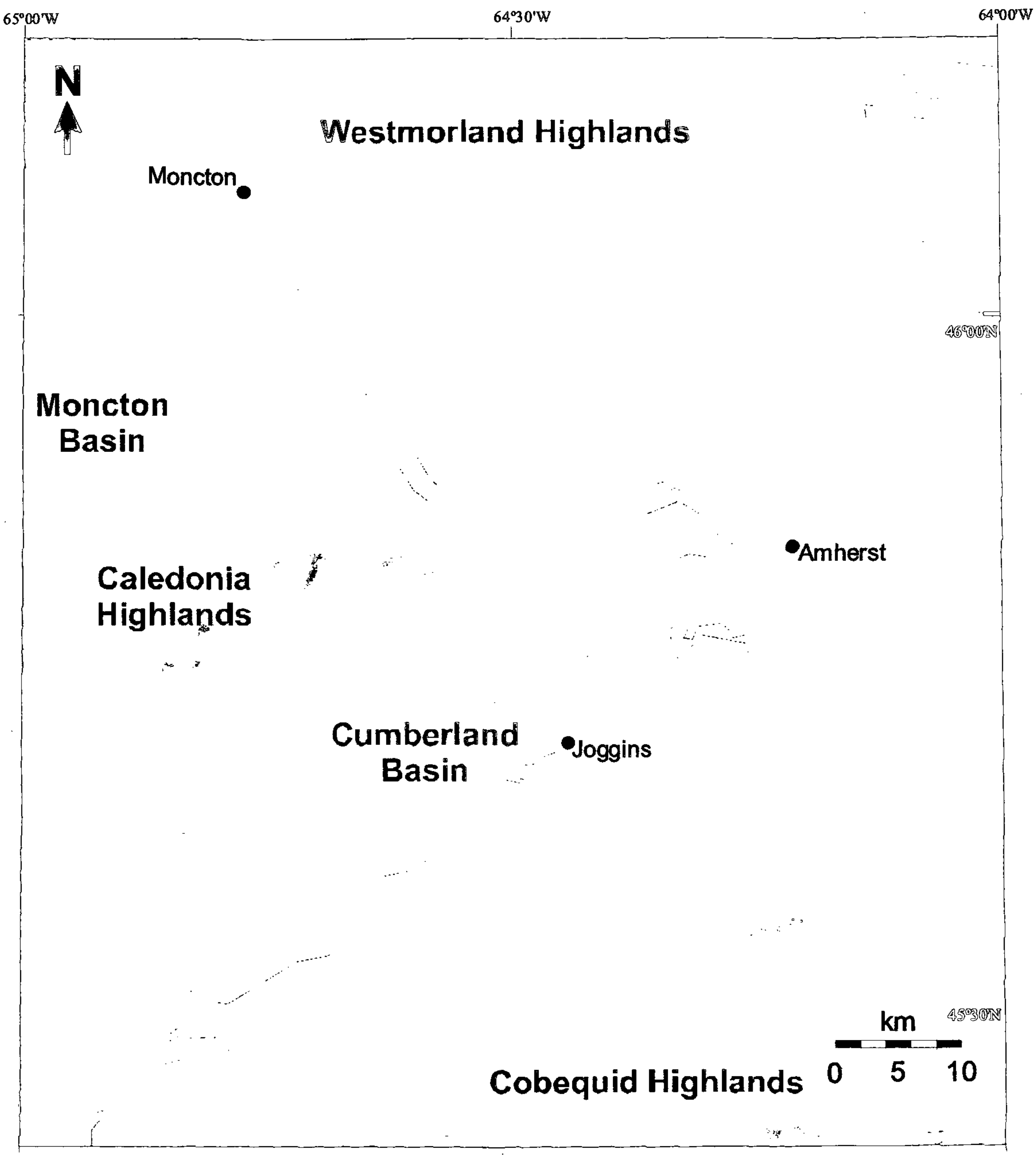


Figure 7.1 First vertical magnetic data overlapped with Bouguer anomaly data in the Cumberland Basin, and identification of basement highs.

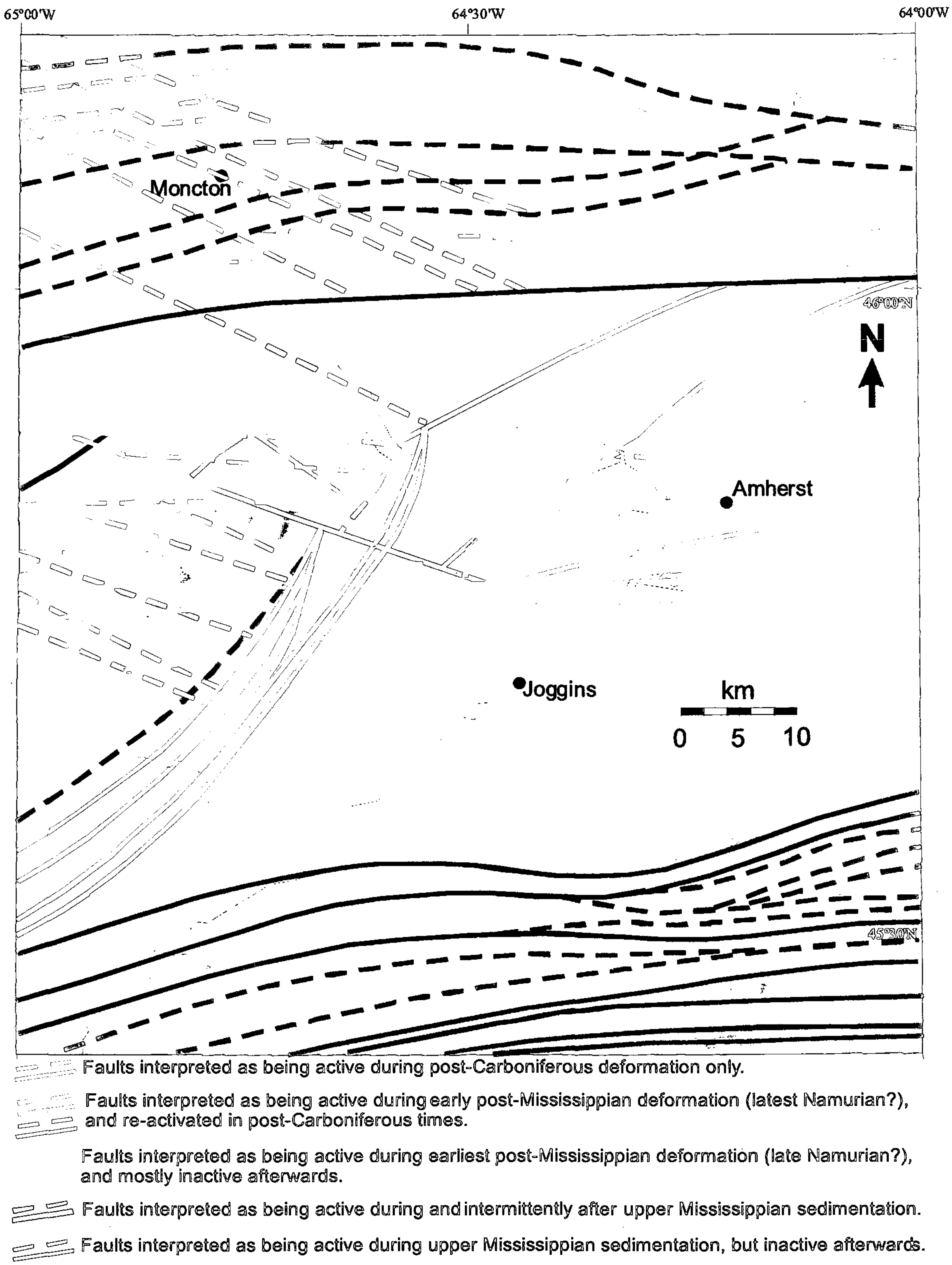


Figure 7.2. Interpreted post-Holkerian faulting (full lines are mapped faults).

Pre- upper Mississippian faults are not illustrated on Figure 8.1b. However, an ENE- to NE-striking system of reverse faults affecting pre-Middle Windsor rocks is well observable in geophysical image in the area of the Caledonian Highlands. In St. Peter (2001), this trend of fault is seen to affect Horton Group and Lower Windsor Group rocks, but not the Hopewell Cape Formation. The interpretation of post-Lower Windsor fault lineaments will be covered in the discussion.

8.0 PALEOCURRENTS

The following paleocurrent data (detailed in tables 8.1 to 8.3 of Appendix 3) were obtained from trough cross-bed orientations in intervals that show trough cross-bedding. Rose diagrams were then placed at each locality, reflecting the dominant paleocurrent trend during deposition of each of the three main intervals, respectively associated with the Bonaventure/Maringouin, Shepody and Enragé formations (Figures 8.1, 8.2 & 8.3). All of the study sites are not represented in each of the three figures due to the fact that not all of the three formations are present at each site.

8.1 Paleocurrents within the Bonaventure and Maringouin formations

Paleocurrent vectors obtained indicate that all three areas of basement highs acted as distinct source areas during the deposition of the Bonaventure and Maringouin formations (Figure 8.1). The Maringouin West, Maringouin East and Downing Cove sections show NNW-driven paleocurrents from the Cobequid Highlands, whereas the Alma and Cape Enragé sections show SE-driven paleocurrents from the Caledonia Highlands. The Hopewell Cape section shows NE-driven paleocurrents from a small dislocated knob of the Caledonia Highlands, which we interpret as being still part of that basement high during Mississippian deposition (see discussion).

The majority of paleocurrent data obtained from the Cape Dorchester section show vectors ranging between 160° and 192°, which corroborate with data from van de Poll and Sutherland (1976), who recorded vectors ranging between 160° and 200°. These SSE-driven paleocurrents suggest that the Westmorland Highlands, which are well observable on the composite geophysical image (Figure 7.1), were an active source area at the time of deposition. This buried basement high runs roughly perpendicular to the paleocurrent vector measurements of the Dorchester Cape section, and is proximal enough to account for the coarse nature of much of the strata within the Shin member.

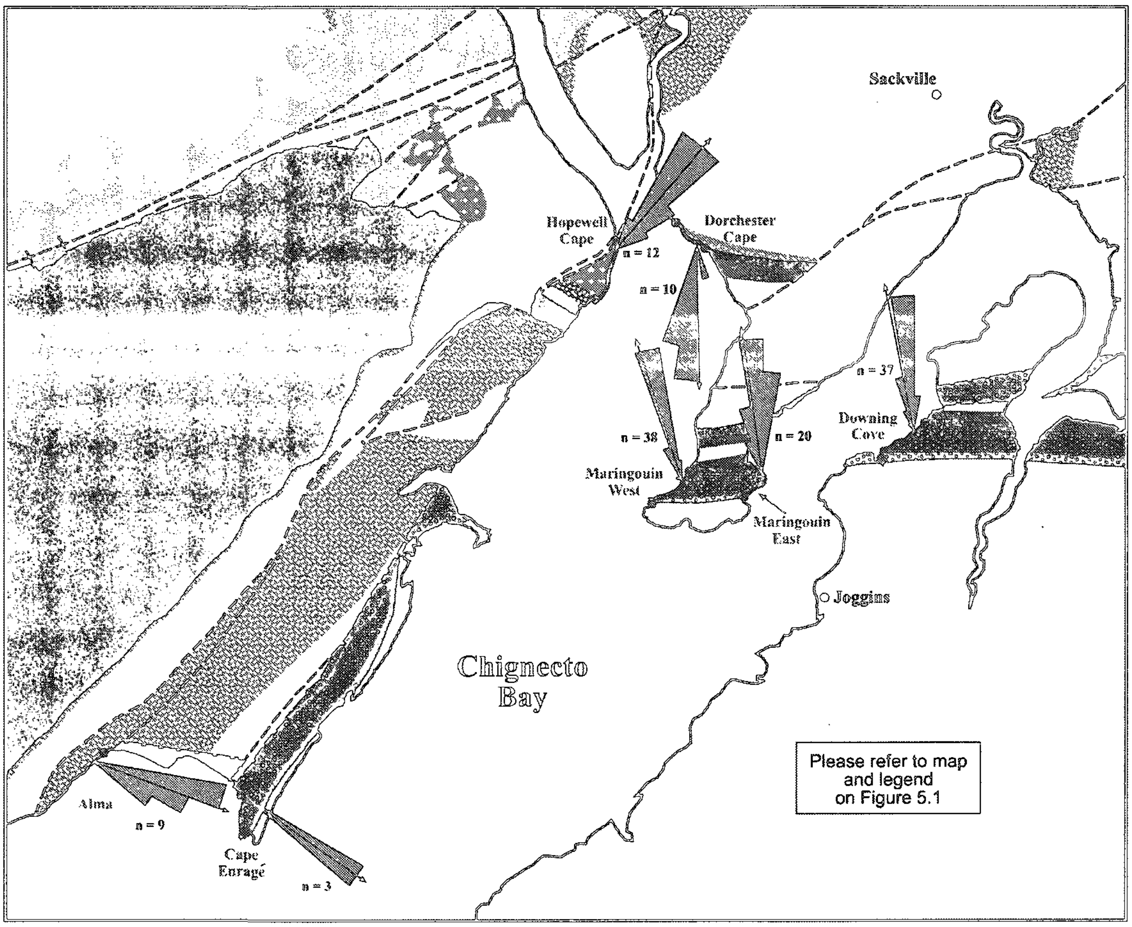


Figure 8.1 Paleocurrent vectors in the Viséan Maringouin and Bonaventure formations based on trough cross-bed orientations.

8.2 Paleocurrents within the Shepody and Enragé formations

Paleocurrent data obtained from the Shepody and Enragé formations show the same pattern as in the Bonaventure and Maringouin formations based on available data (Figures 8.2 and 8.3). The Cobequid Highlands were continuing to source the Downing Cove, Maringouin East and Maringouin West sites, while the Caledonia Highlands were sourcing the Cape Enragé site. Note that the results from Downing Cove show a much more constrained range than that obtained by Hamblin (2001) in the same section.

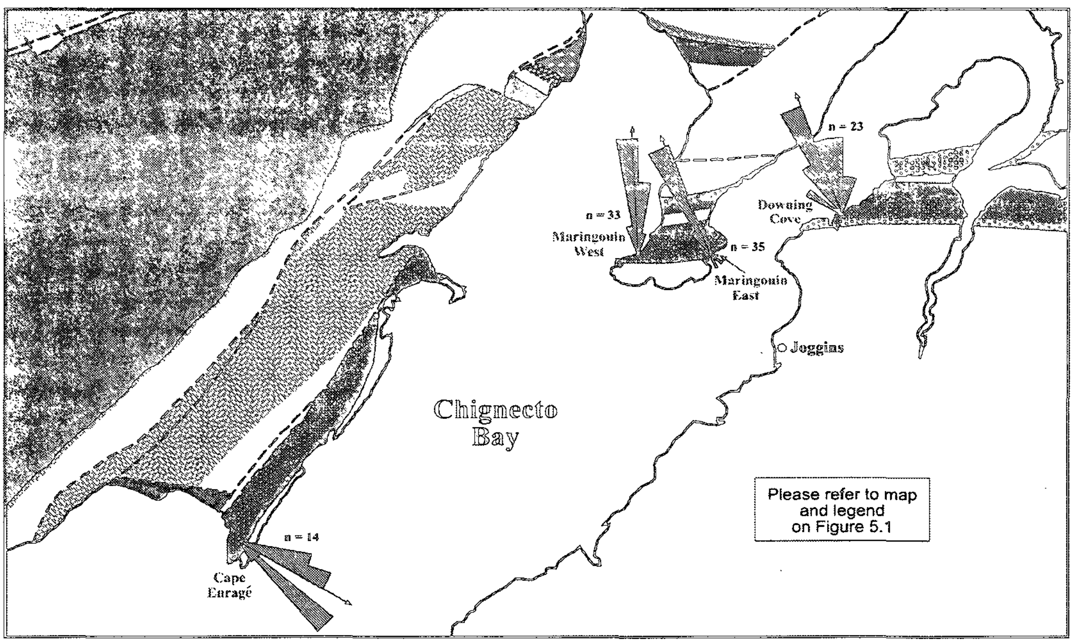


Figure 8.2 Paleocurrent vectors in the Namurian Shepody Formation based on trough cross-bed orientations.

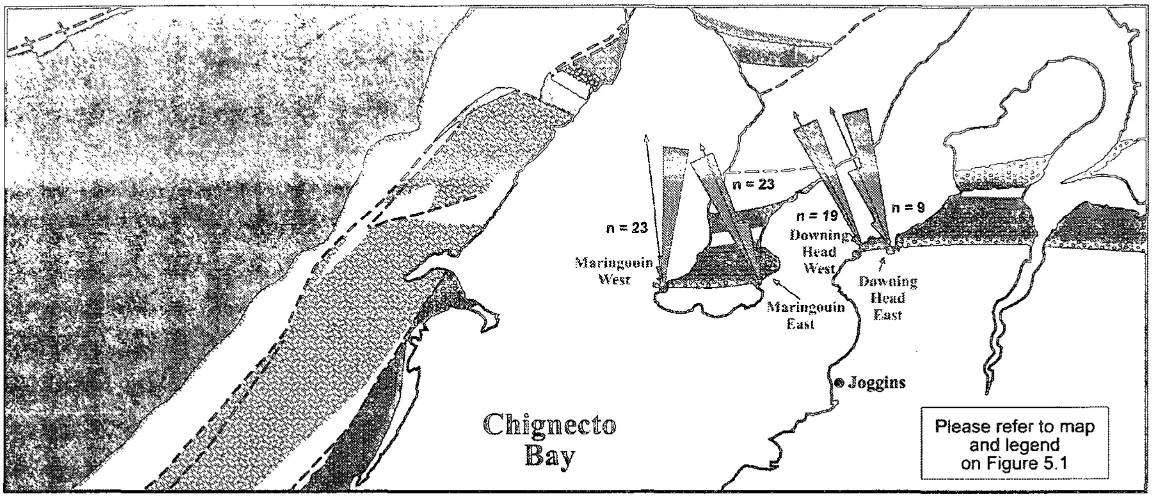


Figure 8.3 Paleocurrent vectors in the Namurian Enragé Formation based on trough cross-bed orientations.

9.0 PROVENANCE

The west Cumberland Basin appears to have been sourced from three distinct source areas based on paleocurrent and geophysical data: the Cobequid Highlands to the south, the Caledonia Highlands to the west and the Westmorland Highlands to the north. These conclusions are here tested with provenance studies.

9.1 Successions sourced from the Cobequid Highlands

The mid-Viséan to early Namurian successions at Minudie, Downing Cove, Downing Head, Maringouin West and East were all sourced from the Cobequid Highlands according to paleocurrent vectors, which consistently show that the sediments were being sourced from the south. Petrographic findings reveal that there is a significant quantity of rhyolite clasts present within sandstone of the Maringouin, Shepody and Enragé formations in the Maringouin sections (Tables 6.8-19 in Appendix 2), an important lithotype in the Cobequid Highlands. The abundant phyllite, schist and polycrystalline quartz in those thin-sections (Tables 6.8-19 in Appendix 2) strongly suggests a source that includes the Cobequid shear zone.

9.2 Successions sourced from the Westmorland Highlands

Among the herein studied sections, the Dorchester Cape section is the only one with paleocurrent vectors indicating a northerly source area, most likely the Westmorland

Highlands based on geophysical data (Figure 7.1) and the coarseness of the succession. The Shin member bears similar clast lithologies to those of the Cobequid Highlands, with abundant volcanic and plutonic rocks, and abundant shear-zone schist. Very little is known about the composition of the Westmorland Highlands due to the fact that they are almost entirely buried beneath Pennsylvanian strata. The conclusion of a Westmorland source is therefore not easily tested through provenance studies, but if that conclusion is correct, the clast contents within the Shin member at Dorchester Cape suggest that, similar to the Cobequid Highlands, the Westmorland Highlands are rich in igneous rock and shear-zone metamorphic rocks.

9.3 Successions sourced from the Caledonia Highlands

Based on geophysical data, sedimentary facies and paleocurrent vectors, the Lime-kiln Brook and/or Bonaventure formation of the Hopewell Cape and Alma sections, as well as the Maringouin Formation of the Cape Enragé section, were sourced from the Caledonia Highlands. At Hopewell Cape, paleocurrents point towards a small, dislocated piece of the Caledonia Highlands (Figure 8.1) which is well-observable on the geophysical image (Figure 7.1b). Interpretation of this post-sedimentary displacement will be discussed in the discussion chapter. As defined in section 6.2.1, petrographic counts in the Hopewell Cape conglomerate indicate a source characterized by abundant granitic rocks and metasedimentary rocks with one (Acadian) or two (Taconian and Acadian) cleavages, which are altogether compatible with a Caledonian source.

10.0 AIR-PHOTO ANALYSIS

Air photos obtained from the Map Library of Service Nova Scotia and Municipal Relations, as well as satellite photos from Google Earth, were used to establish the lateral extent of thick, coarse sandstone units in the Downing Cove and Downing Head sections, and to see how the contacts between the Shepody and Enragé formations and between the latter and the Boss Point Formation evolve laterally. The uppermost three grey sandstone intervals can be traced from Downing Cove to Downing Head West, which are labelled from the top down as G1 to G3 (see Figure 5.2, in pocket) with G1 being separated as G1a and G1b by a thin muddy interval (Figures 10.1 and 10.2). The sandstone units denoted as G3 and G2 display a relatively consistent thickness, with an equally thick succession of red mudrock separating the two units. These units appear to be laterally continuous for several kilometres, spanning the Downing Cove and Downing Head sections, and extending possibly as far as the Maringouin sections based on tentative (and very uncertain) correlations (Figure 5.2, in pocket). On both air photos (Figure 10.2) and stratigraphic sections (Figure 5.2, in pocket), an important thinning of the G1 unit is observable between Downing Cove and Downing Head W due to the truncation of most of the G1a unit by the disconformably overlying Enragé Formation. GPS coordinate data obtained in the field were used to plot the contact on both sides of Downing Cove in Google Earth. The coordinates matched the expected position of the contact based solely on the image. Hence, although only 10m of G1a is missing at Downing Cove West, compared with Downing Cove East, this 10m of downcutting is well observable on air

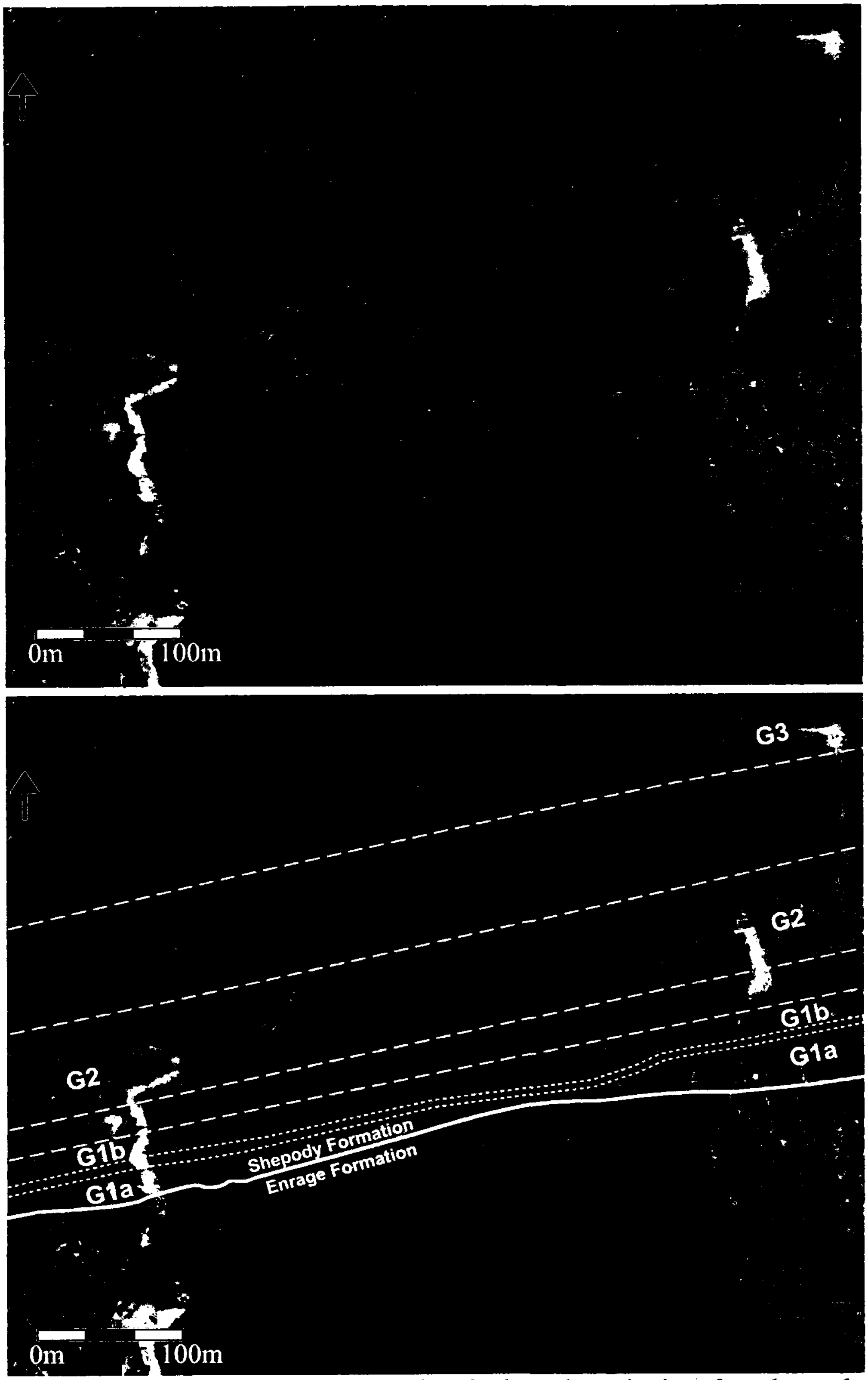


Figure 10.1 The Downing Cove area, showing the lateral continuity of sandstone bed markers as well as the erosive contact between Shepody and Enragé formations.

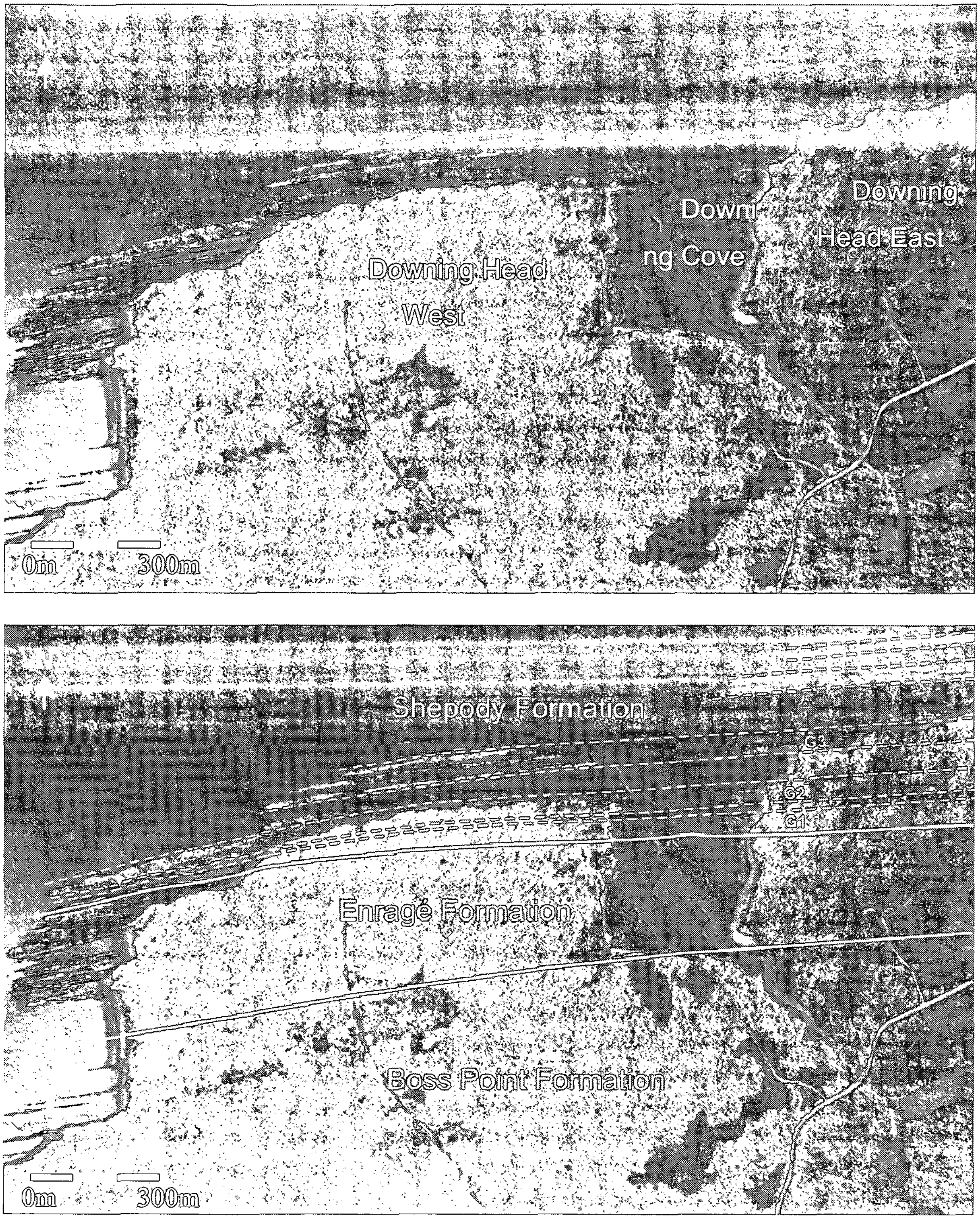


Figure 10.2 The Downing Head and Downing Cove areas, displaying the lateral continuity of thick grey sandstone sequences and intervening red beds.

photos due to the relatively shallow dip of the succession, which ranges between 35° and 40°, and which therefore exaggerates the disconformity. In contrast, the disconformity between the Enragé and the Boss Point formations is much less significant at that scale, based on observable lineaments on the air photo, although the contact is not exposed on the west side of the headland, which makes the amount of downcutting difficult to estimate.

11.0 DISCUSSION

11.1 Sedimentary Environments

11.1.1 Lime-kiln Brook Formation

11.1.1.1 Maccan member

Alternations of laminated red mudstone and stromatolitic carbonate of the Maccan member at Minudie (Figure. 5.2 & 5.3 in pocket) are interpreted as reflecting, respectively, times of high and low siliciclastic inputs and turbidity to a subtidal environment. The idea that even the red bed intervals are subtidal is supported by the presence of hummocky cross-stratification in one of those intervals. The times of low siliciclastic inputs are possibly related to the partial flooding of source areas during highstands, as Giles (2009) demonstrated that Middle and Upper Windsor Group carbonate intervals correspond with warm orbital cycles and the glacial retreats on Gondwana. The limestone intervals become increasingly thin moving up stratigraphy, and eventually cease to be present, potentially due to an increase in siliciclastic inputs, as the succession is gradually coarsening upward in parallel with the eventual disappearance of marine carbonates.

11.1.1.2 Demoiselle Creek member

The Demoiselle Creek member is also a succession of intercalated red beds and marine carbonates, but the red beds are clearly continental and interpreted as sheet flood conglomerates, consisting of poorly-rounded and poorly-sorted gravels (Figure 5.20). Due to the very coarse nature of the sediments and their persistence throughout the section, it can be ascertained that the source area was very proximal to this site. The presence of stromatolitic banks of limestone interbedded with coarse red beds suggests that, despite the proximity to the source area, this locality was also very near sea-level and at times marginally submerged. A normal fault scarp would best provide the high subsidence rates necessary to maintain the presence of a nearby marine body while depositing large quantities of coarse sediment. Also suggesting deposition near base-level is the observation that the conglomerates are planar-bedded and show no substantial downcutting (Figure 5.11), unlike typical arid alluvial fans, which are usually dissected by a braided system of gullies between sheet floods from lesser events of rainfall. Moreover, karst infills that stretch parallel to bedding at several levels also indicate a near surface water table during deposition, and a fast moving aquifer in a groundwater discharge zone. These observations altogether point to a fan delta setting.

11.1.2 Bonaventure Formation

11.1.2.1 Hopewell Cape member

Very thick and coarse successions of red, planar-bedded sheet flood conglomerates typify the Hopewell Cape member (Figure 5.20), with only a few notable beds of granular conglomerate and gravelly sandstone observed, indicating that it was part of an arid alluvial fan system. Again, the near absence of downcutting between sheetfloods signifies that, although the source area must have been proximal, the depositional environment of the Hopewell Cape member was still very close to base level and therefore similar to that of the underlying Demoiselle Creek member of the Lime-kiln Brook Formation. Previously unidentified karst structures that run parallel to bedding at several intervals, and which were subsequently infilled by finer sand and mud, also suggest deposition near base level in a groundwater discharge zone. It is therefore interpreted that through its entire thickness, the Hopewell Cape member was deposited in close proximity to a remnant arm of the Windsor Sea.

11.1.2.2 Shin member

The Shin member displays a rather variable succession of lithologies. At Dorchester Cape, red mudstone and fine sandstone beds show frequent and pervasive occurrences of mottling and root traces, indicating long periods of quiescence during sedimentation. These beds are separated by successions of granular to pebbly conglomerate, usually characterized by trough cross-bedding with minor occurrences of root traces. This pattern of deposition is most likely the result of seasonal or short-term climatic fluctuations, and suggests a sandy to gravelly braidplain environment.

The Alma section also shows cyclical deposition of trough cross-bedded sandstone and conglomerate (Figure 5.3 in pocket). However, the Alma section is overall coarser, more thoroughly trough cross-bedded, and less deeply affected by pedogenic overprints than at Dorchester Cape, suggesting that the depositional environment was also a sandy to gravelly braidplain system, but one that was subjected to higher rates of sedimentation due to its closer proximity to its source area.

11.1.2.3 Dorchester Cape Member

A finer unit than the Shin member, the gradationally overlying Dorchester Cape Member is characterized by mainly calcretized mudstone and fine sandstone units, which indicate that the succession was experiencing low rates of deposition and high rates of evaporation. Centimetre-scale calcrete hardpans are also noted at the top of some of these beds, indicating times of especially low sedimentation rates.

The fining upward pattern from the Shin member to the Dorchester Cape Member and within the latter implies an evolving depositional environment, gradually transitioning from a gravelly braidplain to a playa. Because of the presence of pedogenic calcite cement and root traces throughout the Shin and Dorchester Cape members, this gradational transition is interpreted as being related to decreasing sedimentation rates from decreasing rates of source area rejuvenation rather than to climate change, although a parallel aridification of the climate cannot be ruled out.

11.1.3 Maringouin Formation

11.1.3.1 Minudie member

The Minudie member at Minudie and Cape Enragé is almost exclusively composed of laminar mudstone, with no pedogenic overprint, much like the mudstone of the underlying Maccan member, suggesting a continued subtidal setting. The presence of limestone laminae and calcite-supported siltstone and fine sandstone also supports the iinterpretation of a subtidal setting, and suggests that the "carbonate factory" remained active, but was flooded by increasingly high siliciclastic inputs from an evolving source area. The area of the Maringouin Peninsula shows a higher input of siliciclastic sediment, where sandstone successions account for up to one third of the stratigraphic thickness, suggesting that these sections were closer to the source area. However, the absence of pedogenic overprints still suggests a dominantly subtidal to intertidal setting, with wide sandy tidal channels.

11.1.3.2 Pecks Cove member

The transition from the Minudie member to the sandier Pecks Cove member, which is still mainly planar-bedded but showing modest pedogenic overprints, is interpreted as a transition to a supratidal mudflat environment cut by wide fluvial channels. Some of the vertical variations in this member may be related to sea-level fluctuations, as some of the thicker packages of trough cross-bedded sandstone may indicate a temporary evolution towards a continental braidplain system, whereas finer intervals with interference ripples may reflect times of intertidal conditions. However, the absence of substantial downcutting, apart from small-scale trough cross-bedding in relatively thin tabular sandstone intervals, suggests that this member was altogether deposited quite close to base-level.

11.1.4 Shepody Formation

Cyclic and laterally persistent alternations of coarse grey sandstone and finer red intervals suggest that climatic fluctuations were of great influence during deposition of the Shepody Formation, most likely as a result of Croll-Milankovitch cycles. The large, laterally continuous trough cross-bedded coarse grey sandstone successions with plant remains, which are laterally uninterrupted on exposures that span up to 3 km in some cases, are interpreted as sandy braidplain deposits from a sub-humid setting. The intervals of planar-bedded red mudstone and fine sandstone with pedogenic overprinting are interpreted as playa deposits from semi-arid periods.

Overall, the Pendleian Shepody Formation seems to have evolved in a more purely continental environment than the Brigantian Maringouin Formation, with deeper downcutting and no evidence subtidal or intertidal environments, an observation that is also supported by the regional stratigraphy of Nova Scotia, which records in several areas a transition from marine environments in the Brigantian to continental environments in the Pendleian. In this purely continental environment, the highstand carbonates of the Windsor Group (Giles, 2009) were replaced by grey sandstone sequences during warm Croll-Milankovitch cycles, whereas colder lowstand cycles were still characterized by similar red beds. However, it is noteworthy that the Middle and Upper Windsor carbonates were evolving laterally into continental red beds of the Percé Group even during highstands, and that the Viséan-Namurian transition is therefore not only marked by a final retreat of the Windsor Sea from Nova Scotia, but also by a significant humidification of the climate.

11.1.5 Enragé Formation

The passage from grey sandstones of the Shepody Formation to conglomeratic red beds with no plant remains of the Enragé Formation is interpreted as a return to more arid conditions later in the Namurian, but not as arid as during the Viséan, as reflected by mineralogically more mature conglomerates, mudclasts excluded. Omnipresence of trough cross-bedding suggests that the depositional environment of the Enragé Formation was that of a semi-arid gravelly braidplain. The increase in granulometry might be related to a stronger ratio of mechanical to chemical weathering in the Enragé Formation than in the underlying Shepody Formation, but an increase in tectonic rejuvenation cannot be ruled out, especially given the fact that semi-arid intervals in the Shepody Formation are not very coarse. Very deep and pervasive weathering in the upper part of the Enragé Formation, including well-developed karst, suggests a substantial decrease in sedimentation rates at that level. Sedimentary quiescence seems to have been especially prolonged at the very top of the Enragé Formation, just below the disconformity with the Pennsylvanian Boss Point Formation, which coincides with the Mississippian-Pennsylvanian transition.

11.2 Paleogeographic Model (mid- to upper Viséan)

Based on the three known source areas of the west Cumberland Basin (Cobequid, Caledonia and Westmorland highlands), which were ascertained by geophysical data (see chapter 7) in conjunction with mapping data (St. Peter, 2001; McLeod and Johnson, 1999a,b; Ryan and Boehner, 1994), paleocurrent data (see chapter 8), provenance studies (see chapter 9) and facies distributions (see chapter 5 and previous sub-chapter), a fairly precise paleogeographic model of the west Cumberland Basin can be produced for the mid- to upper Viséan interval, with associated fault scarps (Figure 11.1). The time-slice chosen for the model is that corresponding to deposition of the uppermost carbonate bed of the Lime-kiln Brook Formation at Minudie, with interpreted lateral equivalences based on tentative correlations from one section to the next (Figures, 5.2 and 5.3 in pocket).

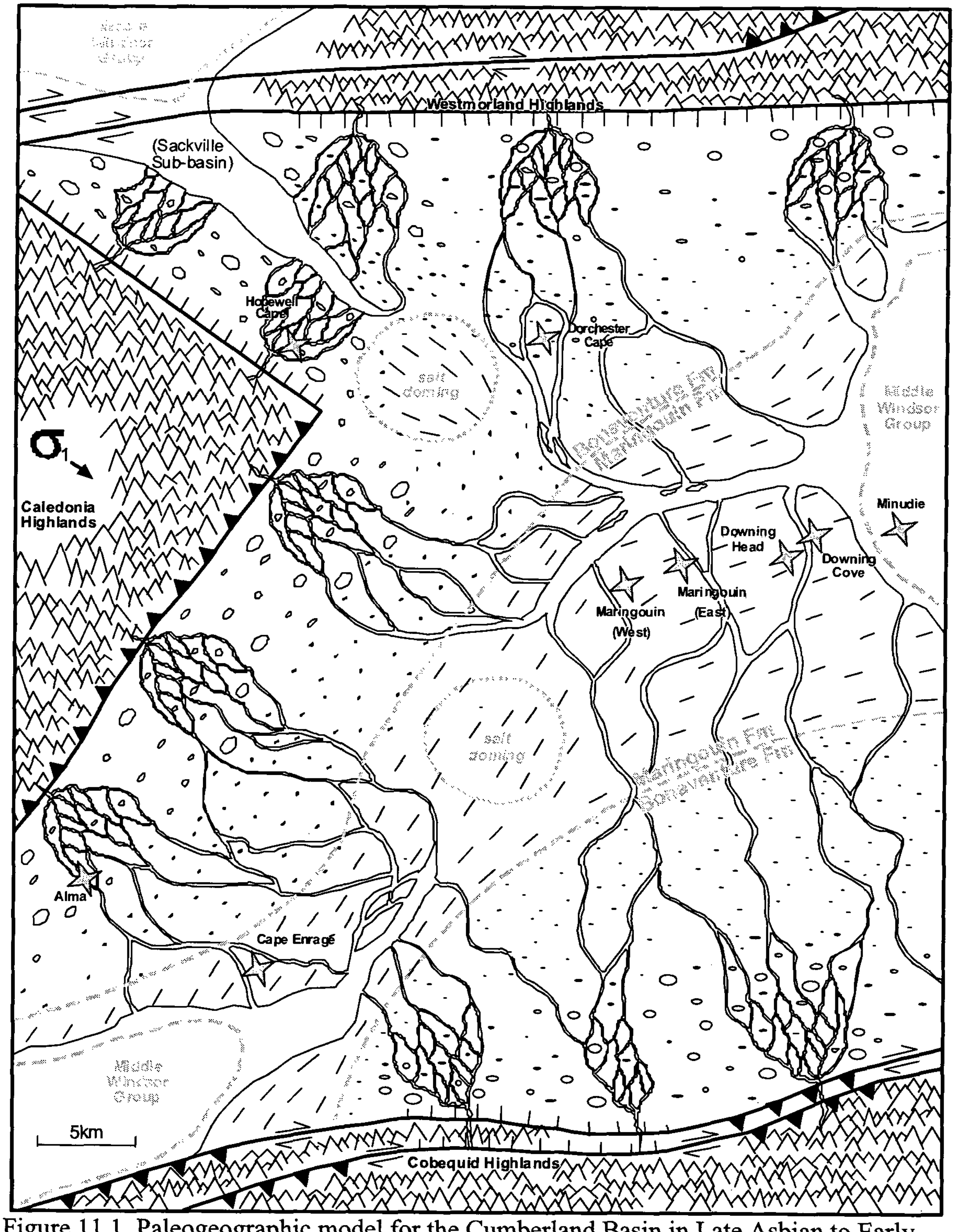


Figure 11.1 Paleogeographic model for the Cumberland Basin in Late Asbian to Early Brigantian times. The main principal stress vector (σ_1) is based on the work of Jutras and Prichonnet (2005) and Wilson and White (2006) on Mississippian units of other areas of the northwestern Maritimes Basin.

Each field location is placed on the model based on the inferred approximate position at the time of deposition. Substantial post-depositional displacement is only inferred for the Alma and Hopewell Cape sections. Mapping data makes it clear that the Alma section has been telescoped towards the southeast along SW-striking reverse faults, bringing closer together the proximal Shin member of the Bonaventure Formation to its distal equivalent, the Pecks Cove member of the Maringouin Formation at Cape Enragé.

The Hopewell Cape section displays a more complicated history of faulting (Figure 11.2). Near the Mississippian-Pennsylvanian boundary, in response to plate readjustments related to the final closure of an ocean that was previously separating west Africa from southeast U.S.A. (a remnant of the Rheic Ocean, often referred to as "Theic"), paleostress vectors rotated clockwise from a NW-SE (Fig. 11.2A) to a NNW-SSE (Fig. 11.2B) main principal stress (Faure et al., 1996; Jutras et al., 2003a, 2005). This is interpreted to have caused the dislocation of the Hopewell Cape section and its immediate source area along a WNW-striking dextral fault, which is inferred from both mapping (Fig. 5.1) and geophysical (Fig. 7.2) data (Fig. 11.2B). This fault is part of a series of NW- to WNW-striking faults that form well-defined lineaments on the gravity-magnetic image (marked as yellow dashed lines on Figure 7.2). In some cases, dextral motion can be inferred by the displacement of geophysical features (Fig. 7.2).

Continuing rotation of paleostresses in early Pennsylvanian times is interpreted to have caused a new episode of reverse faulting to occur along east-west striking faults (Fig. 11.2C), and transtensional sinistral movement along the Harvey-Hopewell Fault system (Fig. 11.2D) due to a nearly north-south main principal stress vector, which is

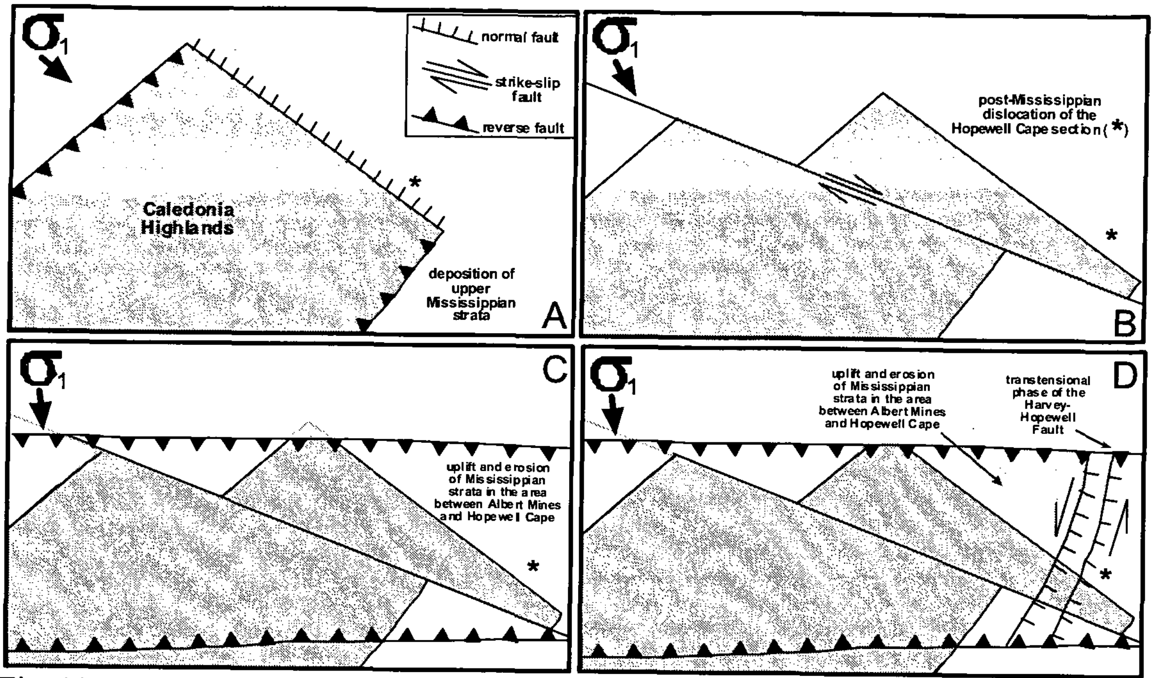


Fig. 11.2 Proposed scenario for the dislocation of the Hopewell Cape section (marked with an asterisk) and immediate source area based on geophysical and mapping data. Dark grey areas show uplifted basement blocks that were sub-aerially exposed; light grey areas show basement blocks with a thin cover of Carboniferous strata; white areas were occupied by thick Carboniferous strata. A: hypothetic geometry of the Caledonia Highlands at the time of upper Mississippian deposition based on mapping data, sedimentological data and paleostress data from Faure et al. (1996), Jutras and Prichonnet (2005), and Wilson and White (2006). B: post Mississippian displacement of the Hopewell-Cape section and immediate source area along a dextral strike-slip fault due to the clockwise rotation of paleostresses (Faure et al.,1996; Jutras et al., 2003a, 2005, 2007a) during the late Namurian Alleghanian deformation. C: east-west striking reverse faults affecting Mississippian strata in NB and NS from the clockwise rotation of paleostresses to a nearly north-south main principal stress (Faure et al.,1996; Jutras et al., 2003a, 2005, 2007a), in later stages of the late Namurian Alleghanian deformation, and generating uplift and erosion of Mississippian strata in the area between Albert Mines and Hopewell Cape prior to deposition of the early Pennsylvanian Boss Point Formation. D: transtensional sinistral movement along the Harvey-Hopewell Fault system in response to a nearly north-south main principal stress (Faure et al.,1996; Jutras et al., 2003a, 2005, 2007a), while ongoing reverse movement occurred along east-west structures during the latest stages of the late Namurian Alleghanian deformation, still prior to deposition of the Boss Point Formation.

recorded at that time in rocks of eastern Quebec (Faure et al., 1996; Jutras et al., 2003a) and northern New Brunswick (Jutras et al., 2005, 2007a). This is interpreted to have caused uplift and erosion of much of the thick Mississippian strata that were occupying the area between Hopewell Cape and Albert Mines (Fig. 11.2C). This area is now occupied by a thin cover of Carboniferous rocks according to its steep gravity and magnetic signatures, which reflect the presence of near-surface basement rocks (Fig. 7.2). According to mapping data, this uplift and erosion occurred prior to deposition of the early Pennsylvanian Boss Point Formation, although these two trends of faults also show evidence for post-Carboniferous activity.

Based on the sedimentology of each stratigraphic unit, as represented on the stratigraphic columns (Figures 5.2 and 5.3, in pocket), a lateral distribution of sedimentary facies can be applied to the mid- to upper Viséan (late Asbian to early Brigantian) (i.e., prior to the post-Mississippian deformation of the basin) model. The west Cumberland Basin was characterized by very coarse siliciclastic material deposited near three source areas and evolving inward towards either finer continental deposits or marine deposits (Figure 11.1). The strike of Mississippian fault scarps is traced perpendicular to paleocurrents, whereas their distance to the sections is based on sediment coarseness linked with existing structures that correspond to the inferred strike on geological (Figure 5.1) and geophysical (Figure 7.2) maps. The kinetics of the faults are inferred to be controlled by NW-compression based on studies on Mississippian rocks in the rest of the northwest sector of the Maritimes Basin (Jutras and Prichonnet, 2005; Wilson and White, 2006; Jutras et al., 2007a). In this scenario, only the NW-striking fault that sourced the Hopewell Cape section would have acted as a purely extensional fault, which is compatible with the greater accommodation rates that are inferred from the stratigraphy of that section. Just as in the Ristigouche and Central basins of eastern Quebec and New Brunswick, SE-striking faults are interpreted as reverse faults, and E-W striking faults as oblique dextral strike-slips (Jutras and Prichonnet, 2005; Jutras et al., 2005, 2007b). Matching kinematics are well registered in the faults that border the Caledonia (McLeod and Johnson, 1999a) and Cobequid (Gibling et al., 2008) highlands, whereas E-W striking faults bordering the Westmorland Highlands are buried by Pennsylvanian strata, but are inferred to have a similar history to that of the E-W striking faults of the Cobequids.

Available data do not allow determining whether or not the Windsor Sea ever occupied the entire Cumberland Basin during the Middle Windsor (Subzone B) interval. However, it can be determined that the marine presence was increasingly limited in extent from one transgression to the next, as suggested by the eastward thickening of the Lime-kiln Brook Formation, and the accompanying increase of carbonate intervals. Available data suggest that the Windsor Sea was subdivided into three arms in late Asbian to early Brigantian times (i.e. near the transition between the Lime-kiln Brook Formation and the Maringouin and Bonaventure formations), as the Cape Enragé, Hopewell Cape and Minudie sections all show evidence of closer proximity to the sea than the Dorchester Cape section, even though the latter is located in a more central area of the basin. This is strongly suggested by marine carbonate occurrences in Hopewell Cape and Minudie sections, paired with an observed lack of downcutting and of penetrative pedogenesis. At Cape Enragé, close proximity to the sea is suggested by the two latter observations, by a very fine granulometry, and by the observation of intertidal interference ripples. It is also suggested by marine carbonate occurrences through the entire Middle and Upper Windsor successions in the adjacent Minas Basin (Giles, 1981), which is only separated from the Cumberland Basin by the Cobequid Highlands. Hence, while most of the Cumberland Basin was continental during the Brigantian, the nearby Minas Basin was still accommodating marine transgressions during warm phases of Croll-Milankovitch cycles. Evidence of nearshore environments in Brigantian beds of the Cape Enragé section therefore suggests that a connection to the Minas Basin must have existed west of the Cobequids (Figure 11.1).

The inferred three part division of the Windsor Sea was possibly in part controlled by salt doming, which was already occurring at the time according to Waldron and Rygel (2005). According to these authors (Figure 11.3), at least two distinct episodes of salt diapirism occurred within the Cumberland Basin, one coeval with late Mississippian deposition, and one postdating that period. An example of post-Mississippian diapirism is noted along the northern portion of seismic line 539, where a consistent thickness of upper Mississippian successions is observed. Coeval upper Mississippian salt diapirism can be seen on the eastern side of seismic line 550, where what is referred to as the Mabou Group by Waldron and Rygel (2005), but which encompasses all post Lower Windsor and pre-Boss Point units (i.e., the Lime-kiln Brook, Bonaventure/Maringouin, Shepody and Enragé formations) distinctively thickens away from both the western and eastern limbs of a salt diapir (Figure 11.3b).

Analysis of paleodrainage patterns, originating from the Caledonia Highlands near the original position of Hopewell Cape, and away from the Westmorland Highlands

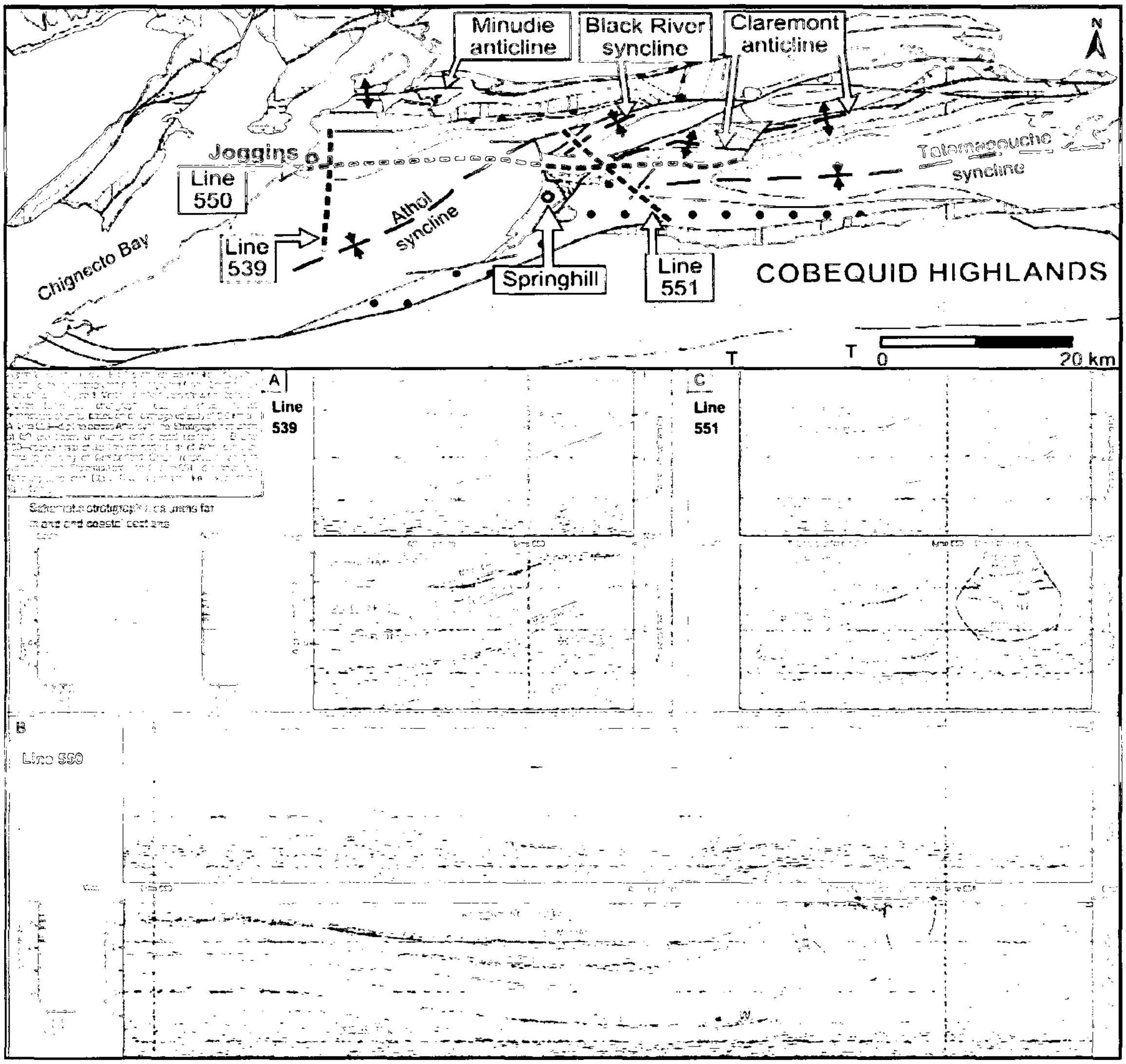


Figure 11.3 Stacked and migrated (uninterpreted and interpreted, above and below) seismic profiles of the Cumberland Basin strata, showing post-Mississippian doming along seismic line 539, and coeval upper Mississippian deposition and doming along seismic lines 551 and 550 (modified from Waldron and Rygel, 2005).

north of Dorchester Cape, shows that these systems were not evolving to flow towards one another, but rather to the northeast and southeast respectively (Figures 8.1 and 8.2). The most plausible explanation is the presence of a syn-sedimentary salt dome between Hopewell Cape and Dorchester Cape, redirecting the paleodrainage systems. Thick occurrences of Windsor Group salt in the Columbia Beaumont L-24, Imperial Dorchester 1 and Shell Dorchester 1 wells (Figure 5.1) near Dorchester Cape and in close proximity to exposures of Horton Group strata overlain by Hopewell Cape strata, with no intervening Windsor, suggests that salt withdrawal and diapirism indeed occurred in this area.

Paleocurrent vectors obtained at the Maringouin sections as well as the Downing Cove and Downing Head sections show dominantly northern directions, quite far from their Cobequid Highlands source (Figures 8.1 and 8.2). Without involving syn-sedimentary salt doming, it would be unexpected to see drainage patterns not converging with river systems flowing along a southeast vector away from the nearby Caledonia Highlands. The persistence of northern paleovectors and the lack of convergence towards the drainage system from the Caledonia Highlands suggest that salt doming was likely occurring in between the two systems, funnelling northward the rivers that were issued from the Cobequids. Based on line 550 (Figure11.3b), northward funnelling would have also been stimulated by syn-sedimentary salt doming to the east. Similar instances of river systems funnelled between syn-sedimentary salt domes are observed in Cretaceous river systems of the Scotian Shelf (Mosher et al., 2009). These north-flowing rivers must have been converging with the south-flowing rivers from the Westmorland Highlands before draining into the Windsor sea arm present at Minudie and east from there. The resulting convergence would have created a large trunk river system evolving into a large tidal channel and flowing directly into the Windsor sea arm.

11.3 Paleogeographic Model (Namurian)

Although not exposed at enough localities to be able to produce a detailed paleogeographical model for them, the Shepody and Enragé formations display similar paleocurrent trends to those of the underlying Viséan units at all localities. This suggests a similar tectonic environment in which sedimentation was controlled by the same fault scarps and was still funnelled by ongoing salt doming. However, a substantial change of climate is apparent for both the Shepody and Enragé formations, and perhaps higher rates of source area rejuvenation for the latter only. Finally, the pronounced disconformity between the Shepody and Enragé formations is probably the result of a substantial lowering of base level at the poorly-controlled time interval (Pendleian-Arnsbergian boundary?) that separates the two units.

12.0 CONCLUSIONS

Based on stratigraphic and petrographic equivalences, as well as precedence, the stratigraphy of upper Mississippian strata between Nova Scotia and New Brunswick (Figure 2.1) was informally revised to mitigate redundancies between stratigraphic units and as a preliminary step to rationalize the stratigraphic nomenclature for that interval. Based on precedence, it is here suggested that the Upperton and Cassidy Lake formations of Anderle et al. (1979) be used rather than the Basal Anhydrite and Pugwash Mine formations of Ryan and Boehner (1994) to refer to, respectively, the Lower Windsor Group sulphate and salt units (Figure 3.1). As for the base of the Lime-kiln Brook Formation of Ryan and Boehner (1994), it is herein placed at the first occurrence of Faunal Subzone B carbonates (Bell, 1929), which typically occur above a thick succession of red mudrock assigned elsewhere to the Tennycape Formation (Weeks, 1948), and included within the Lower Windsor Group (Giles, 1981). In the study area, previous workers were lumping these underlying red beds within the Lime-kiln Brook Formation (e.g. Ryan and Boehner, 1994). The Maccan and Demoiselle Creek members of the Lime-kiln Brook Formation are informally introduced to differentiate successions characterized by interbedded red mudrock and carbonate in the former, and much coarser red beds with carbonates in the latter. Moreover, the Maringouin Formation of Norman (1941) is herein informally separated as the fine grained basal Minudie member and the sandier Pecks Cove member. These units are distinguished from the time-equivalent Bonaventure Formation by a finer granulometry, a lack of substantial downcutting, suggesting proximity to base level, and a lack of penetrative pedogenic overprints. The

Bonaventure Formation of Logan (1845) was recently introduced to the Cumberland Basin stratigraphy based on correlations with northern New Brunswick and eastern Quebec (Jutras et al., 2007b), and is herein informally subdivided into three units, the Hopewell Cape, Shin and Dorchester Cape members. The latter member was introduced by McLeod and Johnson (1999b) to define the finer and deeply calcretized upper part of the Hopewell Cape Formation of Ami (1902), which is here correlated with the Bonaventure Formation after Jutras et al. (2007b), and which is informally referred to as a member characterized more specifically by a succession of coarse, planar-bedded conglomerate. The Shin Formation of van de Poll (1967), which was recently abandoned based on its correlation with the Bonaventure Formation (Jutras et al., 2007a,b), is informally reintroduced as a member to denote the most ubiquitous facies of this formation (its former informal lower member, *sensu* Jutras and Prichonnet, 2005), which is a trough-cross stratified polymictic conglomerate with abundant to occasional sandstone.

Stratigraphic, petrographic, sedimentologic, palynologic and geophysical analyses of the west Cumberland Basin have yielded a more complete understanding of its paleogeographical and paleoenvironmental evolution in upper Viséan to early Namurian times. From a combination of concurring geophysical, provenance, paleocurrent, facies distribution and mapping data, it can be concluded that the Cobequid, Caledonia and Westmorland highlands were the primary fault-bound source areas of the west Cumberland Basin.

During the late Asbian to early Brigantian, marine transgressions in the Cumberland Basin were decreasingly far reaching, exposing much of its central portions, and seemed to have been eventually subdivided into three small sea arms (Figure 11.1). The coarse Hopewell Cape member of the Bonaventure Formation and the much finer Maringouin Formation are interpreted as proximal to those sea arms, based mainly on limited downcutting and pedogenetic overprinting in these units compared with the coeval Shin and Dorchester Cape members of the Bonaventure Formation, which are interpreted as having evolved farthest from the sea.

The exposed sections of the Shin member include only gravelly to sandy braidplain facies, but these facies must have evolved towards alluvial fans closer to the fault-bound source areas. As these gravelly and sandy braidplain river systems evolved towards the lower laying, marine influenced zones of the west Cumberland Basin, syn-sedimentary salt doming seems to have directly influenced paleodrainage patterns within the basin, effectively funnelling drainage from the Westmorland Highlands to the south and preventing the convergence of these river systems with those flowing northeast, away from the Caledonia Highlands, thus creating the more purely continental conditions associated with the Dorchester Cape area. Salt doming also seemed to have funnelled river channels from the Cobequids much farther north than would be expected, and prevented them from merging with the nearby southeast flowing hydrologic system that was issuing from the Caledonia Highlands. The transition from the Shin facies to the finer Dorchester Cape Member, which is also the product of much lower sedimentation rates according to the high maturity of its calcretes, is interpreted as being related to a slow-down of tectonics and relief rejuvenation in the study area near the end of the Viséan.

The Viséan-Namurian transition corresponds to a gradual, but rapid change from a hyper-arid climate to one in which sub-humid and semi-arid conditions were alternating in a cyclic way, as reflected by occurrences of thick coarse grey sandstone beds with fossilized plant remains alternating with semi-arid red playa deposits, which altogether form the lower Namurian Shepody Formation. The climate reverted back to a longer lasting semi-arid climate later in the Namurian when the coarser and barren red beds of the Enragé Formation were disconformably deposited over the Shepody Formation. The Enragé Formation also records a recrudescence of tectonic rejuvenation in the area. A long period of little to no deposition followed, during which the top of the Enragé Formation was deeply weathered and karstified prior to being disconformably overlain by the lowermost Pennsylvanian Boss Point Formation. This weathering-dominated period is interpreted as corresponding to a wide mid-Namurian hiatus associated with an important floral crisis in eastern Canada (Utting, 1987) and corresponding to an important step in the assembly of Pangea at the Mississippian-Pennsylvanian boundary.

12.1 Economic Implications

The economic prospects for the west Cumberland Basin of southern New Brunswick and Nova Scotia are in part founded in historical bitumen exploitation at Albert Mines, in the north-westernmost sector of the basin, which is often referred to as the Sackville Subbasin. There is also current oil and gas production at the Stoney Creek and McCully fields within the nearby Moncton Basin of southern New Brunswick, which bears similar stratigraphy and structural characteristics as the west Cumberland Basin, and which has contributed in maintaining interest and exploration within the Sackville Subbasin of New Brunswick as well.

Oil and gas from the aforementioned wells are sourced from Tournaisian oil shales of the Albert Formation and hosted by younger Tournaisian sandstones, which are altogether present in both basins. The presence of thick evaporites and salt domes throughout the Cumberland Basin creates many opportunities for both seals and structural traps, and the thick and impermeable successions of mudrock in the Minudie member of the Maringouin Formation offer another potential cap rock. The close proximity of the Maringouin Peninsula to the inferred salt doming structure in Chignecto Bay (Fig. 11.1) makes it an especially promising area, as attested by the presence of a small diapir of gypsum on the west side of the peninsula (Figure 5.4; this gypsum was exploited in the earlier part of the 20th century, and could potentially be exploited again in the future).

Finally, the west Cumberland Basin also has a good potential for fault traps, especially in the Cape Enragé area, which is also near the inferred diapir in Chignecto Bay, and which is affected by a tight series of thrust faults. Keeping in mind that the faults probably also affect buried Tournaisian source and reservoir rocks, as well as impermeable Viséan evaporites and mudrocks, they are part of a very interesting oil and gas prospect that clearly calls for additional study and exploration.

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<u>APPENDIX 1:</u> PALYNOLOGICAL INVESTIGATION OF OUTCROP SAMPLES FROM THE CARBONIFEROUS OF THE CUMBERLAND BASIN OF NOVA SCOTIA AND NEW BRUNSWICK

By John Utting of the Geological Survey of Canada (Calgary)

(NTS 21H/9, 21H/10, 21H/16)

The relevant parts of any manuscript prepared for publication that paraphrase or quote from this report should be referred to the author or, if not available, the Chief Paleontologist, Geological Survey of Canada (Calgary) for possible revision.

All references to age determination and paleontological data must quote the authorship of the report, GSC (Calgary) report number and the unique GSC locality number of the fossil collection.

INTRODUCTION:

The aim of the study was to determine the age of the samples, and the thermal maturity. The approximate proportions of the organic matter constituents given for each sample are based on visual estimates of the organic matter prior to sieving. The Thermal Alteration Index (T.A.I.), and equivalent vitrinite reflectance values, are based on the scale proposed by Utting et al. (1989) for the upper Paleozoic of the Sverdrup Basin.

OUTCROP SAMPLES:

GSC LOCALITY C-430728.
FIELD NO: 05-124.
South-westernmost section of the Mabou Group in the Maringouin Peninsula of N.B.
Coordinates: 21H/10; 45°44'08.5"N, 64°32'19.1"W.

ROCK UNIT:
Lowermost Shepody Formation; 0.5 m above contact with Maringouin Formation.

ORGANIC MATTER AND THERMAL MATURITY:
Common finely dispersed organic debris, amorphous particles and exinous material. Abundant woody and coaly fragments.
T.A.I. 2 = Ro% 0.55 ("oil window").

IDENTIFICATIONS:
Auroraspora macra, Calamospora parva Guennel, *Chomotriletes multivittatus, Colatisporites decorus, Crassispora trychera, Densosporites columbaris* Utting, *Ibrahimispores magnificus, Lycospora pusilla* (Ibrahim) Schopf, Wilson and Bentall, *Neoraistrickia versiforma, Punctatisporites glaber, Raistrickia magdalena, Rugospora minuta, R. polyptycha* Neves and Ioannides, *Schopfipollenites acadiensis, Schopfites claviger, Spelaeotriletes arenaceus, S. bellii, S.tuberosus, S. windsorensis* (common), *Vallatisporites* sp., *Verrucosisporites morulatus* (Knox) Smith and Butterworth.
PROBABLE AGE:
The overall assemblage characteristics and the presence of *I. magnificus* suggests a correlation with the *G. spinosa-I. magnificus* Concurrent Range Zone dated as latest Brigantian to Pendleian (Utting and Giles 2004; von Bitter et al. 2007).

GSC LOCALITY C-430729.
FIELD NO: 05-125.
South-westernmost section of the Cumberland Group in the Maringouin Peninsula, N.B.
Coordinates: 21H/10; 45°43'39.5"N, 64°32'44"W.

ROCK UNIT:
Boss Point Formation; 96 m above the uppermost exposures of the Enragé Formation beds (44 m gap between the two units).

ORGANIC MATTER AND THERMAL MATURITY:
Common exinous material and abundant woody and coaly fragments.
T.A.I. 2 = Ro% 0.55 ("oil window").

IDENTIFICATIONS:
Convolutispora sp., *Florinites pumicosus* (Ibrahim) Schopf, Wilson and Bentall, *F.* spp. *Knoxisporites triradiatus* Hoffmeister, Staplin and Malloy, *Potonieisporites elegans*

(Wilson and Kosanke) Kosanke and Venkatachala, *P.* spp., *Florinites/Potonieisporites* complex, *Punctatisporites glaber, Raistrickia magdalena* Utting, *Schopfipollenites acadiensis, Wilsonites*? sp.

PROBABLE AGE:
Common monosaccate pollen of the *Florinites/Potonieisporites* complex is characteristic of the Boss Point Formation of the Joggins section of Nova Scotia, tentatively dated as Yeadonian to Langsettian (work in progress).

GSC C LOCALITY C-430730.
FIELD NO: 05-126.
South-westernmost section of the Cumberland Group in the Maringouin Peninsula, N.B.
Coordinates: 21H/10; 45°43'50.7"N, 64°32'33.2"W.

ROCK UNIT:
Boss Point Formation; 1 m above the uppermost exposures of the Enragé Formation beds (44 m gap between the two units).

ORGANIC MATTER:
Coaly fragments. No palynomorphs.

GSC LOCALITY C-430731.
FIELD NO: 05-127.
South-westernmost section of the Cumberland Group in the Maringouin Peninsula, N.B.
Coordinates: 21H/10; 45°43'52.4"N, 64°32'31.1"W.

ROCK UNIT:
Boss Point Formation; 75 m above the uppermost exposures of the Enragé Formation beds (44 m gap between the two units).

ORGANIC MATTER:
Woody and coaly fragments. No palynomorphs.

GSC LOCALITY C-430732.
FIELD NO: 05-129.
South-westernmost section of the Cumberland Group in the Maringouin Peninsula, N.B.
Coordinates: 21H/10; 45°44'55.5"N, 64°32'29.1"W.

ROCK UNIT:
Lowermost Boss Point Formation; 50 m above the uppermost exposures of the Enragé Formation beds (44 m gap between the two units).

ORGANIC MATTER:
Woody and coaly fragments. No palynomorphs.

GSC LOCALITY C-430733.
FIELD NO: 05-130.
South-westernmost section of the Mabou Group in the Maringouin Peninsula of N.B.
Coordinates: 21H/10; 45°44'16.5"N, 64°32'39.1"W.

ROCK UNIT:
Uppermost Shepody Formation; 1 m below the contact with the Enragé Formation.

ORGANIC MATTER AND THERMAL MATURITY:
Common exinous material, abundant woody and coaly fragments
T.A.I. 2+ = Ro% 0.9 ("oil window").

IDENTIFICATIONS:
Auroraspora solisorta, Chomotriletes multivittatus, Colatisporites decorus, Crassispora trychera, Cyclogranisporites sp., *Granulatisporites tuberculosus, Ibrahimispores magnificus, Knoxisporites stephanephorus* Love,*Kraeuselisporites ornatus* (Neves) Owens, Mishell and Marshall, *Lycospora pusilla* , *Punctatisporites glaber* (abundant), *Raistrickia magdalena, Rugospora minuta, Schopfipollenites acadiensis, Spelaeotriletes arenaceus, S. bellii, S. windsorensis.*

PROBABLE AGE:
The overall characteristics and the presence of *I. magnificus and Kraeuselisporites ornatus* suggests a correlation with the *G. spinosa-I. magnificus* Assemblage Zone dated as latest Brigantian to Pendleian (Utting and Giles 2004; von Bitter et al. 2007).

GSC LOCALITY C-430734.
FIELD NO: 05-157.
South-easternmost section of the Mabou Group in the Maringouin Peninsula, N.B.
Coordinates: 21H/9; 45°44'39.4"N, 64°28"56.4"W.

ROCK UNIT: Maringouin Formation. Intraclastic mud clasts from the base of a conglomerate, 60 m m below the Maringouin/Shepody contact.

ORGANIC MATTER AND THERMAL MATURITY:
Common exinous material; abundant woody and coaly fragments.
T.A.I. 2/2+ = Ro% 0.6 ("oil window").

IDENTIFICATIONS:
Auroraspora macra Sullivan, *Calamospora* sp., *Colatisporites decorus* (Bharadwaj and Venkatachala) Williams, *Crassispora trychera* Neves and Ioannides (abundant) *Discernisporites micromanifestus* (Hacquebard) Sabry and Neves, *Punctatisporites glaber* (Naumova) Playford (abundant), *Rugospora minuta* Neves and Ioannides, *Schopfites claviger* Sullivan, *Schopfipollenites acadiensis* Utting, *Spelaeotriletes bellii* Utting, *S. windsorensis* Utting.

PROBABLE AGE:
The assemblage listed here suggests a correlation with the *acadiensis - K. triradiatus* Concurrent Range Zone of Brigantian age.

GSC LOCALITY C-430735.
FIELD NO: 05-158.
South-easternmost section of the Mabou Group in the Maringouin Peninsula of N.B.
Coordinates: 21H/9; 45°44'35.6"N, 64°28"53.9"W.

ROCK UNIT: Maringouin Formation. Intraclastic mud clasts from the base of a conglomerate; 45 m below the Maringouin/Shepody contact.

ORGANIC MATTER AND THERMAL MATURITY:
Common exinous material; abundant woody and coaly fragments.
T.A.I. 2/2+ = Ro% 0.6 ("oil window").

IDENTIFICATIONS:
Crassispora trychera (abundant),*Punctatisporites glaber* (abundant), *Rugospora minuta, Schopfipollenites acadiensis, Spelaeotriletes bellii, S. echinatus* (Hacquebard) Utting, *S. windsorensis*, *Verrucosisporites verrucosus* (Ibrahim) Ibrahim.

PROBABLE AGE:
The assemblage listed here suggests a correlation with the *acadiensis - K. triradiatus* Concurrent Range Zone of Brigantian age.

GSC LOCALITY C-430736.
FIELD NO: 05-159.
South-easternmost section of the Mabou Group in the Maringouin Peninsula of N.B.
Coordinates: 21H/9; 45°44'33.5"N, 64°28"51.3"W.

ROCK UNIT: Maringouin Formation. Intraclastic mud clasts from the base of a conglomerate; 35 m .below the Maringouin/Shepody contact.

ORGANIC MATTER AND THERMAL MATURITY:
Common exinous material; abundant woody and coaly fragments.
T.A.I. 2/2+ = Ro% 0.6 ("oil window").

IDENTIFICATIONS:
Assemblage poor. *Crassispora trychera* (abundant), *Discernisporites micromanifestus, Punctatisporites glaber* (abundant), *Rugospora minuta, Schopfites claviger, Spelaeotriletes bellii, S. tuberosus* Utting, *S. windsorensis.*

PROBABLE AGE OF MUD CLASTS:
The assemblage listed here suggests a correlation with the *acadiensis - K. triradiatus* Concurrent Range Zone of Brigantian age.

GSC LOCALITY C-430737.
FIELD NO: 05-160
Coordinates: 21H/9; 45°44'33.4"N, 64°28"51.2"W.
South-easternmost section of the Mabou Group in the Maringouin Peninsula of N.B.
ROCK UNIT: Base of the Shepody Formation. Mud clasts in the basal intraclastic conglomerate.

ORGANIC MATTER AND THERMAL MATURITY:
Common exinous material; abundant woody and coaly fragments.
T.A.I. 2/2+ = Ro% 0.6 ("oil window").

IDENTIFICATIONS:
Chomotriletes multivittatus Playford, *Crassispora trychera* (abundant), *Cymbosporites acutus* (reworked?), *Ibrahimispores magnificus* Neves, *Neoraistrickia versiforma* Utting, *Punctatisporites glaber* (abundant), *Raistrickia magdalena* Utting, *Rugospora minuta, Schopfipollenites acadiensis, Spelaeotriletes arenaceus* Neves and Owens, *Spelaeotriletes bellii, S. tuberosus, S. windsorensis.*

PROBABLE AGE:
The overall characteristics of the assemblage and the presence of *I. magnificus* suggests a correlation with the *G. spinosa-I. magnificus* Concurrent Range Zone dated as latest Brigantian to Pendleian (Utting and Giles 2004; von Bitter et al. 2007).

GSC LOCALITY C-430980.
FIELD NO: 05-162.
South-easternmost section of the Mabou Group in the Maringouin Peninsula of N.B.
Coordinates: 21H/9; 45°44`19.0N, 64°29.47'18.8"W
ROCK UNIT: Uppermost Shepody Formation; 0.3 m below the contact with the Enragé Formation.

ORGANIC MATTER AND THERMAL MATURITY:
Common exinous material, abundant woody and coaly fragments.
T.A.I. 2+ = Ro% 0.9 ("oil window``).

IDENTIFICATIONS:
Auroraspora macra, A. solisorta,Colatisporites decorus, Crassispora trychera, Cyclogranisporites aureus, Densosporites anulatus, Punctatisporites glaber (abundant), *Knoxisporites stephanephorus, Leiotriletes* sp., *Raistrickia magdalena, Rugospora minuta, Schopfipollenites acadiensis* (abundant), *Spelaeotriletes bellii, S. tuberosus, S.windsorensis, Vallatisporites* sp., *Verrucosisporites nitidus* (Naumova) Playford.

PROBABLE AGE:
The overall characteristics and the presence of *G. spinosa* suggests a correlation with the *G. spinosa-I. magnificus* Concurrent Range Zone dated as latest Brigantian to Pendleian (Utting and Giles 2004; von Bitter et al. 2007).

GSC LOCALITY C-430977.
FIELD NO: BPB
Northern part of the Joggins section at Downing Cove, NS.
Coordinates: 21H/9; 45°44'56.0"N, 64°24'53.5"W.
ROCK UNIT:
Base of the Boss Point Formation, in a reshuffled regolith disconformably overlying red mudrock of the upper Claremont/Enragé Formation.

ORGANIC MATTER AND THERMAL MATURITY:
Common exinous material, abundant woody and coaly fragments.
T.A.I. 2/2+ = Ro% 0.6 ("oil window).

IDENTIFICATIONS:
Anapiculatisporites baccatus, Auroraspora macra, A. solisorta ,Calamospora parva, Colatisporites decorus, Crassispora trychera, Cyclogranisporites aureus, Florinites pumicosus, Florinites/Potonieisporites complex, *Granulatisporites granulatus, Lycospora pusilla, Potonieisporites elegans, Raistrickia* sp., *Schopfipollenites acadiensis, Triquitrites* sp., *Simonozonotriletes* sp., *Vallatisporites* sp., *Wilsonites*? sp.

PROBABLE AGE:
The presence of *F. pumicosus, P. elegans, Florinites/Potonieisporites* complex and *Wilsonites?* sp., is a characteristic of the Boss Point assemblages for which a Yeadonian to Langsettian age is suggested (work in progress).

GSC LOCALITY C-430978.
FIELD NO: CPD
Cape Dorchester, Maringouin Peninsula, N.B.
Coordinates: 21H/9; 45°44'39.4"N, 64°28'56.4"W.

ROCK UNIT:
Uppermost Shepody Formation near the contact with the Enragé Formation.

ORGANIC MATTER AND THERMAL MATURITY:
Common exinous material, abundant woody and coaly fragments.
T.A.I. 2+ = Ro% 0.9 ("oil window``).

IDENTIFICATIONS:
Calamospora parva, Colatisporites decorus, Crassispora trychera (abundant), *Discernisporites micromanifestus, Grandispora spinosa, Knoxisporites triradiatus, Punctatisporites glaber* (abundant), *Raistrickia magdalena, Rugospora corporata* var. *verrucosus, Schopfipollenites acadiensis, Spelaeotriletes arenaceus, S. tuberosus, S.windsorensis, Vallatisporites* sp., *Verrucosisporites nitidus.*

PROBABLE AGE:
The overall characteristics and the presence of *G. spinosa* suggests a correlation with the *G. spinosa-I. magnificus* Concurrent Range Zone dated as latest Brigantian to Pendleian (Utting and Giles 2004; von Bitter et al. 2007).

GSC LOCALITY C-430979.
FIELD NO: CE1.
Cape Enragé, N.B.
Coordinates: 21H/10; 45°35'44.7"N, 64°47'18.8"W.

ROCK UNIT:
Uppermost Shepody Formation near the contact with the Enragé Formation.

ORGANIC MATTER AND THERMAL MATURITY:
Common exinous material, abundant woody and coaly fragments.
T.A.I. 2+ = Ro% 0.9 ("oil window``).

IDENTIFICATIONS:
Auroraspora macra, Colatisporites decorus, Crassispora trychera (abundant), *Cyclogranisporites* sp., *Densosporites anulatus, Knoxisporites stephanephorus, Leiotriletes ornatus Lycospora* sp., *Punctatisporites glaber* (abundant), *Raistrickia magdalena, Retusotriletes incohatus* Sullivan, *Rugospora minuta, Schopfipollenites acadiensis* (abundant), *Schopfites claviger, Spelaeotriletes bellii, S. tuberosus, S.windsorensis, Vallatisporites* sp., *Verrucosisporites nitidus.*

PROBABLE AGE:
Although the assemblage listed here would suggest a correlation with the *acadiensis - K. triradiatus* Concurrent Range Zone of Brigantian age, the underlying basal Shepody beds (sample C-430728; 05-124) contain an assemblage assignable to the younger *G. spinosa-I. magnificus* Concurrent Range Zone of latest Brigantian to Pendleian age (Utting and Giles 2004; von Bitter et al. 2007). This may reflect the fact that the diagnostic taxa are rare. In addition, if the mud clasts were not penecontemporaneous with the conglomerate bed which contains them then the former may be slightly older.

GSC LOCALITY C-430993
FIELD NO: 02-1
Southeasternmost section of the Mabou Group in the Maringouin Peninsula of N.B.
Coordinates: 21H/9; 45□44'31.3"N, 64□28'49.4"W.

ROCK UNIT:
4 m thick black shale in the lower part of the Shepody Formation, 157 m below the Shepody/Enragé contact.

ORGANIC MATTER:
Exinous, woody and coaly fragments.

(T.A.I.): 2+ to 3- = R0 %0.9 to 1.2 ("oil window")

IDENTIFICATIONS:
Auroraspora solisorta, Colatisporites decorus, Crassispora trychera, Cristatisporites submarginatus, Discernisporites micromanifestus, Grandispora uncata, Knoxisporites triradiatus, Lycospora pusilla, Punctatisporites glaber, Pustulatisporites sp., *Raistrickia Magdalena, Retusotriletes incohatus, Schopfipollenites acadiensis, Spelaeotriletes bellii, S. windsorensis.*

PROBABLE AGE:
Brigantian
Schopfipollenites acadiensis-Knoxisporites triradiatus (Concurrent Range Zone)

GSC LOCALITY C-430994
FIELD NO: J-08-1.
Southwesternmost section of the Mabou Group in the Maringouin Peninsula of N.B.
Coordinates: 21H/10; 45□44'09.9"N, 64□32'12.6"W.

ROCK UNIT:
Grey mud clasts from the base of the lowermost Shepody Formation, at the contact with the underlying Maringouin Formation.

ORGANIC MATTER:
Exinous, woody and coaly fragments.
(T.A.I.): 2+ to 3- = R0 %0.9 to 1.2 ("oil window")

IDENTIFICATIONS:
Auroraspora solisorta, Calamospora parva, Colatisporites decorus, Crassispora trychera, Cristatisporitres submarginatus, Knoxisporites triradiatus, Punctatisporites glaber, Pustulatisporites sp., *Raistrickia magdalena, Retusotriletes incohatus, Schopfipollenites acadiensis, Spelaeotriletes bellii, S. windsorensis, Verrucosisporites nitidus.*
Rare reworked acritarchs: *Veryhachium* sp., *Diexallophasis remota*

PROBABLE AGE:
Brigantian
S. acadiensis-K. triradiatus (Concurrent Range Zone)

GSC LOCALITY C-430995
FIELD NO: J-08-2
Cape Enragé, N.B.
Coordinates: 21H/10; 45□36'18.6"N, 64□47'21.1"W.

ROCK UNIT:
Grey mud clasts from the base of the lowermost Shepody Formation, at the contact with the underlying Maringouin Formation.

ORGANIC MATTER:
Exinous, woody and coaly fragments.
(T.A.I.): 3, to 3+ and 4 = R0 %1.4 to 1.7 and 2.3 (gas prone)

IDENTIFICATIONS:
Auroraspora macra, Colatisporites decorus, Crassispora trychera (common), *Lycospora pusilla, Punctatisporites glaber, Raistrickia clavata, Rugospopora minuta, Schopfites claviger, Spelaeotriletes arenaceus.*

PROBABLE AGE:
Brigantian.
Crassispora maculosa-Spelaeotriletes arenaceus (Subzone)
Schopfipollenites acadiensis-Knoxisporites triradiatus (Concurrent Range Zone).

GSC LOCALITY C-430996
FIELD NO: J-08-3
Cape Enragé, N.B.
Coordinates: 21H/10; 45□36'12.2"N, 64□47'21.6"W.

ROCK UNIT:
Grey mudstone from the lower part of the Shepody Formation, 60 m above the contact with the underlying Maringouin Formation.

ORGANIC MATTER:
Exinous, woody and coaly fragments.
(T.A.I.): 3, to 3+ and 4 = R0 %1.4 to 1.7 and 2.3 (gas prone)

IDENTIFICATIONS:
Crassispora maculosa, C. trychera, Kraeuselisporites ornatus, Ibrahimispores magnificus, Punctatisporites glaber, Spelaeotriletes bellii.

PROBABLE AGE:
Pendleian
Grandispora spinosa-Ibrahimispores magnificus (Concurrent Range Zone)

GSC LOCALITY C-430997
FIELD NO: J-08-4
Cape Enragé, N.B.
Coordinates: 21H/10; 45□35'44.7"N, 64□47'18.8"W.

ROCK UNIT:
Grey mudstone from the upper part of the Shepody Formation, ~50 m below the inferred contact with the overlying Enragé Formation.

ORGANIC MATTER:
Exinous, woody and coaly fragments.
(T.A.I.): 3, to 3+ and 4 = R0 %1.4 to 1.7 and 2.3 (gas prone)

IDENTIFICATIONS:
Calamospora parva, Crassispora maculosa, Knoxisporites triradiatus, Leotriletes sp., *Lycospora pusilla, Punctatisporites irrasus* (abundant), *P. planus* (abundant), *Raistrickia magdalena, Retusotriletes incohatus, Schopfites claviger, Schopfipollenites acadiensis* (abundant), *Spelaeotriletes arenaceus, S. bellii, S. windsorensis.*

PROBABLE AGE:
Brigantian
Crassispora maculosa-Spelaeotriletes arenaceus (Subzone)
S. acadiensis-K. triradiatus (Concurrent Range Zone)

GSC LOCALITY C-483517
FIELD NO: J-08-7
Joggins, N.S., north of Downing Cove.
Coordinates: 21H/16; 45□45'25.3"N, 64□24'05.8"W.

ROCK UNIT:
Grey mud clasts from the basal sandstone bed of the Shepody Formation.

ORGANIC MATTER:
Exinous, woody and coaly fragments.
(T.A.I.): 3, to 3+ and 4 = R0 %1.4 to 1.7 and 2.3 (gas prone)

IDENTIFICATIONS
Calamospora parva, Colatisporites decorus, Crassispora trychera,Discernisporites micromanifestus, Ibrahimispores magnificus, Kraeuselisporites ornatus, Lycospora noctuina, Punctatisporites irrasus, P. planus, Pustulatisporites multicapitis, Rugospra minuta, Rugospora corporate var. *verrucosa, Schopfites claviger, Schopfipollenites acadiensis* (abundant), *Spelaeotriletes arenaceus, S. bellii, S. windsorensis.*

PROBABLE AGE:
Pendleian?
Grandispora spinosa-Ibrahimispores magnificus (Concurrent Range Zone)

GSC LOCALITY C-483518
FIELD NO: J-08-8
Cape Enragé, N.B.
Coordinates: 21H/10; 45□35'52.9"N, 64□47'09.8"W.

ROCK UNIT:
Grey mudstone from a small lens in the uppermost exposure of the Shepody Formation, less than 10 m below the inferred contact with the overlying Enragé Formation. It is part of a 10 m succession of beds that share many affinities with the Enragé Formation, although still bearing more similarities with t he Shepody Formation.

ORGANIC MATTER:
Exinous, woody and coaly fragments.
(T.A.I.): 3, to 3+ and 4 = R0 %1.4 to 1.7 and 2.3 (gas prone)

IDENTIFICATIONS:
Biannulatisporites simplex, Calamospora parva, Crassispora trychera, Kraeuselisporites ornatus, Punctatisporites irrasus, P. glaber, P. planus, Rugospra minuta, Schopfites claviger, Secarisporites lobatus, Schopfipollenites acadiensis (common), *Spelaeotriletes windsorensis.*

PROBABLE AGE:
Pendleian
G. spinosa-I. magnificus (Concurrent Range Zone)

REFERENCES:

Utting, J., Goodarzi, F., Dougherty, B.J. and Henderson, C.M. (1989) Thermal maturity of Carboniferous and Permian rocks of the Sverdrup Basin, Canadian Arctic Archipelago, Geological Survey of Canada, Paper **89-19:** 20p.

Utting, J., and Giles, P.S. (2004) Biostratiographical implications of new palynological data from the Mississippian of Newfoundland and Nova Scotia, Canada, Memoirs of the Association of Australasian Palaeontologists, **29,** 115-160.

von Bitter,P.H., Giles, P.S. and Utting, J. (2007). Biostratigraphic correlation of major cycles in the Windsor and Codroy groups of Nova Scotia and Newfoundland, Atlantic Canada, with the Mississippian substages of Britain and Ireland. Wong, Th. E. (Ed.): Proceedings of the XVth International Congress on Carboniferous and Permian Stratigraphy. Utrecht, the Netherlands, 10-16 August 2003. Royal Netherlands Academy of Arts and Sciences, 513-534.

<u>APPENDIX 2:</u> THIN SECTION ANALYSES.

Minerals	Grain Size (mm)	%	Lithic Clasts	Grain Size (mm)	%	Carbonate Clasts	%	Cement	%
Quartz	0.05 – 1.0	2-3	Chert	0.15 – 3.0	10	Peloids	13	Calcitic (Micrite)	30
Plagioclase	0.46 – 1.0	1-2	Phyllite	0.5 – 3.6	10	Intraclasts	3		
Opaques	0.05 – 0.23	1-2	Schist	0.5 – 1.5	10	Ooids	3		
Muscovite	0.01 – 0.2	1	Polycrystalline Qtz	0.2 – 1.8	5	Bioclasts	1		
Orthoclase	0.05 – 1.0	1	Mudstone/Sandstone	0.8 – 1.2	2				
Chlorite	0.08	Trace	Gneiss	0.75 – 1.2	2				
Microcline	0.8	Trace	Metamorphosed Qtz	0.5 – 1.0	1-2				
Features	Clast-supported, moderately sorted. Lithic clasts are angular – well rounded								
Rock Type	Coarse lithic pelmicrite								

Table 6.1 Sample 04-24 is from the lowermost carbonate interval of the Demoiselle Creek member, 35m below the Lime-kiln Brook/Bonaventure contact at Hopewell Cape.

Minerals	Grain Size (mm)	%	Lithic Clasts	Grain Size (mm)	%	Carbonate Clasts	%	Cement	%
Quartz	0.25 – 1.0	3	Siltstone	1.0 – 3.0	10	Peloids	10	Micrite	40
Opaques	0.05 – 0.75	1-2	Chert	0.8 – 3.0	7	Bioclasts	3	Fe-oxide	2-3
Muscovite	0.4	Trace	Mudstone/Sandstone	0.75 – 4.0	6			Spar	2
Microcline	1.5	Trace	Phyllite	1.0 – 2.25	6				
			Schist	1.0 – 1.5	6				
			Granite	1.0 – 3.0	4				
Features	Matrix supported, poorly sorted. Clasts are sub-angular to sub-rounded								
Rock Type	Very coarse to granular lithic pelmicrite								

Table 6.2 Sample 04-25 is from the lowermost carbonate interval of the Demoiselle Creek member, 32m below the Lime-kiln Brook/Bonaventure contact at Hopewell Cape.

Coated Minerals	Grain Size(mm)	%	Coated Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.05 – 0.6	10	Micritic Coating		20	Spar	20
Micritic Coating		5	Siltstone	0.25 – 1.2	5	Fe-oxide	2
Calcite	0.15 – 0.3	1	Limestone and Intraclasts	0.1 – 0.9	15		
Plagioclase	0.1 – 0.6	<1	Granite	0.1 – 0.75	5		
Muscovite	0.15	Trace	Phyllite	0.1 – 0.6	5		
Chlorite			Chert	0.1 – 0.6	5		
			Schist	0.1 – 0.6	5		
Features	Matrix supported, poorly sorted. Clasts are sub-angular to sub-rounded **NOTE:** 10% of grains are not coated						
Rock Type	Lithic Oosparite						

Table 6.3 Sample 04-26 is from a thin (25 cm) limestone within the red beds that separate the two main carbonate intervals in the Demoiselle Creek member, 25m below the Lime-kiln Brook/Bonaventure contact at Hopewell Cape.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.01 – 0.15	25	Mudstone/Sandstone	0.05 – 0.15	1	Calcitic	45
Muscovite	0.02 – 0.2	5	Chert	0.05 – 0.1	<1	Fe-oxide	15
Opaques	0.01 – 0.2	3	Polycrystalline Quartz	0.05 – 0.15	<1	Carbonate/Silica	1
Calcite	0.05 – 0.15	2					
Chlorite	0.03 – 0.15	1-2					
Orthoclase	0.05 – 0.2	1-2					
Plagioclase	0.05 – 0.2	1					
Biotite	0.05	<1					
Glauconite	0.1	Trace					
Zircon	0.03	Trace					
Features	Matrix supported, well sorted, sub-angular to sub-rounded and laminated						
Rock Type	Red, calcareous siltstone with recrystallized rudaceous bioclasts						

Table 6.4 Sample 07-02 was taken from the red interval that separates the two uppermost stromatolitic mounds of the Maccan member at Minudie, 1 m below that uppermost mound, and 2.5m below the Lime-kiln Brook/Maringouin contact.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.03 – 0.2	40	Polycrystalline Quartz	0.1 – 0.2	5	Spar	40
Muscovite	0.03 – 0.3	1-2	Chert	0.1 – 0.2	1	Carbonate/Silica	1-2
Opaques	0.015 – 0.25	1-2	Mudrock	0.1 – 0.15	1	Limonite	1-2
Orthoclase	0.1 – 0.25	<1	Limestone	0.05 – 0.15	<1		
Chlorite	0.08 – 0.1	<1	Rhyolite	0.1 – 0.2	<1		
Plagioclase	0.05 – 0.2	<1	Basalt	0.15	Trace		
Actinolitic Hornblende	0.1 – 0.15	<1					
Biotite	0.03 – 0.1	<1					
Microcline	0.1	Trace					
Zircon	0.05	Trace					
Features	Matrix supported, well sorted, angular to sub-rounded and weakly laminated						
Rock Type	Very fine, red calcareous lithic wacke with pelsparite laminae						

Table 6.5 Sample 07-03 was taken from the Minudie member of the Maringouin Formation, 5 m above the uppermost Lime-kiln Brook Formation mound at Minudie.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.005 – 0.2	32	Chert	0.05 – 0.2	2-3	Spar	25
Muscovite	0.01 – 0.2	10	Polycrystalline Quartz	0.05 – 0.3	2-3	Fe-oxide	10
Chlorite	0.01 – 0.1	3-4	Limestone	0.08 – 0.15	1-2	Carbonate/Silica	2-3
Opaques	0.015 – 0.45	2-3	Rhyolite	0.1 – 0.15	<1		
Orthoclase	0.05 – 0.15	2-3	Schist	0.1 – 0.15	Trace		
Biotite	0.03 – 0.08	1					
Plagioclase	0.08 – 0.1	1					
Calcite	0.05 – 0.1	Trace					
Glauconite	0.1	Trace					
Microcline	0.08 – 0.1	Trace					
Zircon	0.05 – 0.07	Trace					
Features	Clast-supported, poorly sorted, angular to sub-rounded and laminated						
Rock Type	Laminations of red calcareous siltstone and very fine lithic arenite						

Table 6.6 Sample 05-132 was taken in the Minudie member, 35 m below the contact with the Pecks Cove member in the Maringouin West section of New Brunswick.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.03 – 1.0	50	Polycrystalline Quartz	0.2 – 0.6	5-6	Spar	13
Plagioclase	0.07 – 0.5	3-4	Rhyolite	0.15 – 0.75	5	Fe-oxide	1-2
Orthoclase	0.05 – 0.75	2-3	Chert	0.1 – 1.8	2-3		
Calcite	0.05 – 0.4	1-2	Phyllite	0.1 – 0.5	2-3		
Opaques	0.025 – 1.25	1-2	Mudrock	1 – 3	2		
Actinolitic Hornblende	0.4	Trace	Limestone	0.1 – 0.3	1-2		
Chlorite	0.05 -0.1	Trace	Basalt	0.2 – 0.75	1		
Glauconite	0.1	Trace	Pelmicrite Intraclasts	1 – 3	1		
Microcline	0.1 – 1.75	Trace	Schist	0.2	Trace		
Muscovite	0.03 – 0.15	Trace					
Zircon	0.05	Trace					
Features	Clast-supported, poorly sorted, sub-angular to rounded						
Rock Type	Granular, calcareous lithic arenite with rudaceous pelmicrite intraclasts						

Table 6.7 Sample 07-04 was taken in the Minudie member, 5m below the contact with the Pecks Cove member at Minudie.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.01 – 0.25	45	Phyllite	0.1 – 0.25	5	Calcitic	10
Muscovite	0.01 – 0.3	3-4	Rhyolite	0.08 – 0.15	5	Carbonate/Silica	6-7
Opaques	0.01 – 0.35	3-4	Limestone	0.05 – 0.15	2-3	Fe-oxide	5
Orthoclase	0.03 – 0.2	2-3	Polycrystalline Quartz	0.05 – 0.2	2-3		
Plagioclase	0.05 – 0.2	1	Chert	0.05 – 0.25	1-2		
Biotite	0.01 – 0.1	<1	Mudstone/Sandstone	0.1 – 0.2	<1		
Calcite	0.01 – 0.15	<1					
Chlorite	0.01 – 0.1	<1					
Actinolitic Hornblende	0.03 – 0.15	Trace					
Glauconite	0.1 – 0.15	Trace					
Microcline	0.08 – 0.12	Trace					
Zircon	0.08	Trace					
Features	Clast-supported, angular to sub-rounded						
Rock Type	Fine lithic wacke						

Table 6.8 Sample MPW-UM was taken in the Pecks Cove member, 25m below the Maringouin/Shepody contact at Maringouin West.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.03 – 0.6	45	Polycrystalline Quartz	0.15 – 0.4	10-11	Calcitic	6-7
Opaques	0.03 – 0.5	2	Rhyolite	0.1 – 0.45	10-11	Carbonate/Silica	4-5
Orthoclase	0.1 – 0.6	1-2	Phyllite	0.15 – 0.5	5-6		
Plagioclase	0.1 – 0.5	1-2	Chert	0.08 – 0.6	1-2		
Calcite	0.08 – 0.4	1	Limestone	0.05 – 0.3	1-2		
Chlorite	0.03 – 0.15	1	Basalt	0.1 – 0.4	1		
Muscovite	0.05 – 0.45	1	Mudstone/Sandstone	0.1 – 0.5	1		
Actinolitic Hornblende	0.1 – 0.15	<1					
Biotite	0.08 – 0.1	Trace					
Glauconite	0.1	Trace					
Microcline	0.08 – 0.2	Trace					
Zircon	0.08	Trace					
Features	Clast-supported, moderately supported, angular to sub-rounded						
Rock Type	Fine lithic arenite						

Table 6.9 Sample MPW-LS was taken in the Shepody Formation, 30m above the Maringouin/Shepody contact at Maringouin West.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.01 – 0.35	50	Rhyolite	0.1 – 0.35	5	Carbonate/Silica	10
Chlorite	0.05 – 0.2	3-4	Phyllite	0.1 – 0.4	3-4	Calcitic	5
Biotite	0.05 – 0.25	2-3	Chert	0.05 – 0.35	3	Fe-oxide	1
Opaques	0.05 – 0.45	2-3	Polycrystalline Quartz	0.08 – 0.3	2-3		
Muscovite	0.03 – 0.35	2	Limestone	0.05 – 0.25	1		
Orthoclase	0.05 – 0.3	1-2	Mudstone/Sandstone	0.1 – 0.25	<1		
Plagioclase	0.05 – 0.4	1-2					
Actinolitic Hornblende	0.15 – 0.25	1					
Microcline	0.08 – 0.3	<1					
Calcite	0.05 – 0.15	Trace					
Glauconite	0.15	Trace					
Zircon	0.1	Trace					
Features	Matrix supported, poorly sorted, sub-angular to sub-rounded and very weakly laminated						
Rock Type	Very fine lithic arenite						

Table 6.10 Sample 05-146 was taken in the Shepody Formation, 70m above the Maringouin/Shepody contact at Maringouin West.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.01 – 0.45	40	Chert	0.1 – 0.3	3-4	Calcitic	10
Chlorite	0.05 – 0.25	4	Polycrystalline Quartz	0.1 – 0.3	3-4	Carbonate/Silica	10
Orthoclase	0.08 – 0.5	3-4	Limestone	0.08 – 0.15	2-3	Silica	1-2
Plagioclase	0.05 – 0.4	3-4	Mudstone/Sandstone	0.1 – 0.25	1-2		
Muscovite	0.05 – 0.55	2-3	Phyllite	0.1 – 0.25	1-2		
Opaques	0.01 – 0.25	2-3	Rhyolite	0.1 – 0.2	1-2		
Actinolitic Hornblende	0.1 – 0.25	1-2					
Biotite	0.03 – 0.15	1					
Calcite	0.1 – 0.2	<1					
Microcline	0.05 – 0.25	Trace					
Rutile	0.05 – 0.15	Trace					
Tourmaline	0.05 – 0.15	Trace					
Zircon	0.08	Trace					
Features	Matrix supported, poorly sorted, angular to sub-rounded						
Rock Type	Fine lithic arenite						

Table 6.11 Sample 05-147 was taken in the Shepody Formation, 90m above the Maringouin/Shepody contact at Maringouin West.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.01 – 0.5	40	Rhyolite	0.1 – 0.3	20	Calcitic	2-3
Orthoclase	0.08 – 0.5	3-4	Phyllite	0.05 – 0.2	6-7	Carbonate/Silica	1
Muscovite	0.05 – 0.5	1-2	Mudstone/Sandstone	0.05 – 0.35	5-6	Silica	1
Chlorite	0.08 – 0.15	1	Polycrystalline Quartz	0.05 – 0.4	5-6	Fe-oxide	Trace
Plagioclase	0.05 – 0.3	1	Chert	0.08 – 0.35	3-4		
Opaques	0.008 – 0.25	1	Limestone	0.05 – 0.2	1-2		
Biotite	0.05 – 0.1	<1	Basalt	0.1 – 0.2	1		
Microcline	0.08 – 0.25	<1	Schist	0.08 – 0.2	<1		
Features	Clast-supported, poorly sorted, sub-angular to sub-rounded						
Rock Type	Medium lithic arenite						

Table 6.12 Sample 05-149 was taken in the Shepody Formation, 160m above the Maringouin/Shepody contact at Maringouin West.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.01 – 0.75	55	Polycrystalline Quartz	0.1 – 0.4	12	Calcitic	2-3
Orthoclase	0.05 – 0.65	5	Chert	0.05 – 0.35	11	Dolomite	<1
Plagioclase	0.08 – 0.4	1-2	Rhyolite	0.1 – 0.3	3-4		
Muscovite	0.05 – 0.65	1	Mudstone/Sandstone	0.05 – 0.45	2-3		
Opaques	0.03 – 0.3	1	Phyllite	0.08 – 0.3	2-3		
Actinolitic Hornblende	0.15	Trace	Limestone	0.05 – 0.3	1		
Biotite	0.05 – 0.1	Trace					
Chlorite	0.05 – 0.1	Trace					
Glauconite	0.2	Trace					
Microcline	0.1 – 0.15	Trace					
Zircon	0.05 – 0.08	Trace					
Features	Clast-supported, moderately sorted, sub-angular to sub-rounded						
Rock Type	Medium lithic arenite						

Table 6.13 Sample MPW-US was taken in the Shepody Formation, 20m below the Shepody/Enragé contact at Maringouin West.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.01 – 0.75	50	Polycrystalline Quartz	0.15 – 0.5	11	Carbonate/Silica	3-4
Opaques	0.05 – 0.75	4-5	Rhyolite	0.15 – 0.4	7-8		
Orthoclase	0.05 – 0.6	1-2	Chert	0.05 – 0.4	5-6		
Plagioclase	0.08 – 0.4	1-2	Phyllite	0.1 – 0.35	3-4		
Biotite	0.1 – 0.3	1	Mudstone/Sandstone	0.08 – 0.4	1-2		
Muscovite	0.1 – 0.45	1	Schist	0.1 – 0.35	1-2		
Chlorite	0.08 – 0.25	Trace	Limestone	0.05 – 0.5	1		
Microcline	0.2 – 0.35	Trace					
Tourmaline	0.25	Trace					
Zircon	0.1	Trace					
Features	Clast-supported, poorly sorted, sub-angular to sub-rounded						
Rock Type	Medium lithic arenite						

Table 6.14 Sample 05-164 was taken in the Shepody Formation, 15m below the Shepody/Enragé contact at Maringouin East.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.05 – 1.0	55	Polycrystalline Quartz	0.2 – 0.6	10	Silica	2-3
Orthoclase	0.08 – 0.75	5-6	Chert	0.25 – 1.0	7-8	Silica/Mica	2
Muscovite	0.05 – 0.35	1-2	Phyllite	0.15 – 0.4	3-4	Calcitic	<1
Plagioclase	0.05 – 0.6	1-2	Rhyolite	0.15 – 0.5	3-4	Carbonate/Silica	<1
Opaques	0.05 – 0.5	1	Mudstone/Sandstone	0.1 – 0.5	1		
Biotite	0.3	Trace	Basalt	0.15 – 0.6	<1		
Microcline	0.25 – 0.4	Trace	Schist	0.15 – 0.5	<1		
Tourmaline	0.2	Trace					
Zircon	0.08	Trace					
Actinolitic Hornblende	0.15 – 0.5	Trace					
Features	Clast-supported, moderately well sorted, sub-angular to sub-rounded						
Rock Type	Medium lithic arenite						

Table 6.15 Sample 05-156 was taken in the Enragé Formation, 8m above the Shepody/Enragé contact at Maringouin East.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.01 – 0.4	40	Polycrystalline Quartz	0.07 – 0.25	12	Calcitic	3
Opaques	0.03 – 0.3	5	Chert	0.05 – 0.2	10	Silica/Mica	2-3
Orthoclase	0.05 – 0.4	3	Phyllite	0.08 – 0.25	6-7	Carbonate/Silica	1-2
Plagioclase	0.05 – 0.35	2-3	Limestone	0.05 – 0.15	1	Fe-oxide	1
Chlorite	0.05 – 0.1	1-2	Mudstone/Sandstone	0.03 – 0.3	1		
Muscovite	0.03 – 0.45	1-2	Rhyolite	0.1 – 0.2	1		
Actinolitic Hornblende	0.1 – 0.2	<1					
Microcline	0.1 – 0.15	Trace					
Zircon	0.1	Trace					
Features	Clast-supported, moderately sorted, angular to sub-rounded, very weakly laminated						
Rock Type	Fine lithic arenite						

Table 6.16 Sample MPW-LE was taken in the Enragé Formation, 25m above the Shepody/Enragé contact at Maringouin West.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.02 – 0.75	60	Rhyolite	0.08 – 0.35	10	Silica/Mica	3-4
Plagioclase	0.05 – 0.6	3-4	Phyllite	0.05 – 0.3	4-5		
Orthoclase	0.05 – 0.75	2-3	Mudstone/Sandstone	0.05 – 0.3	3-4		
Chlorite	0.03 – 0.1	2	Polycrystalline Quartz	0.08 – 0.35	3-4		
Actinolitic Hornblende	0.1 – 0.3	1	Chert	0.05 – 0.4	1		
Muscovite	0.03 – 0.6	1	Schist	0.1 – 0.2	<1		
Opaques	0.025 – 0.25	1	Basalt	0.15	Trace		
Glauconite	0.1 – 0.15	Trace					
Microcline	0.1 – 0.2	Trace					
Zircon	0.08	Trace					
Features	Clast-supported, poorly sorted, sub-angular to sub-rounded						
Rock Type	Very fine lithic arenite						

Table 6.17 Sample 05-128 was taken in the Enragé Formation, 35m above the Shepody/Enragé contact at Maringouin West.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.01 – 0.75	55	Chert	0.1 – 0.25	5-6	Fe-oxide	11
Orthoclase	0.05 – 1.05	4-5	Polycrystalline Quartz	0.08 – 0.3	2-3	Carbonate/Silica	<1
Plagioclase	0.08 – 0.5	4	Rhyolite	0.08 – 0.4	1-2		
Opaques	0.03 – 0.5	3-4	Mudstone/Sandstone	0.05 – 0.3	1		
Biotite	0.05 – 0.75	2-3	Phyllite	0.08 – 0.2	1		
Chlorite	0.1 – 0.2	1-2	Basalt	0.1 – 0.4	<1		
Muscovite	0.05 – 0.	1-2	Limestone	0.05 – 0.25	<1		
Microcline	0.15 – 0.25	<1					
Actinolitic Hornblende	0.15 – 0.25	Trace					
Glauconite	0.15	Trace					
Zircon	0.05	Trace					
Features	Clast-supported, very poorly sorted, sub-angular to sub-rounded and weakly laminated						
Rock Type	Medium feldspathic arenite						

Table 6.18 Sample 05-163 was taken in the Enragé Formation, 50m above the Shepody/Enragé contact at Maringouin East.

Minerals	Grain Size(mm)	%	Lithic Clasts	Grain Size(mm)	%	Cement	%
Quartz	0.01 – 2.5	50	Mudstone/Sandstone	0.15 – 2.0	20	Silica	5
Orthoclase	0.08 – 2.5	6-7	Granite	1.0 – 2.0	5-6	Fe-oxide	1-2
Microcline	0.1 – 1.25	3-4	Chert	0.1 – 1.25	5-6	Calcitic	Trace
Opaques	0.05 – 0.75	1-2	Polycrystalline Quartz	0.15 – 2.5	1-2		
Plagioclase	0.15 – 0.75	1-2	Rhyolite	0.15 – 2.0	1		
Chlorite	0.2	Trace					
Muscovite	0.05 – 0.15	Trace					
Features	Clast-supported, poorly sorted, sub-angular to sub-rounded						
Rock Type	Very coarse to granular lithic arenite						

Table 6.19 Sample 05-153 was taken in the Enragé Formation, 6m below the observable top of that unit at Maringouin East.

APPENDIX 3: PALEOCURRENT DATA.

Location	**Bearing**									
Alma (Bo)	100°	120°	105°	110°	110°	120°	118°	105°	100°	
Cape Enragé (Ma)	120°	120°	120°							
Hopewell Cape (Bo)	055°	035°	040°	030°	050°	060°	025°	030°	045°	040°
	045°	035°								
Dorchester Cape (Bo)	080°	085°	190°	189°	192°	185°	180°	190°	165°	180°
Maringouin West (Ma)	350°	348°	343°	332°	346°	340°	338°	348°	349°	349°
	350°	346°	340°	348°	345°	346°	347°	342°	352°	295°
	341°	338°	336°	340°	336°	338°	340°	340°	343°	352°
	340°	344°	345°	332°	346°	348°	340°	342°		
Maringouin East (Ma)	000°	355°	330°	350°	005°	355°	340°	350°	000°	355°
	355°	005°	355°	005°	340°	000°	345°	330°	350°	345°
Downing Cove (Ma)	350°	350°	352°	346°	352°	355°	346°	320°	005°	000°
	335°	350°	355°	355°	355°	345°	350°	000°	350°	340°
	350°	350°	350°	345°	340°	350°	350°	335°	000°	345°
	350°	340°	000°	350°	330°	350°	355°			

Table 8.1 Paleocurrent vectors obtained from trough cross-beds within the time-equivalent Bonaventure (Bo) and Maringouin (Ma) formations at various localities of the Cumberland Basin.

Location	Bearing									
Cape Enragé	130°	115°	130°	130°	130°	125°	130°	105°	105°	115°
	105°	140°	115°	115°						
Maringouin West	352°	342°	351°	355°	358°	001°	354°	354°	350°	348°
	008°	006°	010°	012°	009°	007°	351°	352°	348°	357°
	355°	001°	011°	350°	352°	358°	000°	001°	357°	003°
	348°	350°	005°							
Maringouin East	330°	328°	340°	320°	332°	333°	349°	351°	337°	341°
	335°	336°	330°	331°	330°	338°	334°	340°	332°	336°
	331°	096°	156°	330°	327°	151°	131°	122°	330°	329°
	314°	309°	332°	123°	350°					
Joggins #2	328°	330°	320°	336°	330°	333°	330°	348°	328°	300°
	302°	010°	345°	340°	000°	355°	330°	015°	345°	355°
	000°	350°	350°							

Table 8.2 Paleocurrent vectors obtained from trough cross-beds within the Shepody Formation at various localities of the Cumberland Basin.

Location	Bearing									
Maringouin West	352°	002°	000°	000°	358°	010°	001°	008°	280°	326°
	260°	002°	001°	000°	003°	000°	346°	358°	006°	003°
	007°	001°	348°							
Maringouin East	341°	330°	319°	320°	344°	343°	346°	335°	338°	330°
	336°	336°	334°	351°	342°	350°	335°	336°	340°	337°
	331°	339°	335°							
Joggins #3	335°	332°	334°	337°	331°	329°	335°	336°	332°	334°
	334°	335°	331°	337°	329°	334°	333°	335°	330°	
Joggins #2	340°	338°	330°	342°	340°	340°	325°	334°	342°	

Table 8.3 Paleocurrent vectors obtained from trough cross-beds within the Enragé Formation at various localities of the Cumberland Basin.