The Antigonish Basin of Maritime Canada:
A Sedimentary Tectonic History Of A
Late Paleozoic Fault-Wedge Basin

by

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Submitted in partial fulfillment of the requirements
for the degree of Master of Science
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DALHOUSIE UNIVERSITY

DEPARTMENT OF GEOLOGY

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TO MY GRANDMOTHER

Tu es verus animus virtutis,

virium et amoris.

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Abstract

Late Paleozoic deposition in Maritime Canada primarily occurred in the Fundy Basin, a large trough system which is thought to have formed within a transcurrent fault zone. It consisted of a series of interconnected subbasins and uplifted basement blocks, with remnants of the basins preserved as thick Devono-Carboniferous cover. The Antigonish Basin is one of these remnants. A sedimentological study of its rocks provides insight into its sedimentary tectonic history.

The development of the Antigonish Basin occurred in two stages: (1) an initial stage of tectonic activity, and (2) a final stage of tectonic quiescence. Tectonic activity extended from the Middle-Late Devonian to the Tournaisian, during which time there were at least two major episodes of uplift of the Browns Mountain Massif. A large alluvial-fan system shed extensive deposits to the northeast while a transverse fluvial system occupied more distal regions. The Visean marked the beginning of tectonic quiescence, a period during which local topography was subdued with source areas generally located well beyond the basin margins. A marine invasion of the basin followed with marine waters repeatedly inundating a coastal floodplain. Marine influences ended in the Namurian with the appearance of an extensive lake system. In Early Westphalian time the lake system was

replaced by successive major river systems with distant source areas. Deposition apparently ceased after this time.

The initial tectonic activity in the basin can be explained by movement along two major splaying strike-slip faults, the Chedabucto and Hollow Faults, which partially define the limits of the Antigonish Basin and Browns Mountain Massif. When these dextral faults were concurrently active, a region of compression and uplift developed where they converged. Correspondingly, extension and subsidence occurred where they diverged. This setting produced a major source area to the southwest which supplied relatively constant detritus to the adjacent fault-wedge basin to the northeast. When concurrent movement along the faults declined in the Visean, local tectonism became reduced as well. Consequently all subsequent deposition was influenced by more regional tectonic mechanisms and regional sediment dispersal patterns.

Acknowledgements

The author is grateful to the following people for their contributions. Special thanks are extended to Dr. Paul Schenk for his supervision of the thesis. Dr. Martin Gibling spent several days in the field with me and was available for discussion. Dr. Phil Fralick introduced me to the study area and presented ideas regarding the logistics. Mr. Bob Boehner and Dr. John Waldron provided constructive suggestions as members of the thesis committee. Dr. Brendon Murphy contributed to the understanding of source area relationships. Dr. Kathy Gillis helped in refreshing my knowledge of petrography. The Nova Scotia Department of Mines and Energy produced most of the diagrams in this thesis. Mr. Bill Smith typed the manuscript and provided technical advice in its preparation. For the help of all of these people I am sincerely appreciative; however, any errors in the thesis are the author's sole responsibility.

Finally, I would like to thank Leigh. Without her patience, understanding, and encouragement, this research would never have been brought to a conclusion.

CHAPTER I

INTRODUCTION

Purpose of Study

There is currently a world-wide interest in the tectonic settings of sedimentary basins (e.g. Crowell, 1974a; Ballance and Reading, 1982; Miall, 1981). This stems largely from the development of plate-tectonic theory in the 1960's and the understanding that sedimentary basins have definite tectonic associations (e.g. Reading, 1978). Sedimentology and stratigraphy are important tools in the interpretation of tectonic development, primarily due to the recent advances in sedimentology and facies analysis. Thus basin modelling has become a widely used technique which can provide clues to regional tectonism (Miall, 1984).

Following the advent of the plate-tectonic model, the thick Carboniferous cover of Atlantic Canada has been interpreted in terms of wrench-fault tectonics (Webb, 1969; Belt, 1968a). Several basins within the system have been interpreted as strike-slip in origin (e.g. McMaster *et al*., 1980; Fralick and Schenk, 1981; Bradley, 1982; Hyde, 1984; Yeo, 1985; Gibling *et al*., in press). The Antigonish Basin lies within this wrench-fault zone and adjacent to some of these pull-apart basins. The author selected it for a thesis study as a continuation of research into

Carboniferous sedimentary-tectonics in the Maritimes. This basin was chosen because of its small areal extent and proximity to interpreted pull-apart basins. Thus the study would provide a comparison with adjacent basins as well as throw more light on the regional tectonic development of the Carboniferous in the Maritimes.

Geological Background

Following the climax of the Acadian Orogeny during the Middle Devonian, a large, complex, intracontinental basin developed along the east coast of North America, and possibly continued into Great Britain and Scandinavia (Poole, 1976). In Atlantic Canada, Bell (1958) termed the basin system the Fundy Basin of deposition and identified its component basins, which he termed sub-basins (Fig.1.1). He described it as an intermontane basin in which the component sub-basins developed as down-folded troughs between up-folded basement highs. Subsequently, Belt (1968b) saw the component basins as bounded by wrench faults, and interpreted the Fundy Basin as a rift valley resulting from transcurrent fault movement. Large volumes of continental clastic sediments, marine carbonates, evaporites, and volcanics accumulated in the component basins. Erosional remnants of the basins exist today as areas of thick Devono-Carboniferous strata, which locally attain a thickness of 10 km (Howie and Barss, 1975). The

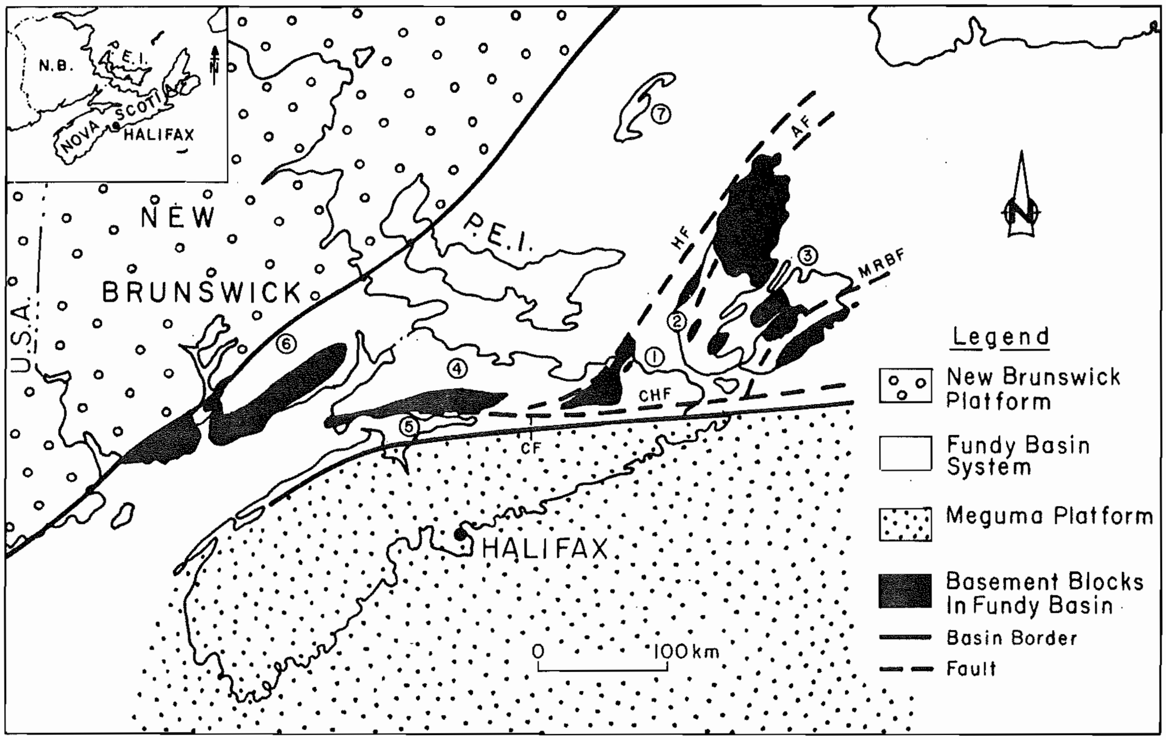


Figure 1.1. Fundy Basin System in Maritime Canada, including major basement highs and component basins: (1) Antigonish Basin; (2) Mabou Basin; (3) Sydney Basin; (4) Cumberland Basin; (5) Minas Basin; (6) Moncton Basin; (7) Magdalen Basin; (CF) Cobequid Fault; (CHF) Chadabucto Fault; (HF) Hollow Fault; (AF) Aspy Fault; (MRBF) Mira River - Bateston Fault (modified from Belt, 1968a).

Antigonish Basin is one of these remnants with a composite thickness of at least 11 km of strata as determined in this study.

The Antigonish Basin

i) Introduction

The Antigonish Basin is defined here as the Carboniferous structural basin located in Antigonish County, on the northeastern mainland of Nova Scotia (Fig.1.2). It is bounded to the northwest by the Browns Mountain Fault (of Benson, 1974), to the west by the Antigonish Highlands, and to the south by the Glenroy Fault (of Boehner and Giles, 1982). It extends to unknown limits northeastward under St. Georges Bay. The thesis area includes the subaerially exposed portion of the basin (approximately 400 sq. km.) to the south and west of St. Georges Bay.

ii) Physiography

Two physiographic subdivisions occur in the Antigonish Basin (Goldthwaite, 1925): (1) the Antigonish-Guysborough Lowlands occupy most of the basin, with maximum elevations of 150 m in the northwest and 50 m in the south; and (2) a small outlier of the Antigonish Highlands 230 m in height occurs 3 km north of Antigonish.

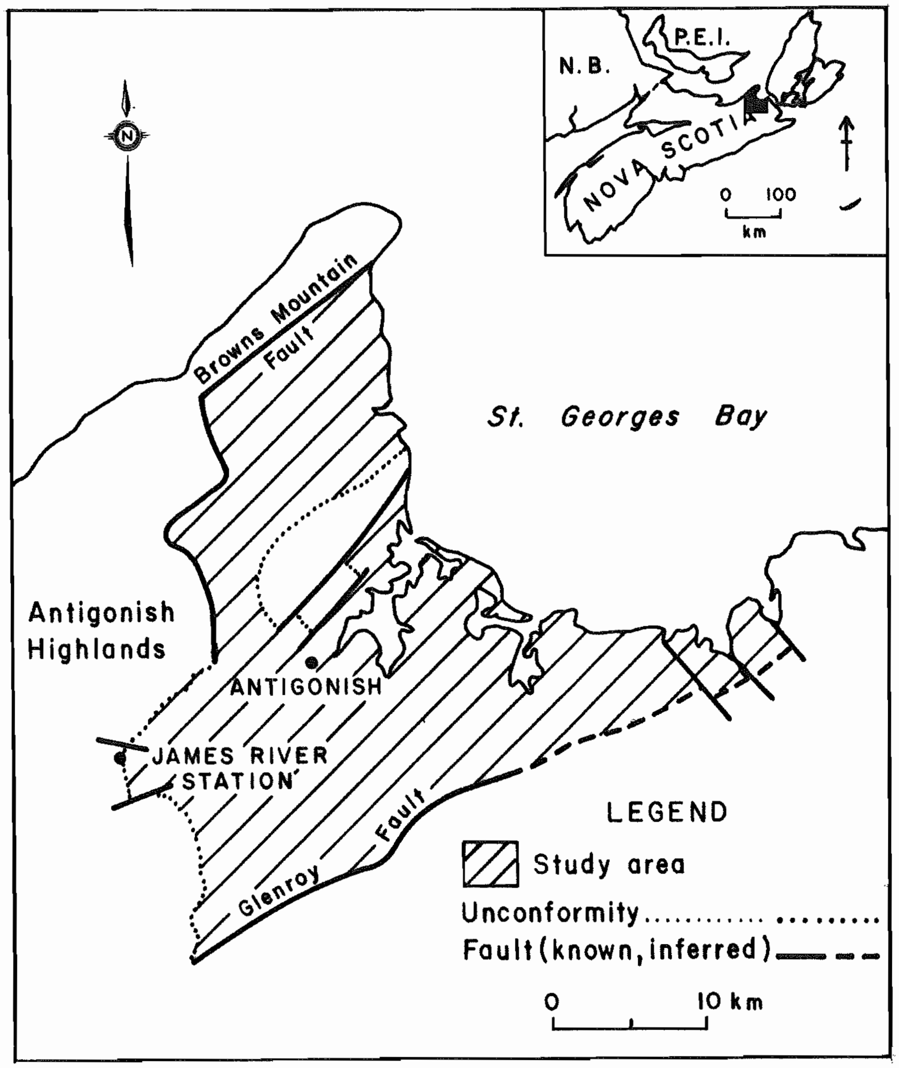


Figure 1.2. Location map showing area studied in the Antigonish Basin.

All rivers in the basin drain into St. Georges Bay. To the northwest of the bay the rivers are generally entrenched, cutting deep valleys into the glacial cover and bedrock. To the south and east, meandering rivers and floodplains are more common. Where estuaries enter the bay, barrier beaches and islands are common. The remaining coastline consists of resistant headlands separated by sandy beaches.

Two factors severely limit the exposure of rock in the basin: (1) a thick blanket of till, outwash, kame terraces, and eskers cover most of the area, and (2) plant cover is heavy. Thus exposure is scattered and commonly of poor quality. In general, the best outcrops occur as sea cliffs although examination of these locations was often impeded by tides and foul weather. Inland exposures occur primarily along road cuts and river banks where accessability is good.

The field work was conducted in the autumn of 1981 and the summer of 1982.

iii) Previous Work

The earliest series of geological descriptions of the Antigonish area date from the mid-nineteenth century (Gesner, 1845; Dawson, 1868; and Honeyman, 1867 and 1874). Fletcher and Faribault (1887) first mapped the area in detail. Williams (1914) later remapped the rocks with a more detailed examination of stratigraphic relationships and paleontology.

The 1920's marked the beginning of the long and distinguished career of W.A. Bell. Over a period of 40 years he completed a series of studies on the stratigraphy and paleontology of the Carboniferous in the Maritime Provinces (e.g. Bell, 1921, 1924, 1925, 1927, 1929, 1944, and 1960). He was also the first to recognize and name the Fundy Basin, identified its interconnected basins and discussed its tectonic development (Bell, 1958).

In the late 1940's and throughout the 1950's, the Massachusetts Institute of Technology conducted a geological field school at Crystal Cliffs. Numerous unpublished theses and field reports on the rocks around Antigonish were compiled at this time and some were later published (e.g. Decker, 1949; Sage, 1953; Murray, 1960). The study by Decker (1949) included a stratigraphic and sedimentological examination of the upper part of the Horton Group in the Cape George area. Sage (1953) studied the stratigraphy of the Windsor Group near Antigonish and its relationship with both under- and overlying Carboniferous rocks. Murray (1960) mapped the Horton Group of the Cape George - Antigonish area. He suggested a facies model for the Carboniferous fill, and attempted to correlate Horton strata with equivalent units elsewhere in the province.

Belt (1964, 1965, 1968b, 1970) focused attention on problems in the mid - Carboniferous stratigraphy of Atlantic Canada. He also made important contributions toward understanding the tectonic development of the Fundy Basin system (Belt, 1968a).

During the last half-century there has been substantial economic and scientific interest in the Windsor Group rocks, especially the carbonates and evaporites. This includes several studies in the Antigonish area (Hayes and Pohl, 1931; Sage, 1954; Schenk, 1969 and 1975; Boehner, 1980a, b; Boehner and Giles, 1982).

Most recently, interest has been rekindled in the history of sedimentary tectonics in the various basins of the Fundy Basin system (e.g. Fralick and Schenk, 1981; McCabe et al., 1980; Hyde and Ware, 1981; Bradley, 1982, 1986; Yeo, 1985). Fralick (1977, 1980) and Fralick and Schenk (1981) interpreted the tectonics of the eastern Cumberland Basin which adjoins the Antigonish Basin to the west. Bradley (1982) suggested that the basins of the Fundy Basin developed during two stages of subsidence: (1) an initial stage of extension accompanied by rapid sedimentation and sporadic volcanism, and (2) a final stage of thermal subsidence related to crustal stretching, resulting in the expansion of the basin and onlap of strata onto bordering basement rocks.

iv) Stratigraphy

The Antigonish area has been the subject of several stratigraphic studies (Table 1.1) based on Bell's (1944) general subdivisions of the Horton, Windsor, Canso, and Riversdale groups (e.g. Sage, 1954; Murraay, 1960; Belt, 1964, 1965). However, no single study has satisfactorily described and resolved the complex stratigraphy of the entire Antigonish Basin.

The detailed stratigraphic framework in this thesis is a composite of two studies. Boehner and Giles (1982) mapped the southern part of the basin and their stratigraphic interpretations are used here for the Windsor Group and overlying units (Fig.1.3). Murray (1960) subdivided the Horton Group in the northwestern part of the basin into several formations which are used here for all strata below the Windsor Group (Fig.1.4). This includes the "Devono-Carboniferous" rocks of Boehner and Giles (1982). The Wilkie Brook Formation presents a problem in that it has been included in both the Windsor Group (Murray, 1960; Schenk, 1975) and the Horton Group (Boehner and Giles, 1982). This will be discussed at length in the text.

Sage (1954)		Murray (1960)		Benson(1970a,b;1974)		Boehner & Giles (1982)	
RIVERS-DALE GROUP	Undivided	RIVERS-DALE GROUP	*Cribbean Head Formation*	RIVERS-DALE GROUP	*Port Hood Formation*	COARSE FLUVIAL FACIES (of Belt, 1964)	*Port Hood Formation*
CANSO GROUP	Undivided			CANSO GROUP	*Pomquet Formation*	MABOU GROUP	*Pomquet Formation*
					Hastings Formation		*Hastings Formation*
WINDSOR GROUP	Subzone E			WINDSOR GROUP	Undivided	WINDSOR GROUP	*Hood I. Formation*
	Subzone D						*Wallace Brook* (*Add. Fm.*)
	Subzone C						*Lakevale Fm.* (*Add. Fm.*)
							Hartshorn Fm.
	Subzone B						*Bridgeville Fm.*
							Gays River Fm.
	Subzone A	WINDSOR GROUP	Subzone A				*Macumber Fm.*
(hatched)			*Wilkie Brook Fm.*	HORTON GROUP	*Rights River Formation*	HORTON GROUP	*Wilkie Brook Fm.*
HORTON GROUP	Undivided	HORTON GROUP	*Rights River Fm.*				Undifferentiated Devono-Carboniferous
			S. Lake Creek Fm.				
			Ogden Brook Fm.				

Table 1.1. Stratigraphic classification of the rocks in the Antigonish Basin. Note that Sage (1954) focused attention on the Windsor Group, Murray's (1960) mapping was restricted to the northwest side of the basin, and Boehner and Giles (1982) primarily examined the area to the south.

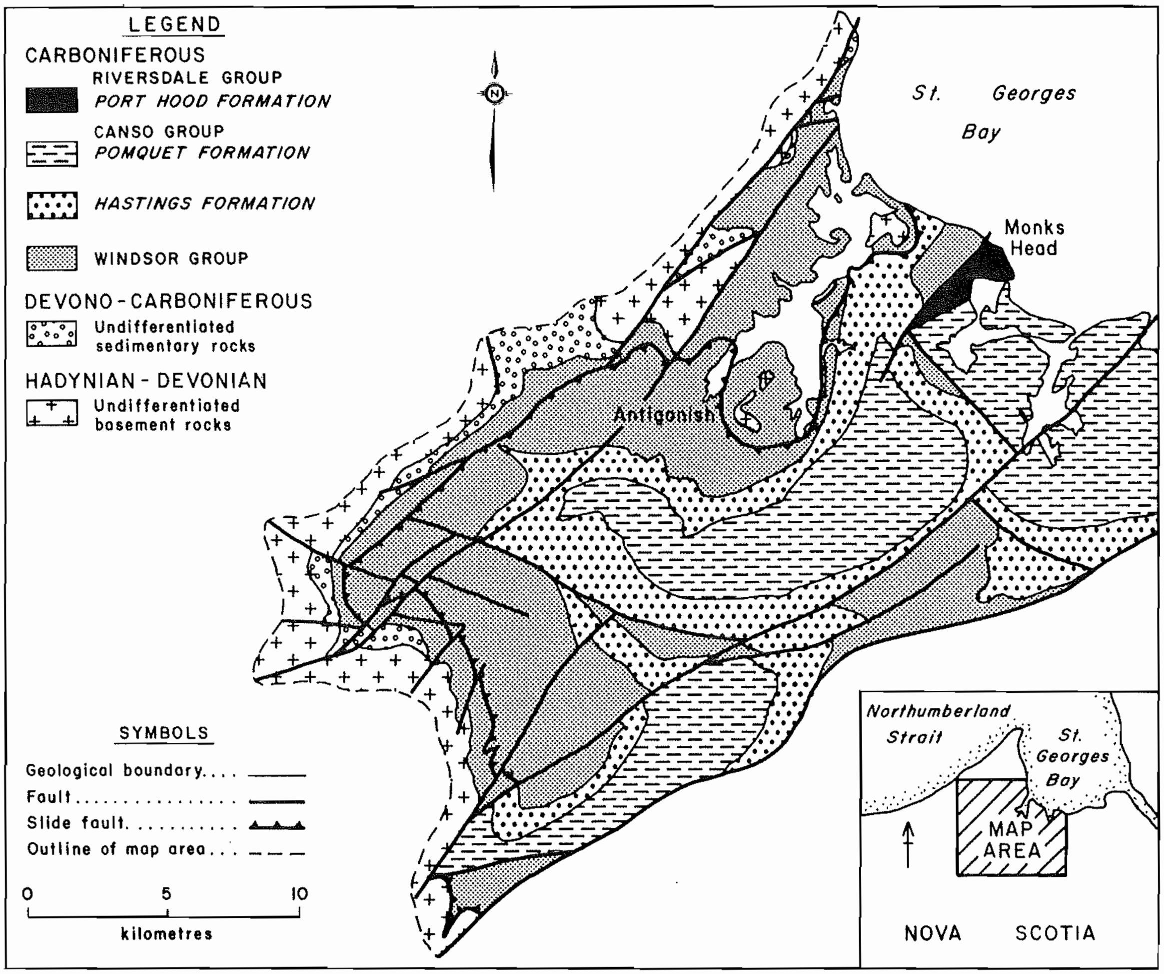


Figure 1.3. Geology of the southern part of the Antigonish Basin (modified from Boehner and Giles, 1982).

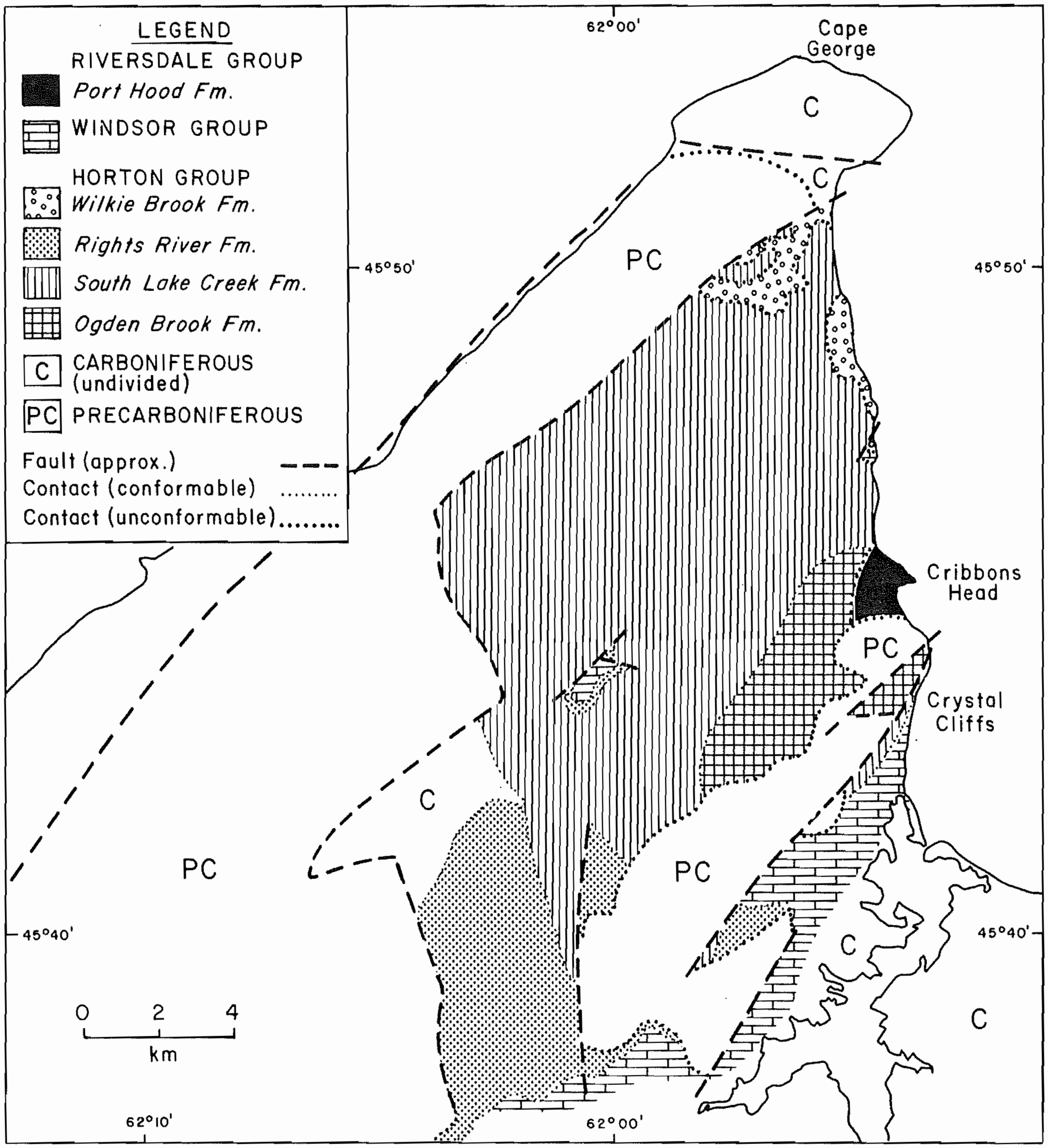


Figure 1.4. Geology of the northwestern part of the Antigonish Basin (modified from Murray, 1960).

In this thesis, each group and its constituent formations is described successively in ascending order. The data are used to reconstruct the tectonic evolution of the basin.

v) <u>Methodology</u>

Alluvial deposits are described by Bates and Jackson (1984) as consisting of alluvium or "detritial deposits made by streams on river beds, floodplains, and alluvial fans..." They have been chosen for emphasis in this study because: (1) the Antigonish Basin is filled predominantly with alluvial sediments, and (2) alluvial sedimentation in a depositional basin is considered to be a sensitive indicator of its tectonic history (Miall, 1981). A field approach was chosen with emphasis on three types of information: (1) stratigraphy, (2) sediment dispersal patterns, and (3) provenance.

The examination of the stratigraphy consisted of the documentation of detailed stratigraphic sections. This information was used to interpret the paleoenvironments and paleogeography.

Lithofacies units based on Miall's (1977 and 1978) classification were used to characterize the stratigraphic sections (Table 1.2). The features described included

Lithofacies Unit	Lithofacies Description
Gms	conglomerate; granule- to boulder-sized; matrix-supported; massive; rare imbrication; poorly-sorted; angular to subangular clasts.
Gm1	conglomerate; granule- to boulder-sized; clast -supported; massive to poor planar-parallel stratification; well-sorted; rare poorly-sorted units; common imbrication; poorly- to well-sorted; subangular and rounded clasts.
Gm2	conglomerate; intraformational; massive; sandy matrix; comprised of shale and/or carbonate clasts and/or plant fragments.
Gt	conglomerate; granule- to cobble-sized; clast-supported; trough cross stratification; well-sorted; subangular to rounded clasts.
Gp	conglomerate; granule- to cobble-sized; clast-supported; planar cross stratification; generally well-sorted; subangular to rounded clasts.
Sh1	sandstone; medium- to coarse-grained; pebbles common; planar parallel stratification; commonly appears massive; primary current lineation uncommon; generally poorly-sorted.
Sh2	sandstone; very fine- to coarse-grained; pebbles rare; planar parallel stratification; primary current lineation common.
Ss	sandstone; medium- to coarse-grained; pebbles common; intraclasts common; erosional scouring; massive or with crude cross stratification; well-sorted.
St	sandstone; fine- to coarse-grained; pebbles common; trough cross statification; well-sorted.
Sp	sandstone; fine- to coarse-grained; pebbles common; planar cross stratification; well-sorted.
Sr	sandstone; very fine- to medium-grained; commonly silty; ripple cross lamination; includes ripple marks of all types; poorly- to well-sorted.
Fm	mudstone; massive or poorly-stratified; commonly silty, sandy, or pebbly; desiccation cracks common; generally poorly-sorted.
Fs	shale to siltstone; fissile or laminated; usually well-sorted.
Fl	laminated to thinly interbedded sandstone, siltstone, and/or mudstone; planar parallel stratification; ripple cross lamination uncommon.

Table 1.2. Lithofacies classification used in the stratigraphic sections of this study (modified from Miall, 1978).

lithology, colour, grain size, sorting, fossils, sedimentary structures, and contacts. The location of each section is described in Appendix I and plotted on appropriate maps throughout the text.

As noted above alluvial deposits are emphasized in this study. Rock types interpreted by the author as being predominantly lacustrine or marine in origin were described in more general terms.

Many of the sections were analyzed using Markov Chain analysis (Appendix II). This is a statistical tool used in determining cyclicity in sedimentary successions. A brief discussion of the technique, as it is applied here, is presented in Appendix II.

Sediment dispersal patterns were determined using paleocurrent indicators. The purposes are to establish paleoslope and to infer directions to source areas. Paleoslope is defined here as the general slope of the ancient terrain along which the major drainage systems flowed. Paleocurrent indicators are those sedimentary features which indicate a sense of current movement. All types of indicators were used in the thesis (Appendix III) and were divided into two types: (1) directional data, indicating the direction of movement, and (2) axial data, indicating an axial trend for the movement but not a direction.

In collecting the data for linear structures, only those folded beds dipping at 25 degrees or more were rotated to horizontal before paleocurrent directions were determined (Ramsay, 1961). For all other paleocurrent indicators, the folded beds were reoriented regardless of the degree of dip. This was done in the field using a clip board and chalk. Although deposition on a horizontal plane is implied using this method, many of the strata were probably deposited with an initial dip. However, if the primary dip is less than 25 degrees the error in assuming horizontality is negligible or well within the inherent variability of the sedimentary process.

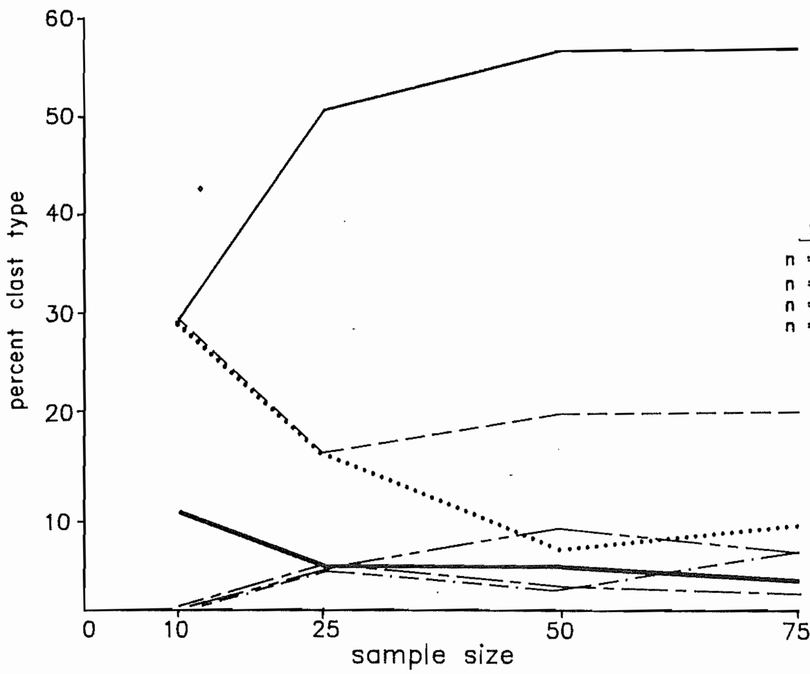
Paleocurrent diagrams were constructed using the method described by Potter and Pettijohn (1977). Class intervals of 20 degrees were used for all data. Calculations for the paleocurrent data consisted of the vector mean (X) and vector magnitude (R and L) (from Potter and Pettijohn, 1977). A discussion and the tabulated results are in Appendix III.

The degree of reliability in using paleocurrent indicators as a measure of paleoslope is a function of the types of indicator used (Miall, 1974) and the sample size. Another factor is whether the data represent local topographic expression or more regional trends. The validity of using all types of paleocurrent indicators, as is done here, may be questioned within some of the formations and will be discussed in the appropriate chapters. Rawleighs test (Curray, 1956) was used to quantitatively test the reliability of the paleocurrent data (Appendix III). This test indicates the level of significance which may be attached to the data computed. The problem of regional versus local paleocurrent trends can only be eliminated if abundant data from a large area of the basin is available. In many of the formations dealt with here this was not possible.

Provenance studies were conducted by examining the conglomerates. The lithology of their clasts was studied to help establish the nature of the source rocks and possibly their location. The proportion of each clast type was determined by point-counting with a string knotted at 2 cm intervals and stretched taut between two chalk marks parallel to the stratification. Clasts greater than or equal to 2 mm long that contacted with the knots were removed to record lithology. The string was then moved 2 cm and placed parallel to the first line. Sampling continued in this manner until 50 clasts were recorded. The choice of sample size (n = 50) was based on repeated testing of different sample sizes at one station. The test results, including a chi-square test of similarity between samples (from Folk, 1974), are shown in Figure 1.5. They indicate that the proportion of each lithology remained relatively constant for n greater than or equal to 25, thus n = 50 provides a safe margin for obtaining a representative sample. Maximum clast size at each station was calculated as the average diameter of the five largest clasts.

Representative clasts of each lithology were collected for examination and comparison with potential source areas. Where necessary they were thin-sectioned to obtain a precise identification. A description of each lithology is in Appendix IV.

Finally, structural data on the area were examined. This consisted of the identification of major faults, their sense of movement, and the timing of the movement. This information, in conjunction with the stratigraphy and sedimentology, was considered vital in establishing tectonic events and developing a tectonic model. This model will be presented in the final chapter.



X^2 TEST RESULTS

BETWEEN SAMPLE SIZES	SIMILARITY CONFIDENCE
n = 10 , n = 50	< 90 %
n = 25 , n = 50	98 %
n = 25 , n = 75	99.5 %
n = 50 , n = 75	> 99.5 %

Figure 1.5. Sample size (n) determination for conglomerate point counts. Each line represents a clast type and illustrates its relative abundance for the sample sizes indicated. Chi-squared test (from Folk, 1974) results suggest that the clast composition of a sample remains relatively constant where n is greater than or equal to 25.

CHAPTER II

HORTON GROUP

The Horton Group in the Antigonish Basin consists of continental deposits with Middle Devonian through Early Carboniferous spore assemblages (Benson, 1974; Boehner and Giles, 1982). The strata rest unconformably on the underlying Haydrynian - Devonian basement rocks and are overlain conformably to unconformably by the overlying Windsor Group. Murray (1960) divided the Horton Group into three formations: the Ogden Brook (base); the South Lake Creek;, and the Rights River (top). Exposure of the Horton Group is restricted to the western side of the study area at the base of the Antigonish Highlands (Fig.1.4).

Ogden Brook Formation

i) Lithological Description

The Ogden Brook Formation (Fig.2.1) is composed of red conglomerates, pebbly sandstones, and sandy to pebbly mudstones. The conglomerates are polymictic and include both clast-supported and matrix-supported strata. The sandstones are lithic wackes.

ii) Age

Fossils have never been reported from this strongly

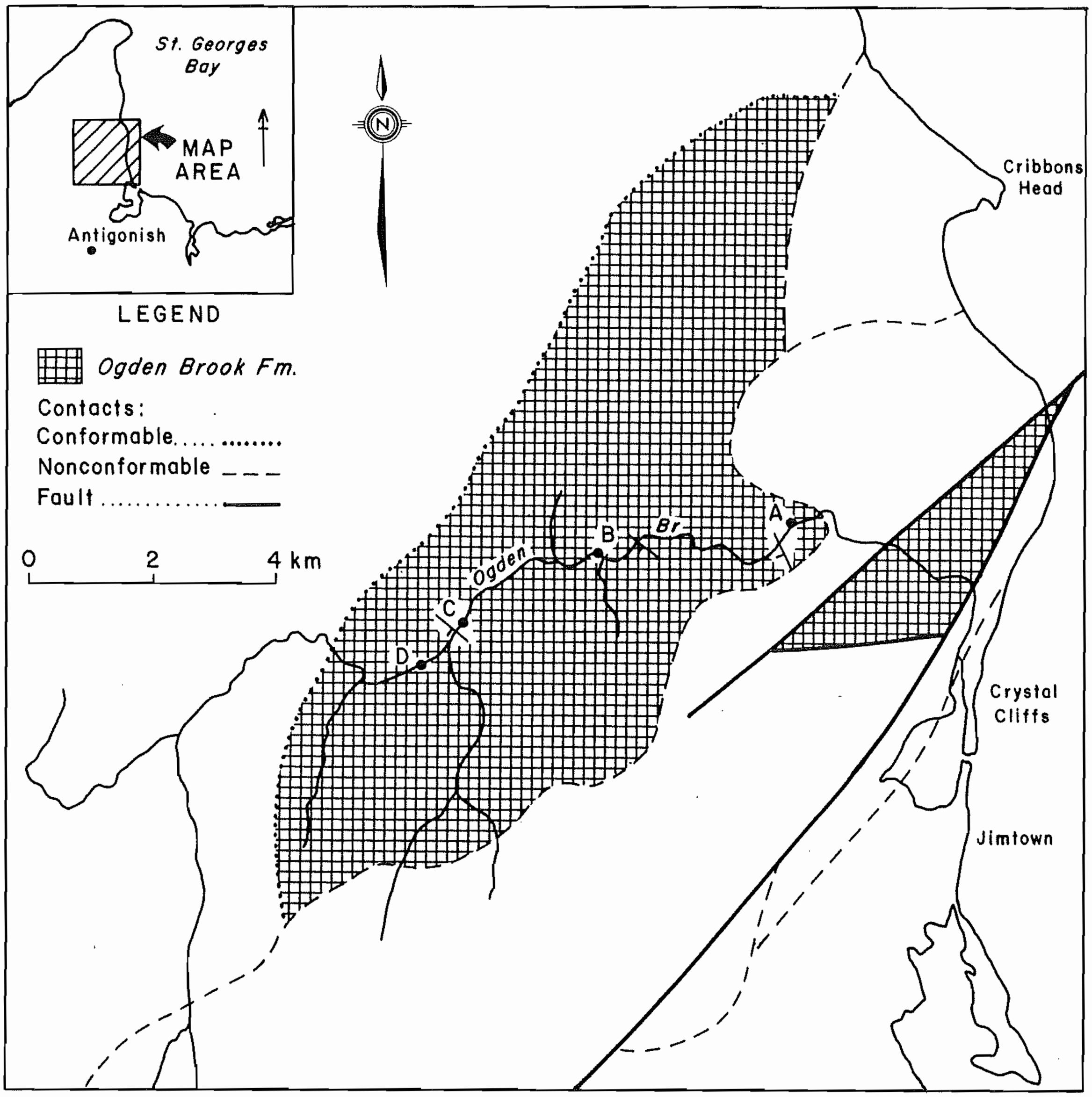


Figure 2.1. Location map showing the Ogden Brook Formation.

oxidized rock. Its conformable contact with overlying Late Devonian strata (the South Lake Creek Formation) suggests an approximate age of Middle to Late Devonian and not younger than Late Devonian.

iii) Thickness

The stratotype at Ogden Brook is approximately 2000 m thick and represents the thickest measured section.

iv) Contact Relationships

The formation unconformably overlies basement rocks and conformably underlies the South Lake Creek Formation with a gradational contact.

v) Lithofacies Descriptions

As an introduction to the lithofacies discussion, Figure 2.2 represents a key to the symbols used for all of the stratigraphic sections in the thesis.

Three stratigraphic sections were recorded in the Ogden Brook Formation (Fig.2.3) with each location indicated on Figure 2.1. Section 1 (Fig.2.3; Location A, Fig.2.1) occurs at the base of the formation, Section 2 (Location B) is approximately one-third of the thickness (700 m) from the base and Section 3 (Location C), approximately two-thirds

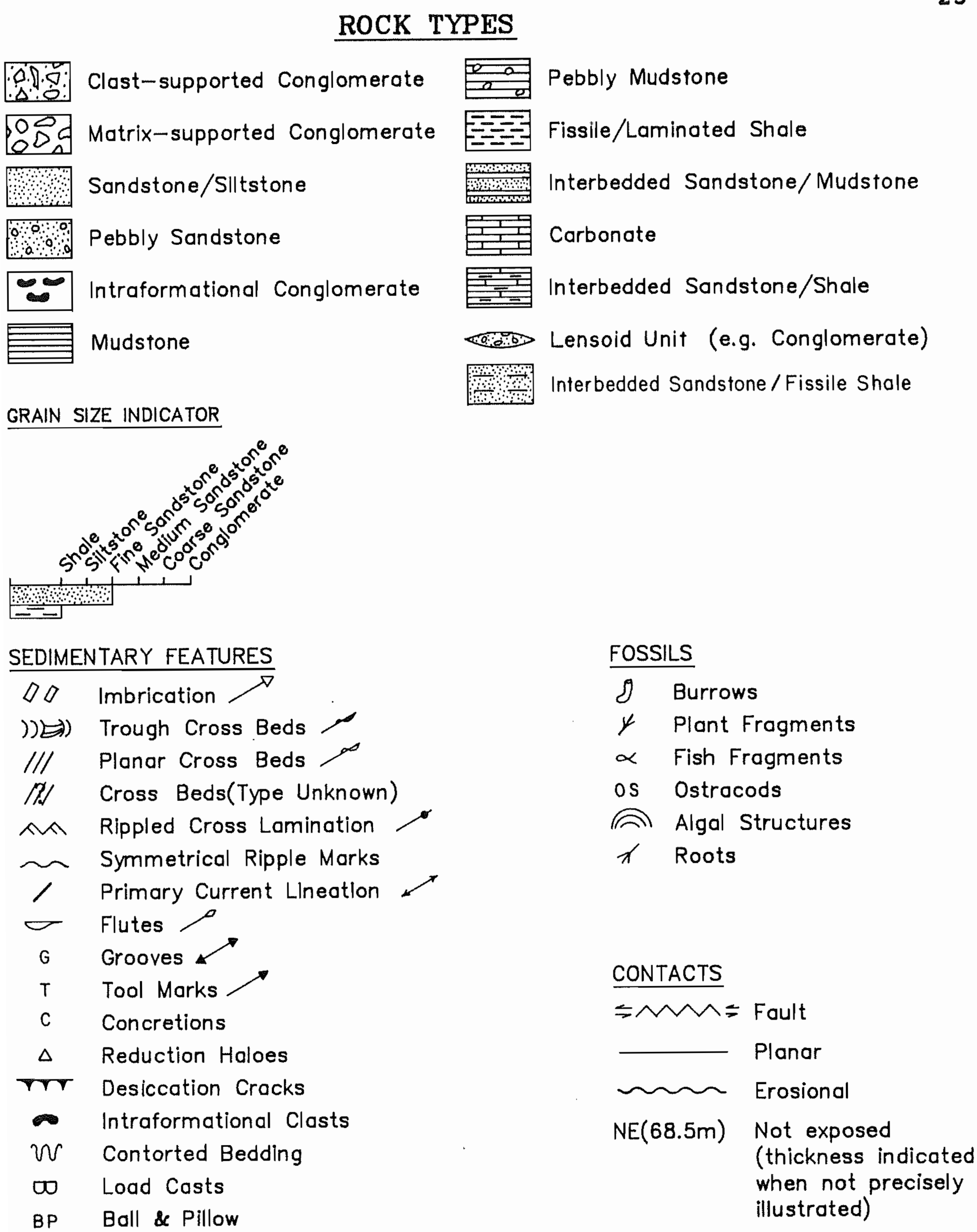


Figure 2.2. Key to the symbols used in the stratigraphic sections. Note that the arrow symbols to the right of the sedimentary features indicate paleoflow directions.

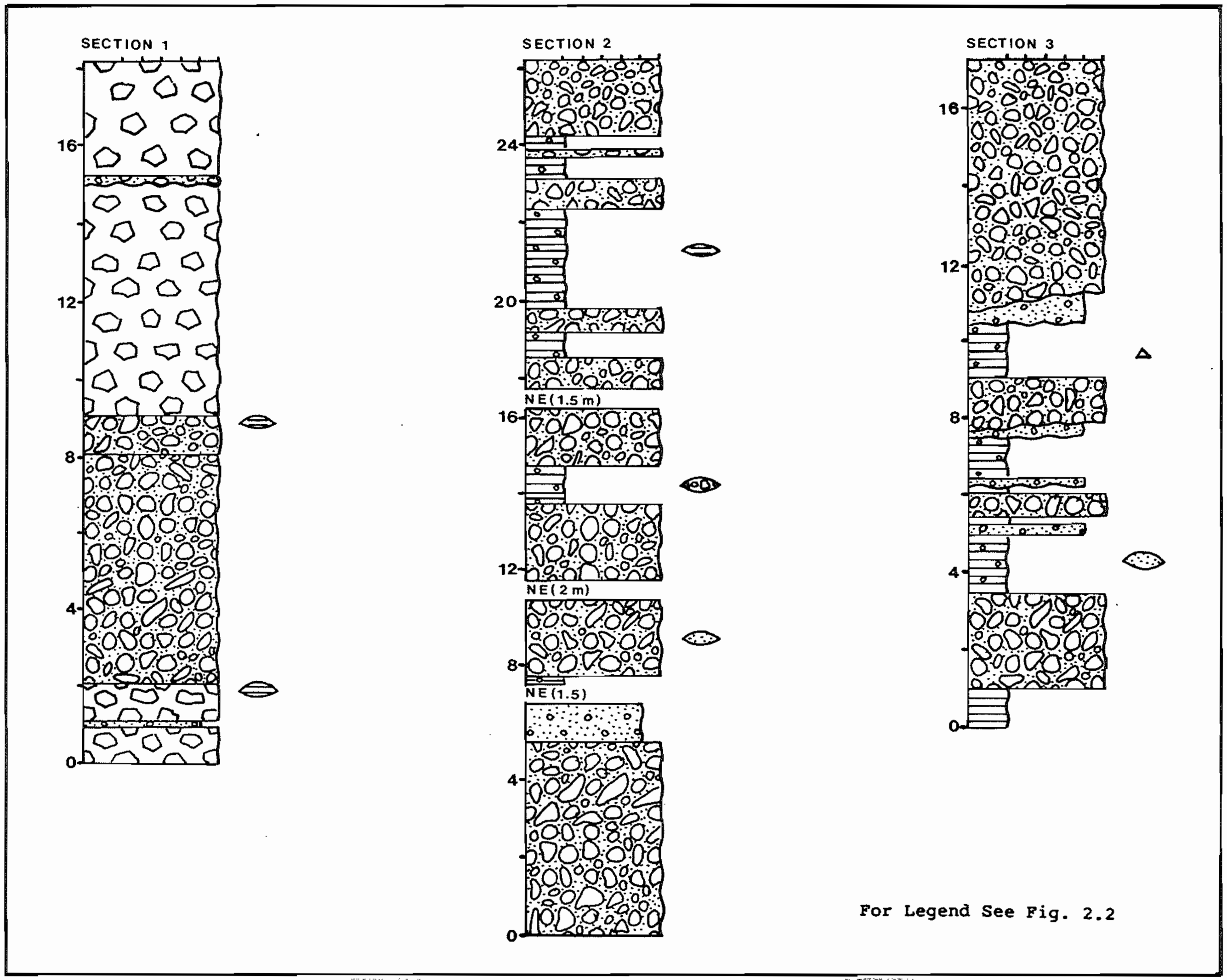


Figure 2.3. Stratigraphic sections from the Odgen Brook Formation (Section 1 = Location A, Section 2 = Location B, and Section 3 = Location C; Fig.2.1).

(1400 m) from the base. Markov Chain analysis was not performed on the sections because of the relatively small number of transitions and rock types.

Five lithofacies are observed in the Ogden Brook Formation:

Matrix-supported conglomerate (Gms) consists of thick beds of extremely poorly-sorted conglomerate (Fig.2.4). The clasts are subangular to subrounded. Clast size varies from granules to boulders up to one metre in diameter. Some beds exhibit horizontally oriented clasts whereas others infrequently contain a crude stratification.

Clast-supported conglomerate (Gm) (Fig.2.5) consists of massive or crudely bedded conglomerate varying from moderately well-sorted to poorly-sorted. The clasts are subangular to subrounded. Clast size varies from granules to boulders. Imbricated clasts are rare. Sandstone and mudstone lenses are common. One variant of the lithofacies exhibits fair sorting and often contains crude bedding. The other variant is more poorly-sorted and usually massive. Some strata are intermediate between these two. Lithofacies Gm occurs with the highest frequency in the formation.

Trough cross-stratified conglomerate (Gt) consists of festoon cross-stratified, clast-supported conglomerate. The

Figure 2.4. Matrix-supported conglomerate (Gms) in the Ogden Brook Formation (Location A, Fig.2.1). Unit is approximately 6 metres thick, defined by red sandstone lenses to upper left and lower right. Clasts indicate a fabric parallel to the bedding which dips steeply to the left. View is normal to the bedding. Field book (arrow) is 18 cm long.

Figure 2.5. Clast-supported conglomerate (Gml) in the Ogden Brook Formation (Location A, Fig.2.1.). Quite well-sorted with angular clasts and planar parallel bedding. View is normal to the bedding. Field book is 18 cm long.

cross-strata occur in sets 1-2 m thick which appear to be laterally continuous over several metres. This lithofacies is uncommon in the formation and not observed in the sections documented in Figure 9.

Massive- to parallel-stratified sandstone (Shl) consists of coarse-grained sandstone to pebbly sandstone. It is massive or rarely laminated, and poorly-sorted with abundant matrix of clay. Some beds are laterally continuous over the length of the outcrop (5-10 m); others are lensoid, pinching out laterally over a few metres (Fig.2.6).

Massive mudstone (Fm) consists of poorly-sorted mudstone. It is generally very sandy to pebbly (Fig.2.7) or locally clay-rich. Lenses of sandstone and conglomerate 2-10 m thick are common (Fig.2.8).

Characteristics common to all the lithofacies are the scattered presence of carbonate nodules and reduction blotches, and the absence of fossil remains. The carbonate nodules are typically subspherical bodies 2-3 cm in thickness. At some locations they occur interconnected in small clusters. The reduction blotches are green and can occur in almost any shape. They are usually associated with the conglomeratic lenses. Organic matter was observed within one of the haloes.

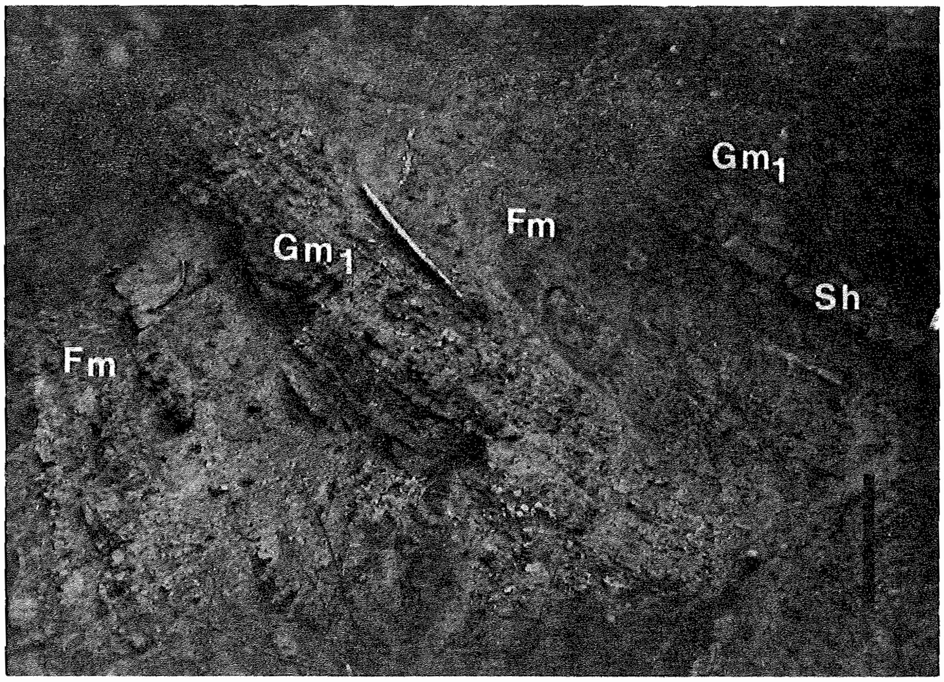


Figure 2.6. Sequence of conglomerate, mudstone, and sandstone in the Ogden Brook Formation (Location C, Fig.2.1). Thick conglomerate units (Gm1) occur in the upper right and centre of the photo. Sandstone (Sh1) lenses occur immediately below both conglomerate units. Remaining strata consist of pebbly mudstone (Fm) with interspersed conglomerate and sandstone lenses. Bar scale is 1 metre long.

Figure 2.7. Pebbly mudstone (Fm) in the Ogden Brook Formation (Location C, Fig.2.1). Example is gradational with lithofacies Gms. View of bedding surface with twenty-five cent piece for scale.

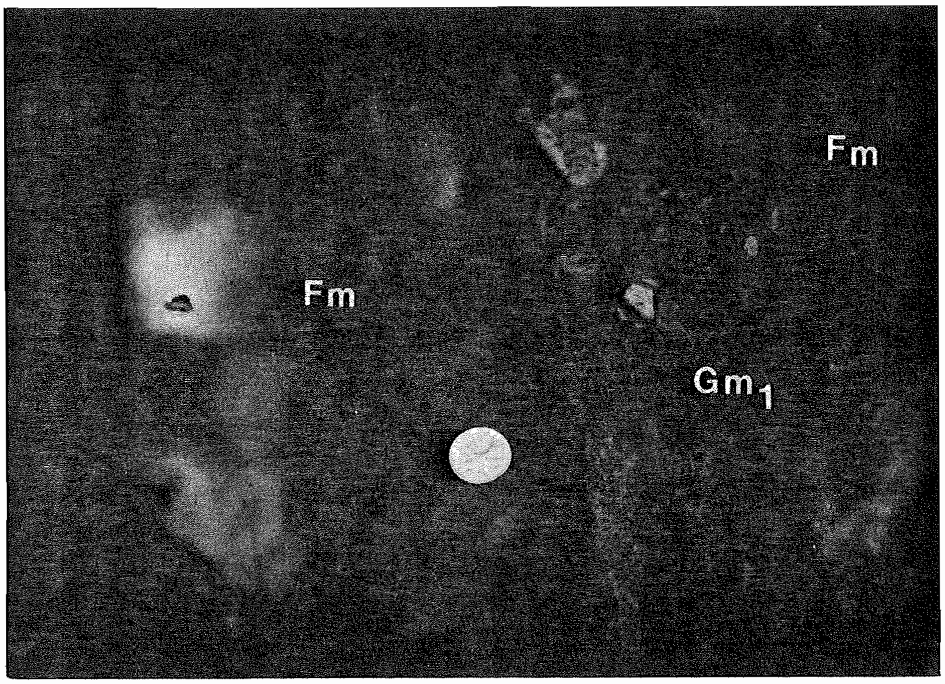


Figure 2.8. Pebbly mudstone (Fm) with conglomerate lens in the Ogden Brook Formation (Location D, Fig.2.1). Conglomerate pinches outside of photo. View is normal to bedding in subcrop exposure on river bottom. Twenty-five cent piece for scale.

Most of the units exhibit lateral continuity and constant thickness over lateral strike of tens of metres. Contacts between lithofacies are abrupt.

Several vertical trends are recognized. Firstly, the distribution of the lithofacies appears to be governed by stratigraphic position (Fig.2.3). In the lower part of the formation, Gml and Gms predominate. In the upper part, Fm and Shl are more abundant. Secondly, the percentage of fines (mudstone and sandstone) increases toward the top of the formation with Section 1 containing less than 1 percent, Section 2 containing 30 percent, and Section 3 containing 37 percent. Finally maximum grain size decreases upsection (Fig.2.9).

vi) <u>Depositional Environment</u>

In general, the Ogden Brook Formation is interpreted here as an alluvial-fan deposit by analogy with the studies of Blissenbach (1954), Hooke (1967) and Bull (1972).

Lithofacies Gms is interpreted as debris-flow deposits. Both the matrix-supported framework and the large subangular clasts are characteristic of this mode of deposition. The lateral continuity and sharp contacts of the strata further indicate that they were deposited as sheets, normally associated with the upper reaches of modern fans. The large boulders also suggest a proximal position. The presence of horizontally layered and imbricated clasts in some strata indicates that these flows were of low viscosity (Bull, 1963).

Lithofacies Gm is interpreted as a mixture of sheet flood and low-viscosity debris-flow deposits. The better sorted, crudely-bedded strata were deposited during sheet flood events, probably on the proximal areas of the fans where shallow distributary channels shifted to form sheets of sand and gravel. They resemble the sheet flood deposits described from arid fans by Bull (1972). The massive, poorly-sorted strata may represent low-viscosity debris-flow deposits or Bull's (1963) intermediate deposits. The shale and sandstone lenses in this lithofacies are considered to be remnants of thin mudflow or sheet flood deposits eroded by successive sheet flood events.

Lithofacies Gt is interpreted as channel deposits formed as dunes during periods of relative channel stability. The low abundance of this lithofacies in the formation suggests relatively proximal deposition, within channels that were shallow and readily abandoned.

Lithofacies Shl is interpreted as channel deposits resulting from upper-stage flow conditions. The lateral continuity of some of the deposits probably reflects the magnitude of the channels. The larger deposits of this lithofacies may also represent sheet flood deposits.

Lithofacies Fm is interpreted as mudflow deposits similar to those described by Bull (1972). This interpretation is based on the massive texture, poor sorting, and lateral continuity of the strata. It is unlikely that they are floodbasin muds which intertongued with the alluvial fans along the edge of a floodplain. This possibility is unlikely because of the generally sandy to pebbly texture of the strata. Water-laid floodbasin deposits should exhibit better sorting and a finer grain size.

The coarse-grained sandstone and conglomerate lenses in lithofacies Fm are interpreted as small channel deposits. They most likely formed during reworking of sand and gravel at the top of individual mudflow deposits. The reworking may have resulted from relatively minor flood events. Alternatively, it may represent a dewatering process immediately following deposition, similar to descriptions of mudflow deposits by Blackwelder (1928). During the dewatering event, rills may have developed, that resulted in minor reworking within these small channels.

The carbonate nodules appear to have originated <u>in situ</u> rather than as sedimentary clasts; thus, they are interpreted as pedogenic calcrete.

The nodules and reduction haloes probably represent chemical reactions with groundwaters. The absence of plant fossils may have resulted from: (1) an environment not conducive to plant growth, and/or (2) strong oxidative conditions which prevented preservation. Thus the evidence suggests a climate which was probably semi-arid at times during deposition of the Ogden Brook Formation.

The relative increase in fine-grained strata up section accompanied by a decrease in clast size, indicates that fan activity decreased through time. The retreat of the fans was probably a gradual process, as reflected by the apparently uninterrupted succession of fanglomerates. Interfingering with the overlying South Lake Creek Formation near the contact indicates that the two formations were lateral equivalents, at least in part.

vii) Paleocurrent Analysis

The Ogden Brook Formation revealed little sediment dispersal information (Appendix III). Four readings of pebble imbrication were the only directional data obtained. The imbrication indicates paleoflow to the northeast.

viii) Provenance

The clast composition of the Ogden Brook Formation (Fig.2.9) indicates that the source area consisted predominantly of felsic metavolcanics, metasediments, and granitic rocks. Percentages of each lithology remain relatively constant through the formation, apart from monzogranite which disappears in the upper half. In all samples, felsic metavolcanics predominate.

Basement rocks in the Antigonish Highlands closely resemble the clast types of the Ogden Brook Formation (Brendon Murphy, pers. comm., 1983). This probable source area is currently situated 5-20 km southwest of the Ogden Brook exposures and its position corresponds well with the paleocurrent data.

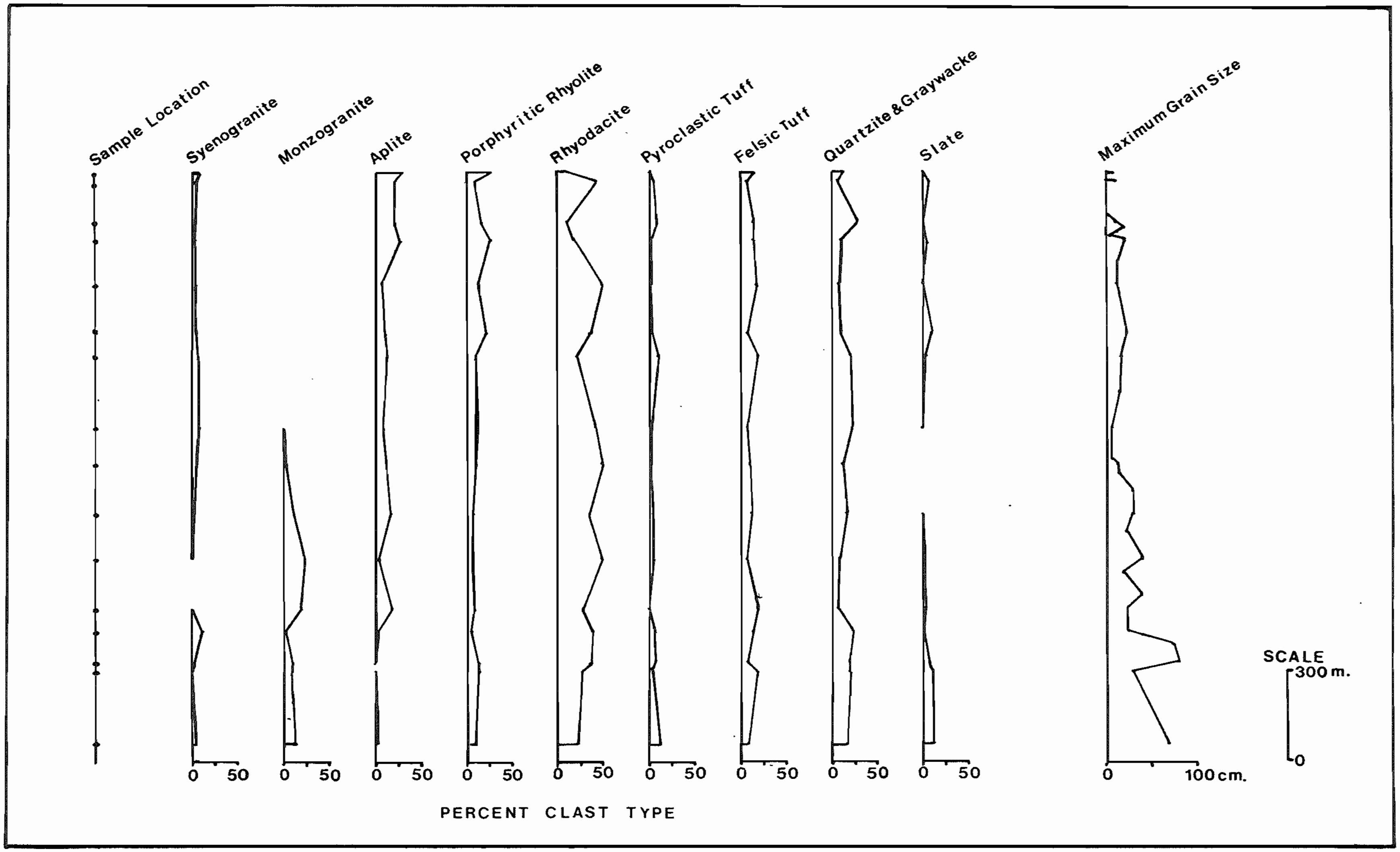


Figure 2.9. Clast composition of the Ogden Brook Formation conglomerates based on samples along Ogden Brook (see Fig.2.1).

South Lake Creek Formation

Murray (1960) subdivided the South Lake Creek Formation into members on the basis of grain size and colour. Descriptions of the members were limited and they were never shown on his map. He described them as being areally extensive and deposited one above the other in a layer-cake fashion. Due to poor exposure, the validity of these subdivisions is questionable. The author was unable to distinguish between two of the members using Murray's description. Moreover the members may not have been deposited in succession but may represent repeated lateral facies changes. Thus the formation was not subdivided in this thesis. Figure 2.10 is a location map showing the extent of the formation.

i) Lithological Description

The formation consists predominantly of sandstone, with lesser amounts of orthoconglomerate, mudstone, fissile shale, and felsitic volcanics. The sandstone is light brown, micaceous arkose containing abundant plant fossils. Grain size ranges from fine- to coarse-grained and is commonly pebbly. The colour of the orthoconglomerate is red, brown or gray; of the mudstone, red or gray; of the shale, gray or black. The black shale is commonly carbonaceous, petroliferous, and/or calcareous.

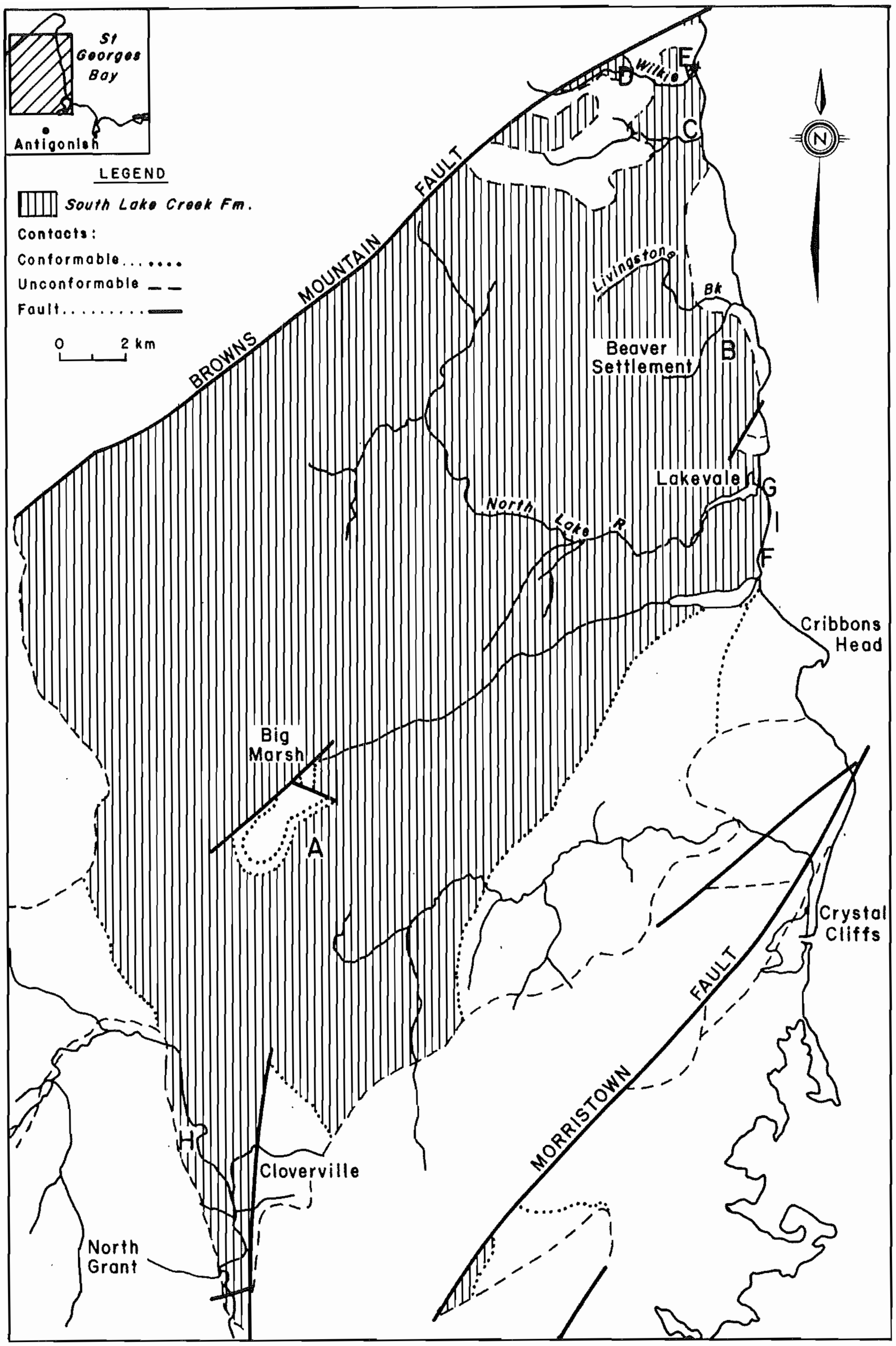


Figure 2.10. Location map of the South Lake Creek Formation.

ii) Age

Palynomorphs indicate a Late Devonian age for the South Lake Creek Formation (Benson, 1970a; McGregor, 1970).

iii) Thickness

The thickness of the formation has never been determined due to problems of uncertain structure and poor exposure. However, a minimum thickness of 500-600 m is estimated in this thesis based on oil shale studies by Potter (1975) in the Big Marsh area.

iv) Contact Relationships

The lower contact with the Odgen Brook Formation is gradational. The upper contact with the Rights River Formation is conformable to discordant (Murray, 1960).

v) Lithofacies Descriptions

The poor understanding of the stratigraphy and structure of the South Lake Creek Formation seriously hampers a discussion of its depositional history. The principal problem is that the sections measured for the thesis cannot be correlated. Thus interpretations are general and do not represent a chronological sequence of events.

Eight stratigraphic sections were measured. Three of these (Figs. 2.11, 2.15 and 2.19) represent the different lithofacies combinations encountered and will be used to discuss the general depositional setting.

Ten lithofacies are observed in the sections: massive to poorly-bedded orthoconglomerate (Gm1); intraformational conglomerate (Gm2); trough cross-stratified orthoconglomerate (Gt); internally scoured sandstone (Ss); parallel stratified sandstone (Sh2); trough cross-stratified sandstone (St); planar cross-stratified sandstone (Sp); ripple cross-stratified sandstone (Sr); fissile shale (Fs) and mudstone (Fm).

Section 4 (Fig.2.11; Location CE near Ballantynes Cove, Fig.2.10) consists of light brown to red strata of orthoconglomerate (Gm and Gt) and sandstone (Sh1, St, Sh2, and Sr) separated by thick mudstone units (Fm) (Fig.2.12). Conglomerate and sandstone comprise 62 percent of the section and shale, 38 percent. The section is representative of the coarsest strata in the formation and can be divided into two lithozones based on grain size and sedimentary structures.

Lithozone 1 (0-102 m) consists of sandstone (70 percent), mudstone (21 percent), and minor conglomerate (9 percent). It contains conglomerate/sandstone cycles that

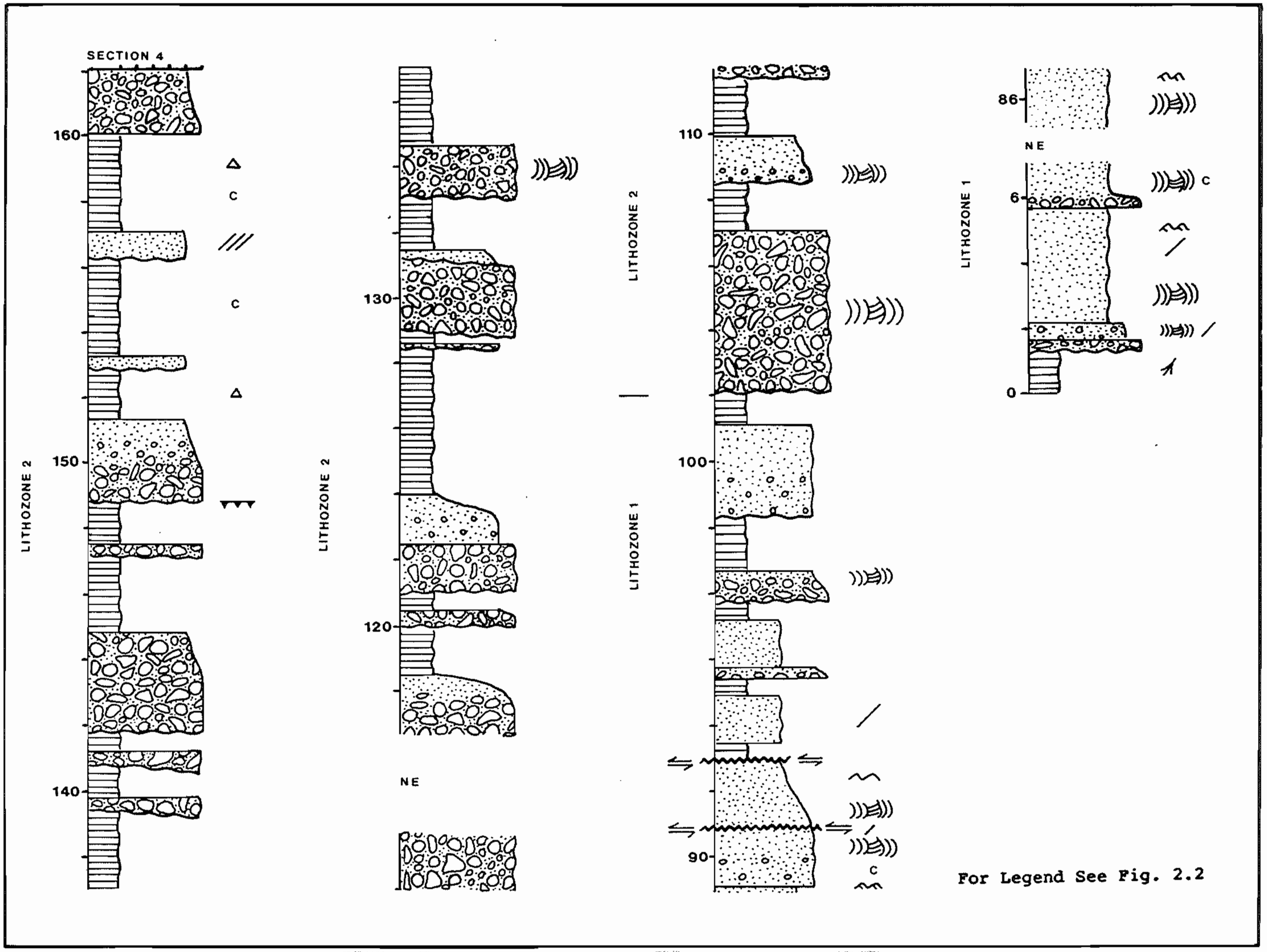


Figure 2.11. Coarse-grained section of the South Lake Creek Formation at Wilkie Brook near Ballantynes Cove (Location CE, Fig.2.10).

exhibit fining upward in grain size. The sedimentary structures of the cycles commonly suggest an upward decrease in flow power. A typical example of this transitional sequence consists of massive pebble conglomerate/ or trough cross-bedded sandstone to planar parallel-bedded sandstone and/or ripple cross-stratified sandstone. The lower lithozone has a sandstone/conglomerate ratio of approximately 8:1.

Lithozone 2 (102-162 m) is coarser grained, with a greater abundance of mudstone. It consists of conglomerate (39 percent), sandstone (11 percent), and mudstone (50 percent). Fining-upwards sequences are common, including an upward grain size reduction in the conglomerate units not illustrated in the section. A typical sequence of lithofacies in the lithozone has massive conglomerate or trough cross-bedded conglomerate at the base followed by planar parallel-bedded sandstone with mudstone at the top (e.g. 21-124 m). This indicates an upward decrease in flow power. In general, the cycles are erosional at the base and massive to poorly stratified throughout (Fig.2.13). Lithofacies Fm is often sandy at the base and clay-rich at the top, indicating a gradational change between the sandstone and overlying mudstone, rather than the sharp grain size change indicated in Figure 2.11. In other locations, lithofacies Fm contains some sandstone and conglomerate lenses. Large desiccation cracks (0.5 m deep)

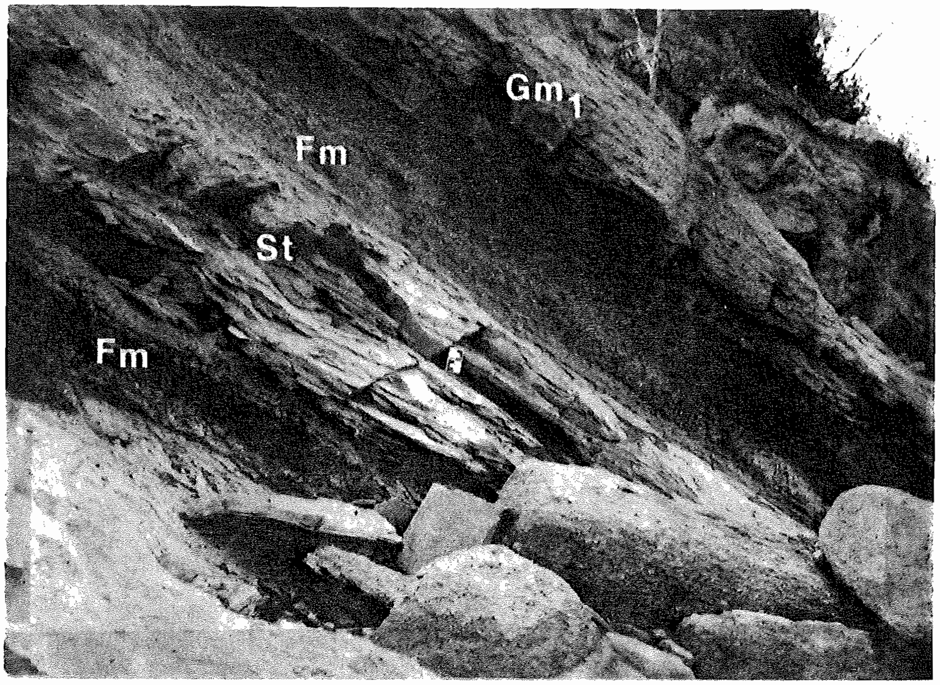


Figure 2.12. Example of interstratified coarse-/ fine-grained units in the South Lake Creek Formation at Wilkie Brook (Location E, Fig.2.10). The two mottled mudstone units (Fm) are separated by trough cross-bedded sandstone (St). Overlying the top shale is a poorly-stratified conglomerate unit (Gml).

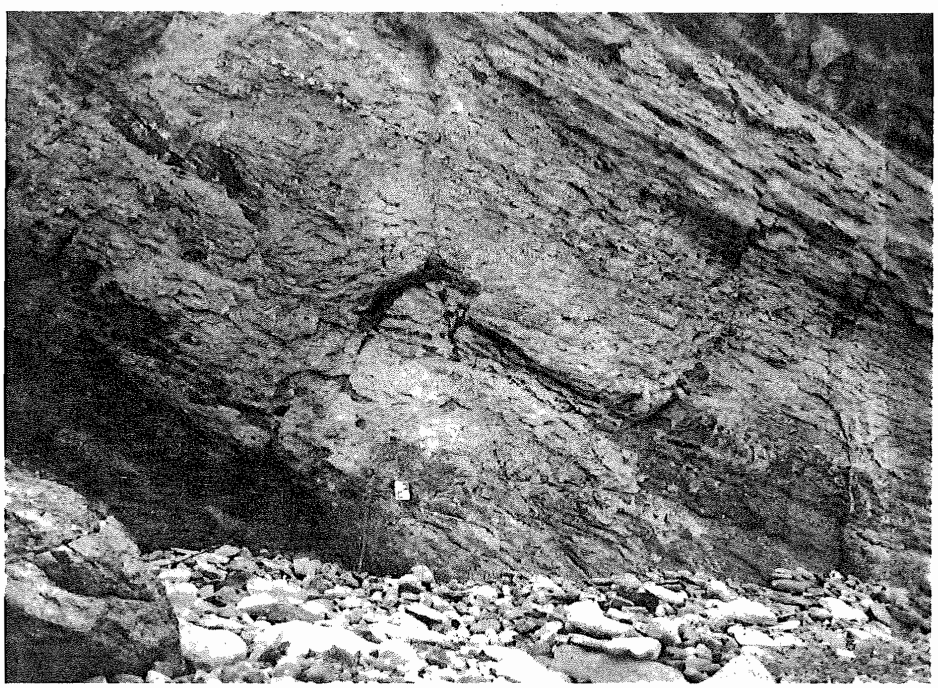


Figure 2.13. Thick, poorly-stratified, fining upward conglomerate unit (Gml) in the South Lake Creek Formation (Location E, Fig.2.10). Lower contact with Fm occurs below notebook. Upper contact occurs at grass in upper right. Unit is 5 metres thick.

extending into Fm are present at one location. Rare carbonate nodules, here interpreted as in situ caliche nodules, are present. The lithozone consists of a sandstone/conglomerate ratio of 1:4 and contains 4.3 times more conglomerate than the lower lithozone.

Markov Chain analysis of Section 4 (Fig.2.14; Appendix II) is relatively complex; however, it does demonstrate the tendency for coarse-grained units to be succeeded by fine-grained units during a decrease in flow power. For example, one upward transitional sequence shows massive conglomerate (Gml) to trough cross strata (St) to planar parallel strata (Sh2) to ripple cross-laminated strata (Sr). This is consistent with observation of Lithozone 1. Similarly, the sequence of massive conglomerate (Gml) to planar parallel strata (Sh2) to mudstone (Fm) to massive conglomerate (Gm) is a cycle typical of Lithozone 2. In spite of the general trends observed in the Markov Chain analysis visual inspection of the stratigraphic section is considered more revealing.

Section 5 near Lakevale (Fig.2.15) consists of light brown-coloured, medium- to coarse-grained sandstone (81 percent) with minor intraformational conglomerate (1 percent) and red to gray mudtone (18 percent). Thick coarse-grained sandstone units of lithofacies St, Sh2, and Ss abruptly give way to thin mudstone units (Fm) (Fig.2.16).

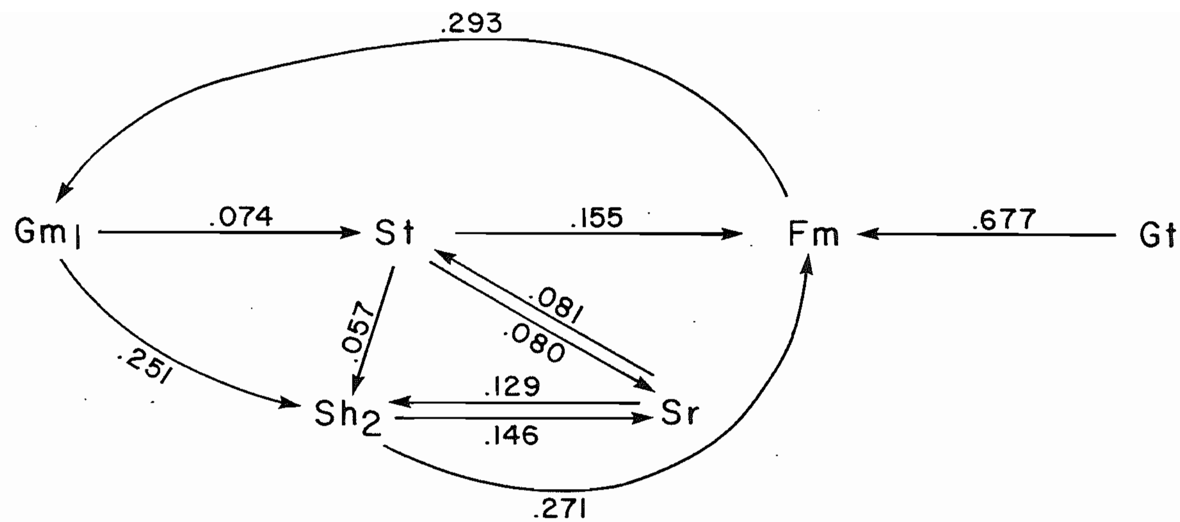


Figure 2.14. Markov Chain flow diagram for Section 4 of the South Lake Creek Formation. Numerical values are positive numbers obtained from the difference matrix (Appendix II) for this and all subsequent flow diagrams.

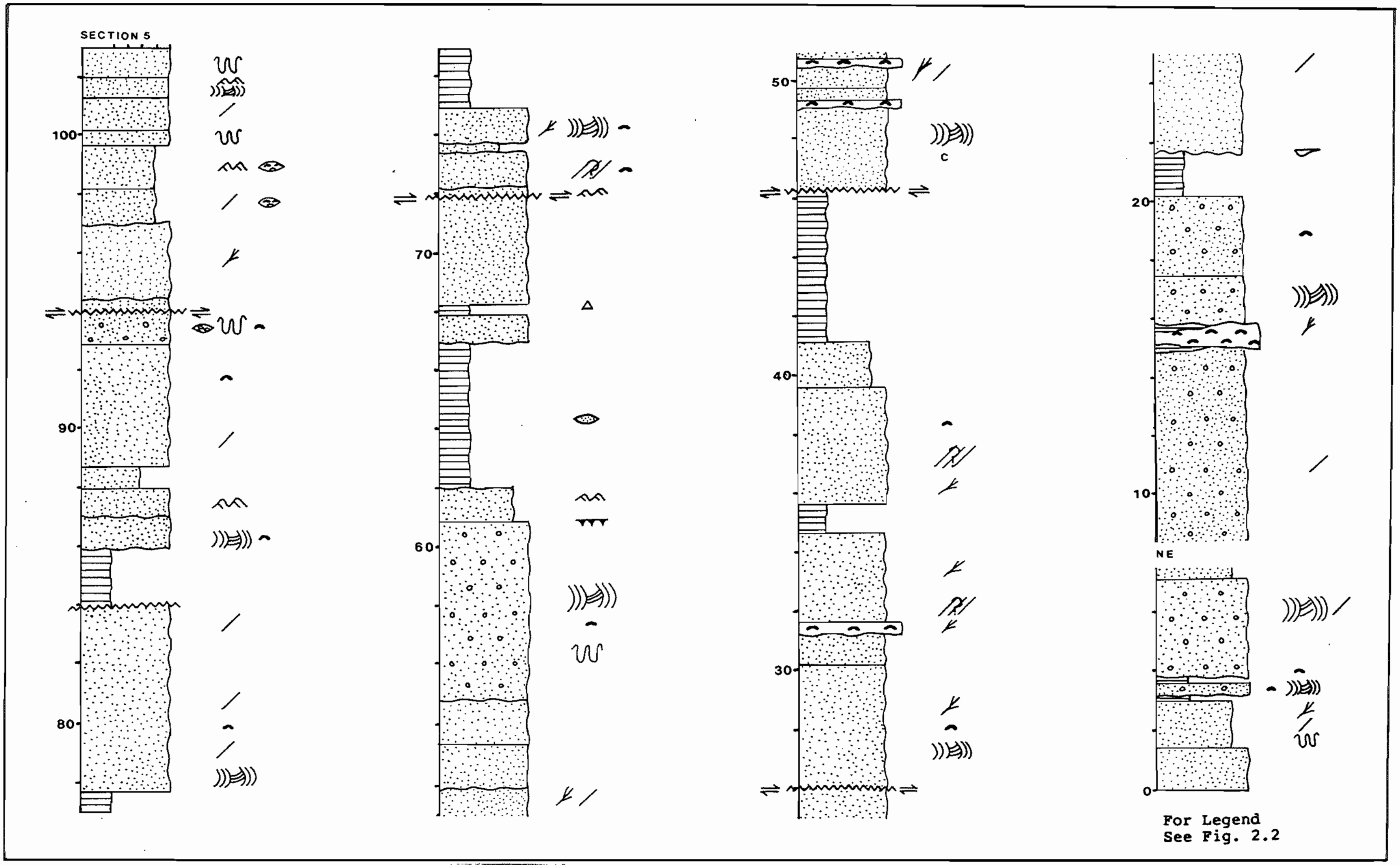


Figure 2.15. Section of the South Lake Creek Formation at Lakevale (Location FG, Fig.2.10).

The sandstones show erosional bases and contain abundant mudstone intraclasts. Figure 2.17 illustrates how thick these sandstone bodies can be. Visual inspection of Section 5 indicates that fining-upward sequences are rare. Large scale, planar cross-stratification (Sp) was observed at one location in proximity to, but laterally outside of, the measured section (Fig.2.18).

Markov Chain analysis of Section 5 suggests an absence of any major cycles (Fig.2.19). One prominent transitional sequence is intraformational conglomerate (Gm2) to trough cross-stratified sandstone (St) to mudstone (Fm). This shows the abrupt change which occurs between upper flow regime deposition (St) and deposition by settling from suspension (Fm).

Section 6 near North Grant (Fig.2.20) consists of sandstone (48 percent), shale (40 percent), and shale (12 percent), and represents the most fine-grained sandstone sequence in the South Lake Creek Formation. It contains two major coarse-grained units (0-10 m, 101-109 m) that consist of intraformational conglomerate (Gm2), scoured sandstone (Ss), parallel-stratified sandstone (Sh2) and ripple cross-stratified sandstone. The lower unit (0-10 m) maintains its coarse grain size throughout and is abruptly overlain by blue-gray fissile shale (Fs). The upper unit (101-109 m) fines upward slightly and is abruptly overlain

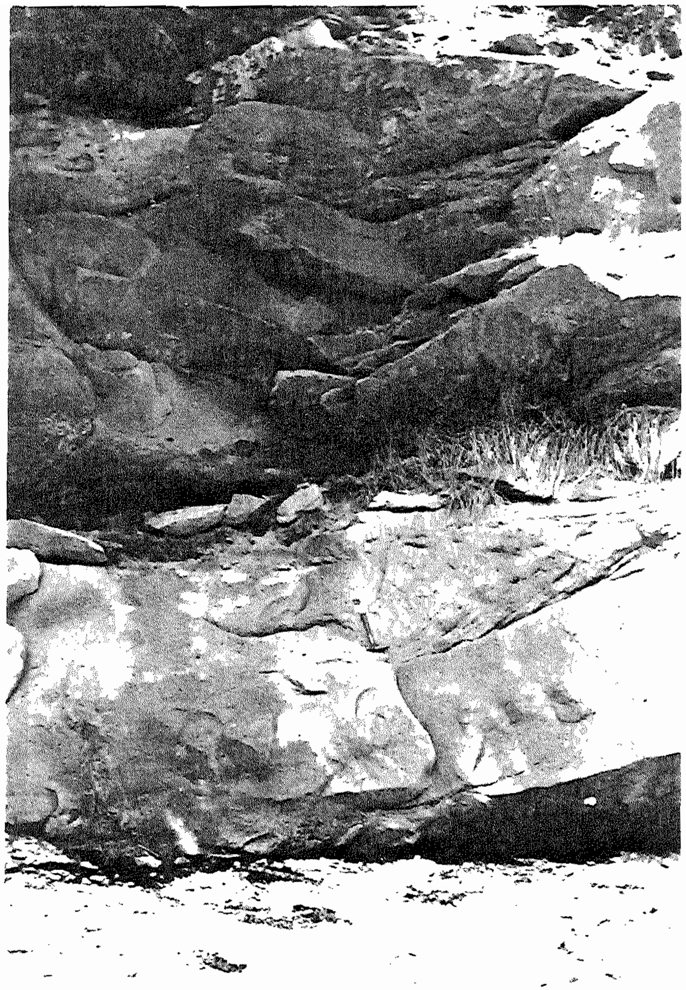


Figure 2.16. Two trough cross-bedded sandstone units (St) in the South Lake Creek Formation (Location F, Fig. 2.10). Units are separated by thin mudstone unit (grass line) which pinches laterally.

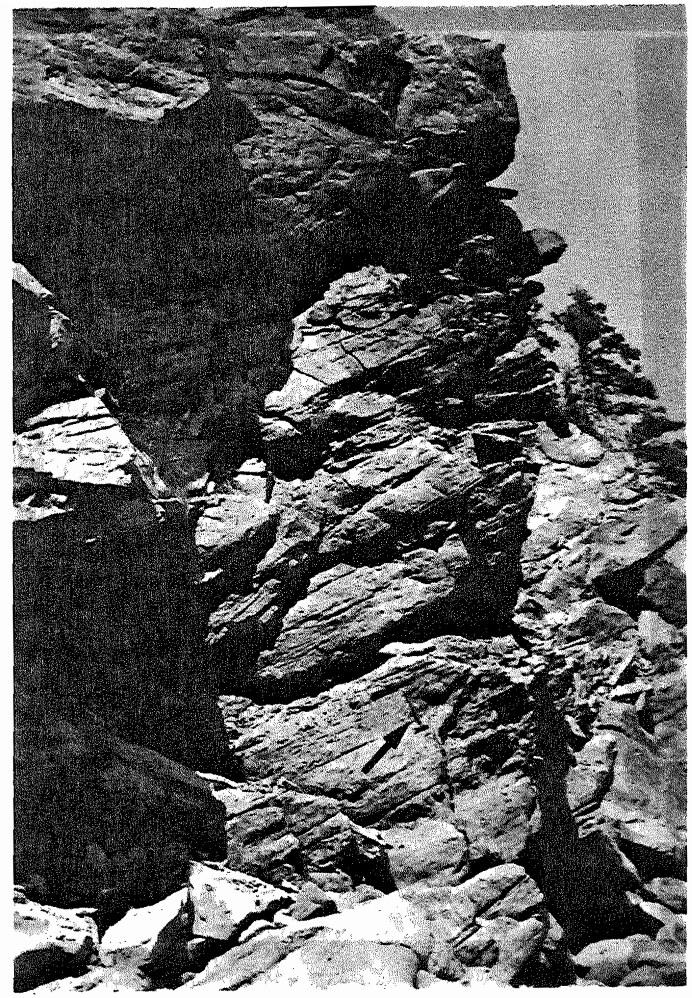


Figure 2.17. Continuous sandstone body illustrating thickness of sandstone units in South Lake Creek Formation (Location I, Fig.2.10). Hammer (arrow) lies on Sh2 which extends for about 1 metre below hammer. Remainder of outcrop is St.

Figure 2.18. Planar cross-bedded sandstone in the South Lake Creek Formation near Lakevale (Location I, Fig.2.10). Cross-beds seen as horizontal layering behind hammer (30 cm). General bedding attitude at this location (observed in top centre of photo) is diagonally across the photo to the lower left.

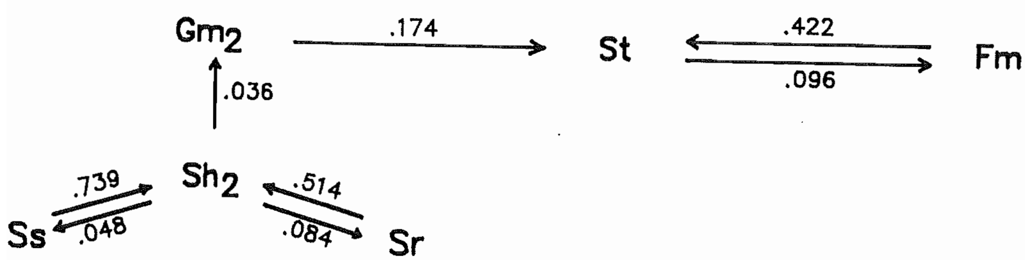


Figure 2.19. Markov Chain flow diagram for Section 5 of the South Lake Creek Formation (from Appendix II).

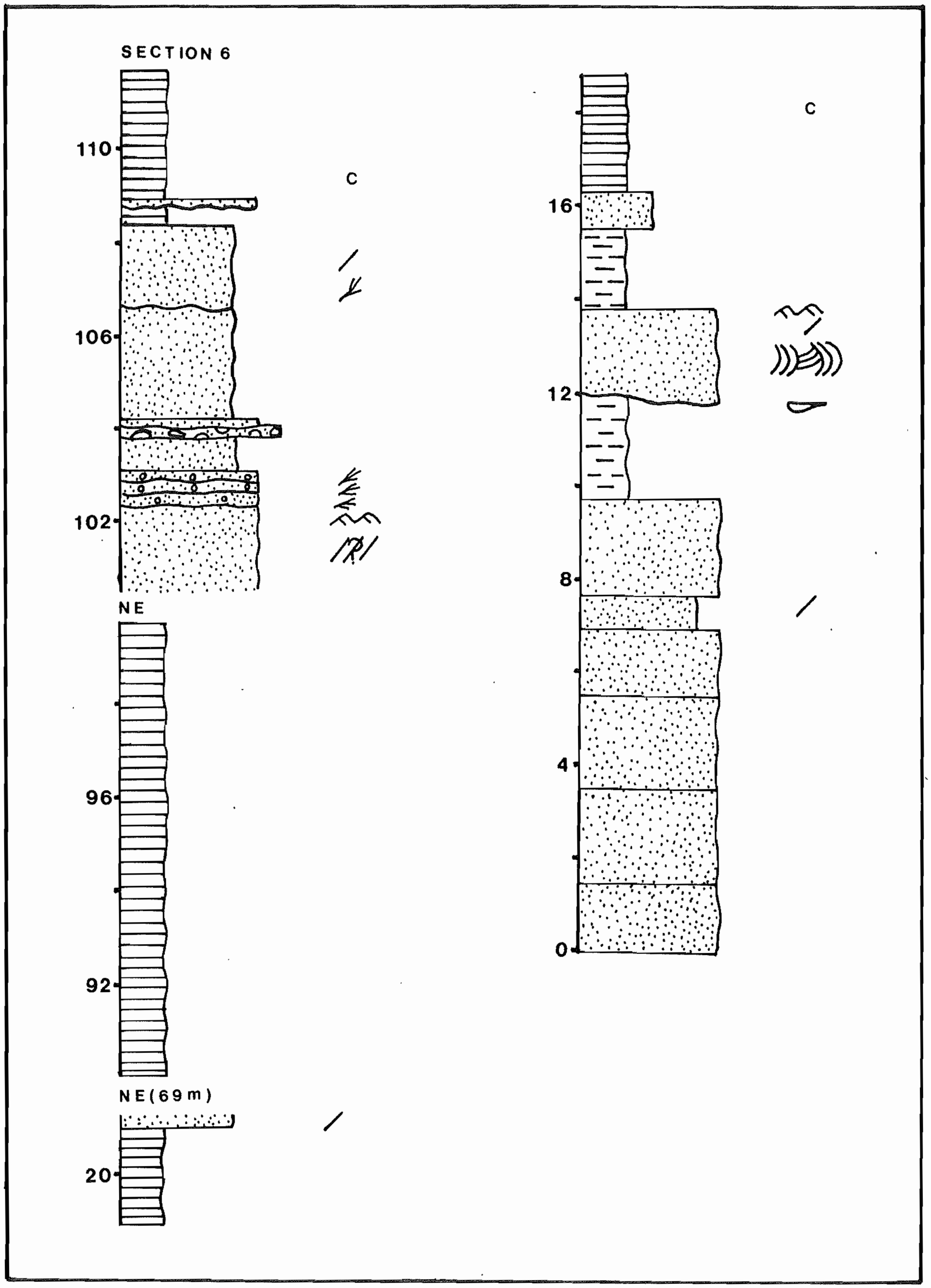


Figure 2.20. Section of the South Lake Creek Formation at North Grant (Location H, Fig.2.10).

by mudstone. A third thinner sandstone unit (12-14 m) occurs within a blue-gray fissile shale (Fs) and consists of scoured sandstone (Ss) and thin interbeds of mudstone (Fm). Mudstone intraclasts and plant fragments are common thoughout the sandstone units. The remaining strata are fine-grained, consisting of fissile shale and mudstone. The fissile shale is blue-gray in colour and contains thin sandy interbeds. The mudstone is generally red-coloured with mottling and what are interpreted here as pedogenic calcrete nodules. Fine-grained, parallel-stratified sandstone locally occurs as interbeds within the mudstone units.

In addition to the sandstone-dominated sequences, thick uninterrupted black shale sequences are found at Big Marsh (Fig.2.10, Location A) and Beaver Settlement (Fig.2.10, Location B). Mazerolle and MacGillvary (1974a,b) mapped these shales as a continuous zone (Fig.2.21). Drilling indicates that the thickness of the sequences ranges from 122 m at Big Marsh to 76 m at Beaver Settlement (Potter, 1975). The upper and lower contacts are gradational with gray to green shale, red shale, siltstone, sandstone, and conglomerate (Macauley and Ball, 1984). The shales are pyrobituminous, contain abundant fish and plant fossils, and are locally micaceous and calcareous (Macauley, 1981).

Porphyritic rhyolite and tuff reported by Fletcher and Faribault (1887) and Murray (1960) as interbeds within the

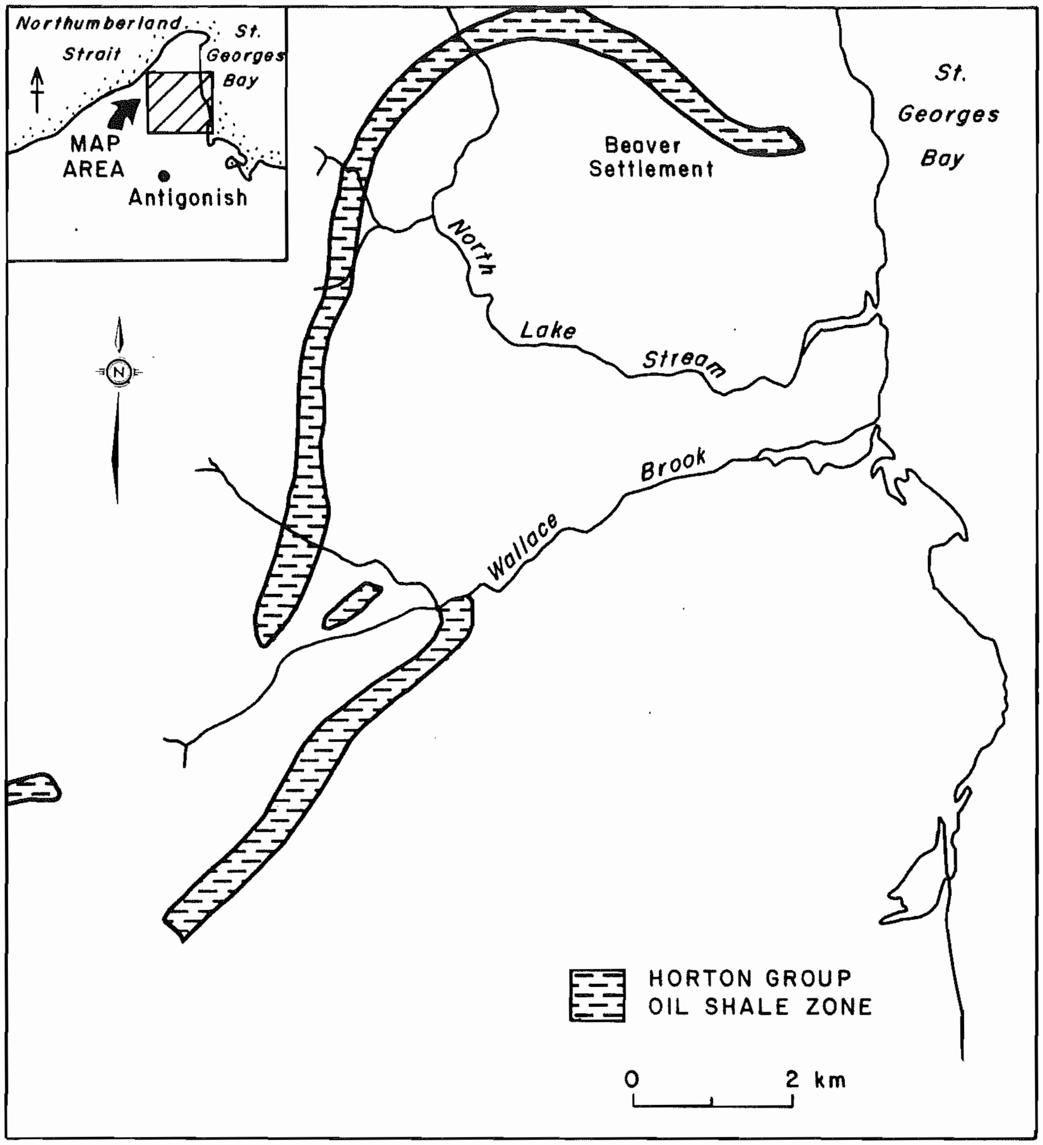


Figure 2.21. Location map showing the oil shale occurrence in the South Lake Creek Formation (modified from Macauley, 1981).

South Lake Creek Formation near the mouth of Graham Brook (Fig.2.10, Location C) were not found in the present study. Approximately 1.5 km upstream from the mouth of Wilkie Brook occurs another thick porphyritic rhyolite body (Fig.2.10, Location D). Its lower contact is unknown whereas the upper contact may be unconformable with the overlying Wilkie Brook Formation (Murray, 1960). Murray concluded that this volcanic body was part of the South Lake Creek Formation. Boucot et al. (1974) suggested that the volcanic unit is probably much older, tentatively placing it in the Cambrian to Early Silurian. Based on this study a clear stratigraphic assignment of these rocks cannot be made.

vi) Depositional Environments:

The South Lake Creek Formation is interpreted as generally fluvial and lacustrine. The sandstone sequences represent fluvial deposition and the thick black shales represent lacustrine conditions. The fluvial sediments include meandering, braided, and ephemeral river deposits.

Section 4 near Ballantynes Cove is interpreted as being meandering and ephemeral stream deposits. The lower part of the section, lithozone 1 (0-102 m), was deposited during relatively stable conditions within a meandering river system. The fining upward lithofacies transitions St to Sh2 to Sr are characteristic of lateral accretion and the development of point bars (Allen, 1965) although lateral accretion sets were not observed. The mudstone units (Fm) are interpreted as overbank fines deposited on a floodplain, or mud drapes which covered the point bars at the top of the fining upward cycles. Both vertical accretion types of deposit settle from suspension during the final stages of flooding, but the relatively large thickness of the mudstone units suggests that they are floodplain deposits. The percentage of fines in Lithozone 1 is small, and there is no evidence of sandstone interbeds that could be interpreted as crevasse splay deposits. These characteristics suggest a proximal location within the meandering river system. This conclusion is supported by the coarse grain size of the deposits.

Another possible model for Lithozone 1 is a distal braided river environment, similar to that in which the Battery Point Formation was deposited (Cant, 1978). However, this seems less likely based on characteristics of cyclicity and percentage of mudstone. The fining upward cycles in the lower lithozone are generally complete and separated by thick shale strata whereas in the Battery Point Formation, the cycles are generally incomplete and multistoried with a relatively small proportion of shale. Lithozone 1 suggests deposition in stable channels with little evidence for lateral migration of the channels and erosion into underlying cycles. Cant (1978) pointed out that fine lithofacies are more likely to be preserved in a meandering river environment.

Lithozone 2 (102-162 m) of Section 4 represents a continuation of the proximal meandering system with a more ephemeral deposition, similar to descriptions by Glennie (1970). Ephemeral conditions are suggested by the following observations: (1) the deep desiccation cracks and common calcrete nodules in the shale lithofacies are features characteristic of aridity; (2) the increase in frequency, thickness, and grain size of the conglomerate strata, as compared to the lower lithozone, reflects a corresponding increase in flood intensity and transporting capacity for the fluvial system; (3) the fining-upward cycles are generally massive to poorly bedded and sedimentary structures characteristic of point bar development are not observed; this suggests rapid deposition in the upper flow regime which failed to establish a sequence of well-structured bed forms; (4) gradational contacts between the coarse sediments (Shl) and the fine sediments (Fm) in the fining upward cycles indicates poor segregation of grain size by the flow.

The coarse-grained units (Gm, Gt, Shl, and St) were deposited as channel fills in the periodically active system. As flooding subsided, silt and mud (Fm) were deposited. The relatively great thickness of the mudstone units suggests that they formed as overbank fines, although the lack of interbedded crevasse splay deposits implies proximal floodplain conditions. The gradational contact between many sandstone and mudstone units suggests deposition of mud in the channels at the top of the fining upward succession. Reineck and Singh (1980) pointed out that thick mud deposits are commonly associated with ephemeral channels. The conglomerate and sandstone lenses in lithofacies Fm represent smaller-scale channels or possibly splay events.

Section 5 near Lakevale (Fig. 2.15) is interpreted as a distal braided river deposit and is analogous to the modern South Saskatchewan River as discussed by Cant (1978). The coarse lithofacies (Gm2, Ss, St, and Sh2) were deposited in channels during high-stage flow. The abrupt contact with overlying mudstone units (Fm) suggests that the mud was deposited and preserved in abandoned channels. Thick red mudstone units (e.g. 41-46 m) may represent minor floodplain deposits. The relatively low percentage of fines in the section indicates that either the floodplain was poorly developed (a feature typical of distal braided river environments; Cant, 1978), or was subsequently eroded away. Abundant erosional surfaces, internal scouring, incomplete fining-upward cycles, and an abundance of intraclasts thoughout the sandstone strata suggests vigorous reworking, probably in response to lateral migration of the braided channels. The single occurrence of planar cross-bedded sandstone (Sp) suggests that bars or sand waves were present but rarely preserved (Miall, 1977).

Two major differences are observed between Section 5 and typical South Saskatchewan River deposits. The South Saskatchewan River shows better fining-upward, and well-developed bars are abundant. The absence of complete cycles in Section 5 suggests a higher energy fluvial system in which strong discharge fluctuations prevented cyclic-sequence development and/or the top portion of the cycles was consistently eroded away by subsequent migrating channels. The low frequency of planar cross-stratified bar deposits in the section may also be explained by channel migration and erosion, as lithofacies Sp usually occurs in the upper part of channel bars.

Section 6 near North Grant (Fig. 2.20) is tentatively interpreted as proximal meandering river deposits. The two coarse-grained sandstone units (0-10 m, 101-109 m) correspond to channel deposits, with the intraformational conglomerate, scoured sandstone, and planar stratified sandstone indicative of the upper flow regime. The mudstone and interbedded planar stratified sandstone units correspond to the floodbasin deposits of Allen (1970).

The blue-gray fissile shale and sandstone units at

10-18 m may represent a meander loop cut-off. The evidence includes the abrupt contact of the blue-gray shales with underlying channel deposits (at 10 m) and the interruption of these reduced shales several times by thin sandstone beds. Channel abandonment was followed by vertically accreted fines deposited from suspension in an oxbow lake. The lake was re-opened several times by flood events during which coarser layers were deposited (12-14 m). The lake eventually filled with fines and was later covered by floodbasin muds (Fm) and crevasse splay sands (Sh2). Alternatively, the reduced shales may represent a larger lake system, the deposits of which interfingered with the meandering river system.

The thick oil shale sequences at Big Marsh and Beaver Settlement were interpreted as fluvio-lacustrine deposits by Bell (1958). Macauley and Ball (1984, p.20) suggested that they represented "a local restricted lacustrine environment, contained in isolation within a regionally broader area of alluvial fan deposition". This conclusion was based on the lateral variation in thickness of the shales attributed to facies changes. A brief examination of the Big Marsh area in the present study resulted in agreement with a lacustrine interpretation. This is based on the large thickness of fine-grained strata, the abundance of fish fragments, and the high hydrocarbon content.

The porphyritic rhyolite flows and tuffs interbedded in the South Lake Creek Formation (Murray, 1960) indicate the presence of volcanic activity in the basin during the Late Devonian. The extent of the volcanism during this period is uncertain for two reasons: (1) the exposure of the volcanic interbeds is extremely limited; (2) the larger porphyritic rhyolite body upstream on Wilkie Brook has never been dated.

In summary, deposition of the South Lake Creek Formation resulted from several fluvial styles, including braided, meandering, and ephemeral rivers. During at least part of this time a relatively stable lake system developed in the basin, resulting in the deposition of a thick sequence of oil shales. Localized volcanic activity also occurred.

vii) <u>Paleocurrent Analysis</u>

Results of the paleocurrent analysis are inconclusive (Fig.2.22, Appendix III); however, they do suggest a westerly to southwesterly paleoflow. The large variance in the data may be attributed to variations in fluvial styles on the alluvial plain, or to interacting river systems with different source areas. However, the relatively consistent petrographic composition of the deposits favours a single source area. In Miall's (1984, p.265) discussion of paleocurrent analysis, he states that "depositional

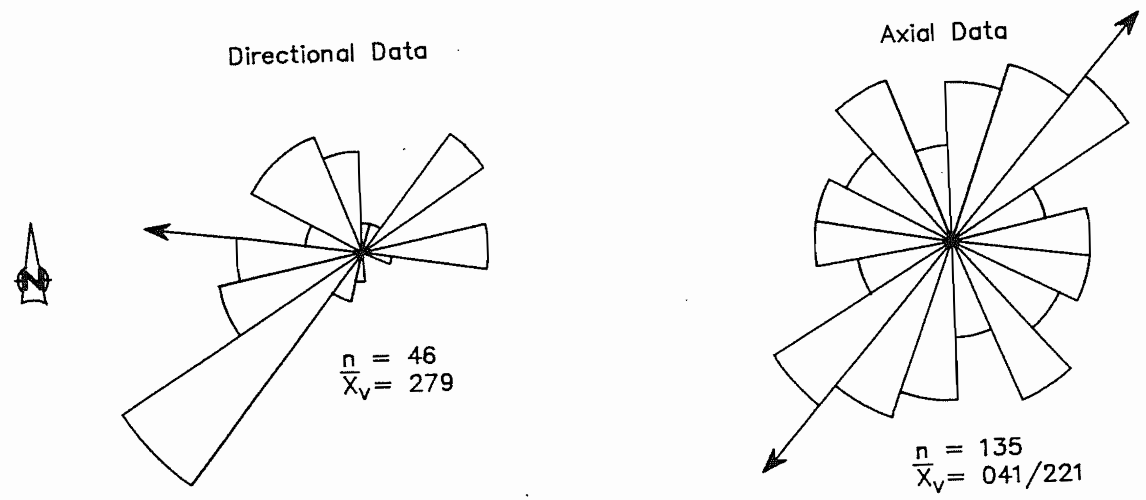


Figure 2.22. Paleocurrent trends in the South Lake Creek Formation.

environment, bedform hierarchy and sampling scale all affect the consistency, variance and 'modality' of the data". This statement is especially significant in the South Lake Creek Formation where the data was obtained from several depositional environments which often could not be distinguished at the outcrop scale. Thus, selectivity in collecting the data was not possible and probably is the main reason for the high variability in paleoflow direction.

viii) Provenance

The clast assemblage of the formation (Fig.2.23) is composed of porphyritic rhyolite, granitoids, schist, vein quartz, and felsic tuff. Its source area is unknown. One possibility suggested by Murray (1960), the porphyritic rhyolite and tuff upstream along Wilkie Brook (Fig.2.10, Location E), is unlikely because it occurs in the downflow direction as indictated by paleocurrents. Furthermore the granitoid and schist lithologies observed in the conglomerates are not found in the vicinity of this porphyritic rhyolite. An alternative source area, based on the paleocurrent analysis, is the Craignish Hills in southwestern Cape Breton Island. The author examined representative rock samples from this area collected by G. C. Milligan (Dalhousie University); however, they did not match the South Lake Creek Formation clast lithologies.

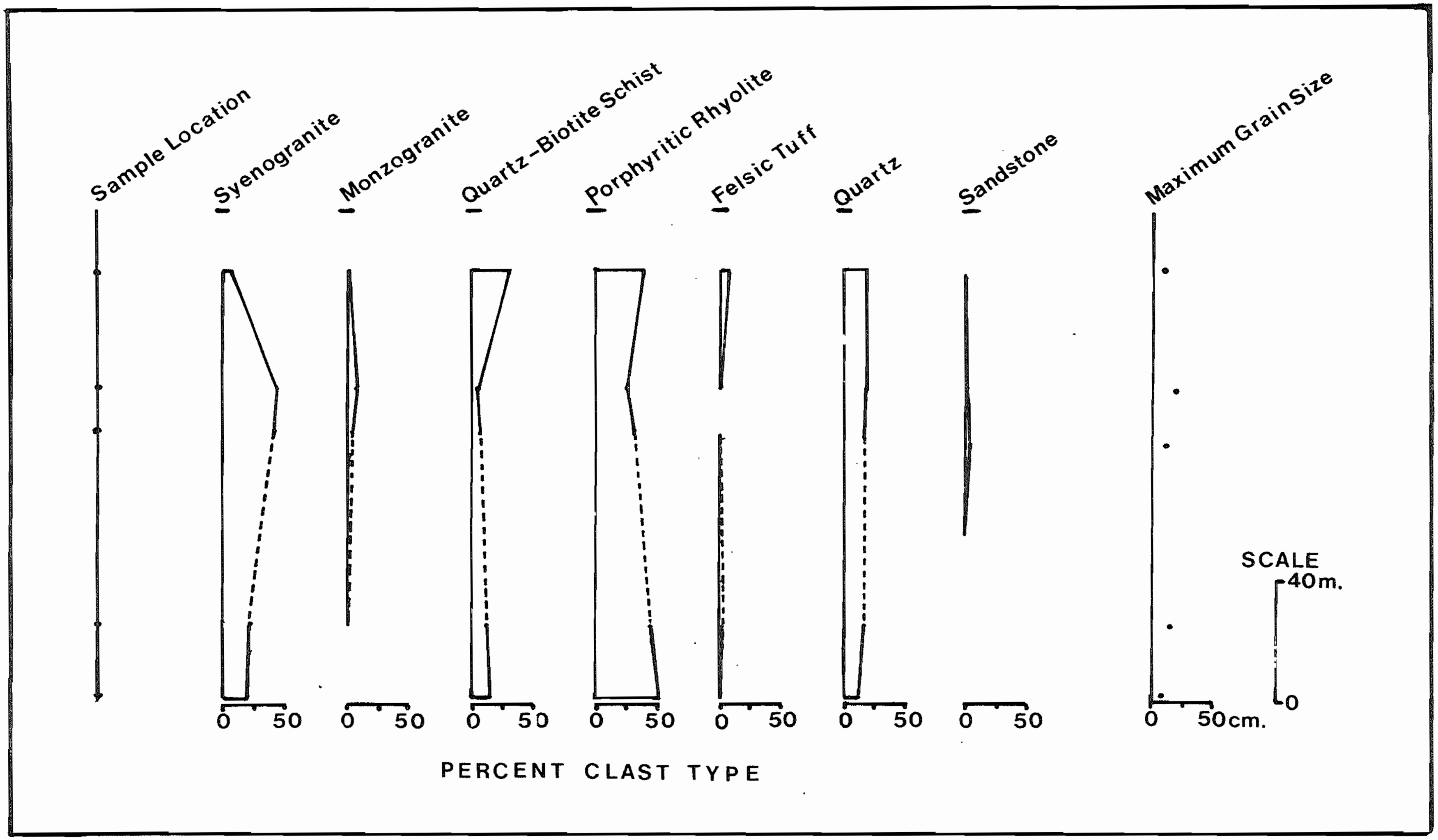


Figure 2.23. Clast composition of the conglomerates of part of the South Lake Creek Formation at Wilkie Brook (Location CE, Fig.2.10).

The absence of evidence tying clast lithology in the South Lake Creek Formation to adjacent basement rock may indicate (1) a poor understanding of drainage direction using paleocurrent analysis, (2) the source area was eroded to the degree that it disappeared and what is exposed today stratigraphically underlies the source material, (3) post-deformational faulting has offset source and depositional areas, or (4) the source area lies buried under subsequent deposits.

Rights River Formation

i) Lithological Description

The Rights River Formation (Fig.2.24) is lithologically similar to the Ogden Brook Formation in that it consists mainly of red conglomerates, pebbly sandstones, and pebbly shales. The conglomerates are polymictic and clast-supported. The sandstones are lithic graywackes. Minor amounts of gray conglomerate, calcareous sandstone and shale, carbonate, and red-brown sandstone are also present.

ii) Age

Palynological results are minimal in the formation; however, Boehner and Giles (1982) report a Tournaisian age based on palynomorphs.

iii) Thickness

Sage (1954) and Murray (1960) estimated a thickness of 750 m. In the present study the thickness was calculated as greater than 1200 m using trigonometry and relatively consistent bedding attitudes that occur along Rights River.

iv) Contact Relationships

According to Murray (1960) the Rights River Formation overlies the South Lake Creek Formation conformably in some

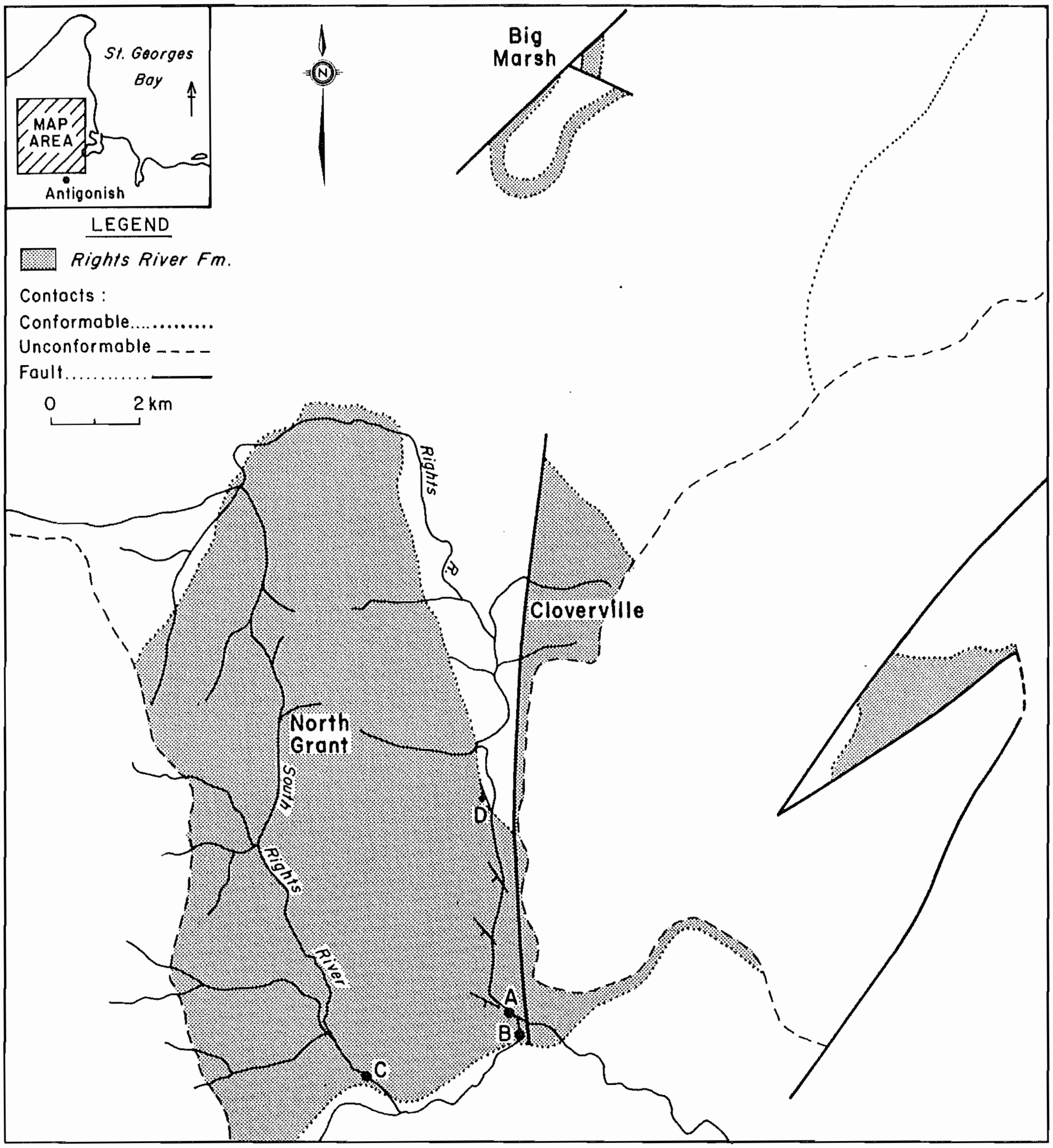


Figure 2.24. Location map of the Rights River Formation.

locations and with angular discordance in others. The formation in turn is overlain by the Windsor Group. This contact is a disconformity and locally there is an angular discordance (Murray, 1960). The contacts with the Windsor Group observed by the author were all disconformable.

v) Lithofacies Descriptions

Two stratigraphic sections were measured in the upper part of the formation on Rights River (Figs. 2.25 and 2.26). Section 7 (Fig.2.24, Location A) and 8 (Fig.2.24, Location B) contain four clastic lithofacies which are described below.

Massive to poorly-stratified conglomerate (Gm) consists of granule to boulder clast-supported conglomerate. Some units, which are poorly-sorted and matrix-rich (Fig.2.27), resemble facies Gms but show a clast-supported framework. Others exhibit better sorting and less matrix (Fig.2.28). These differences are not always distinguishable in outcrop. Sandstone and mudstone lenses are common.

Trough cross-stratified conglomerate (Gt) consists of festoon cross-stratified, clast-supported conglomerate. It is uncommon in the formation.

Massive to poorly-stratified sandstone (Shl) consists

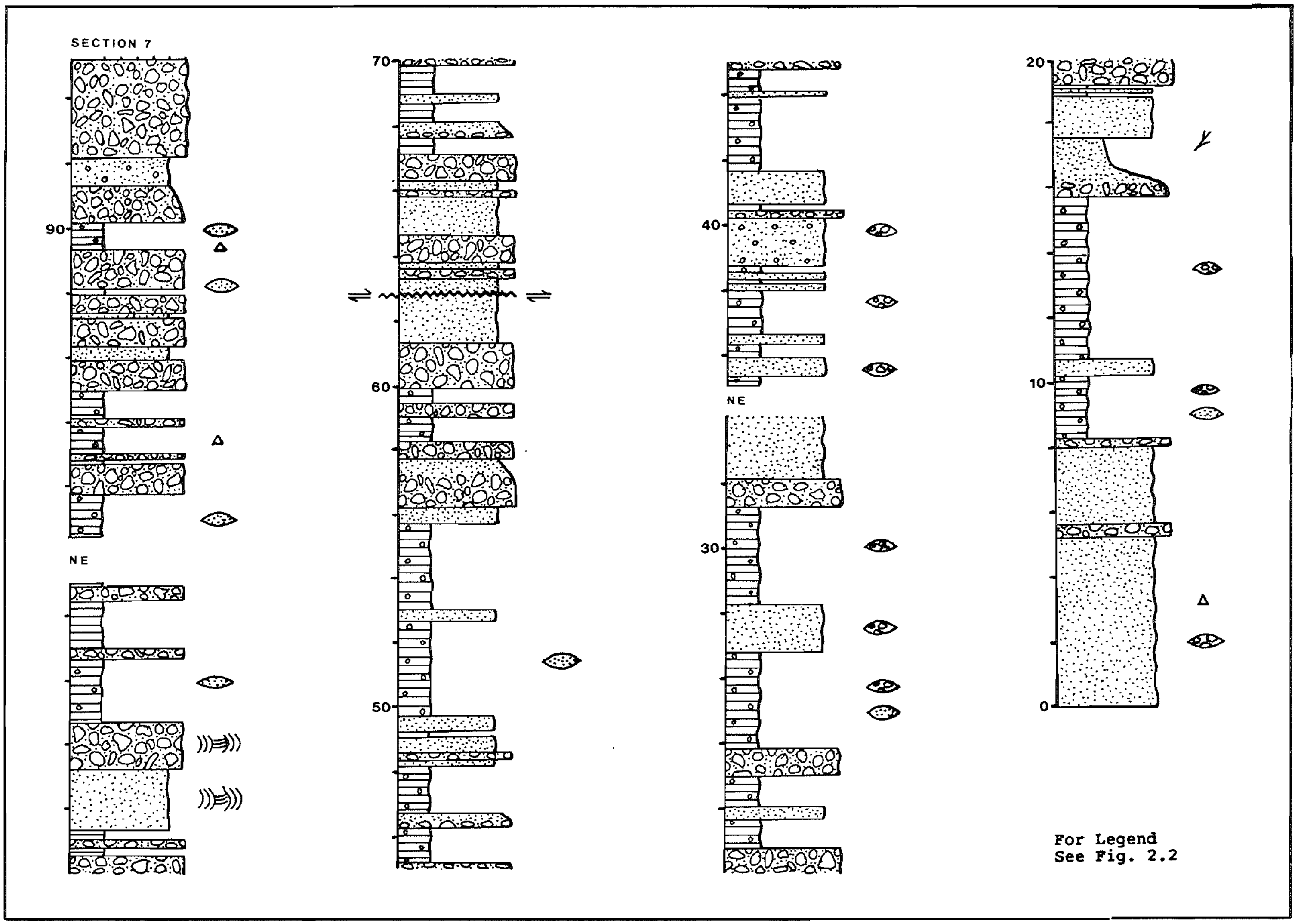


Figure 2.25. Section of the Rights River Formation on Rights River near Antigonish (Location A, Fig.2.24).

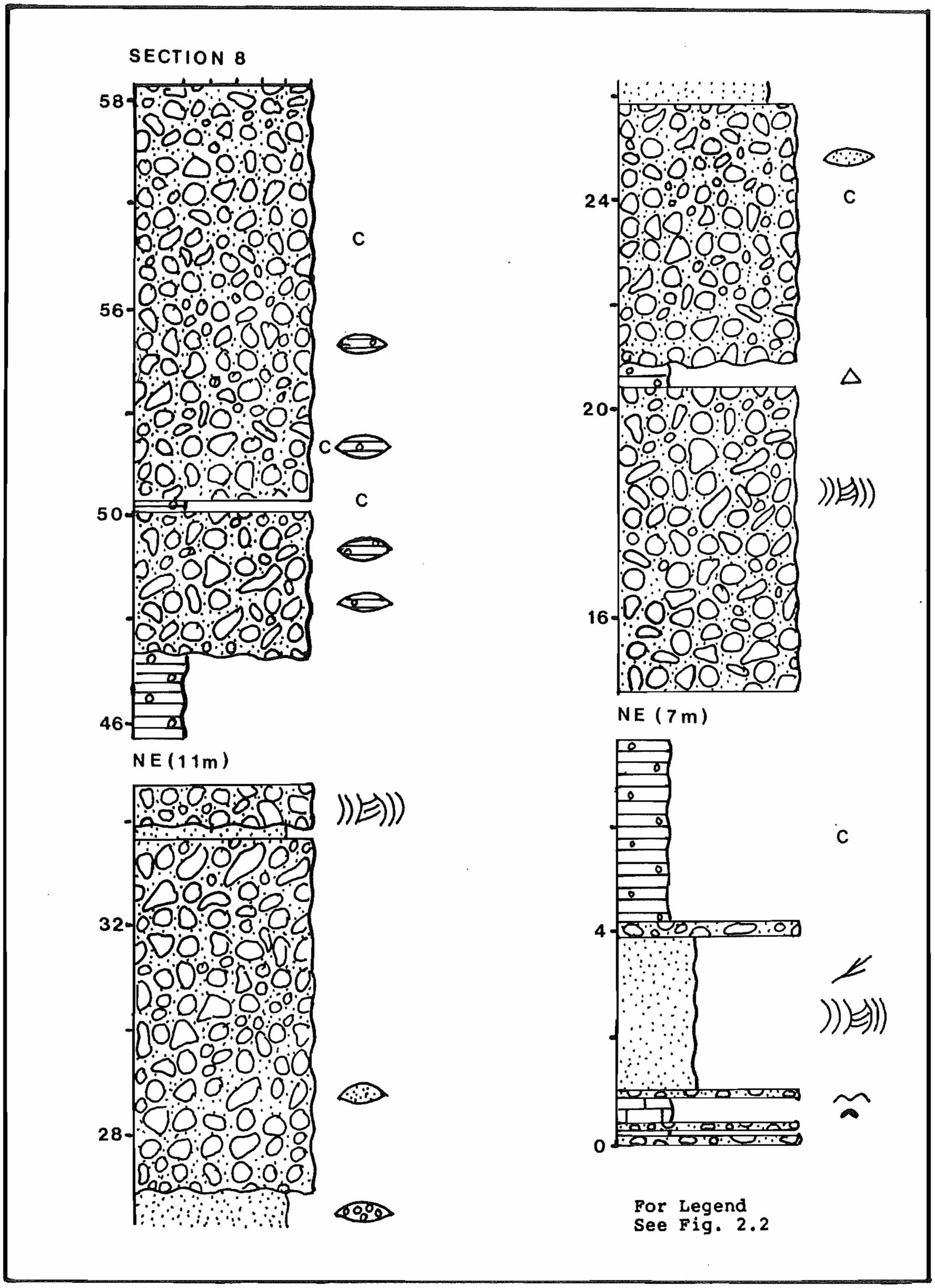


Figure 2.26. Section of the Rights River Formation on Rights River near Antigonish (Location B, Fig.2.24).

Figure 2.27. Poorly-sorted, clast-supported conglomerate (Gm?) in the Rights River Formation (Location A, Fig.2.24). Lens cap (6cm) for scale.

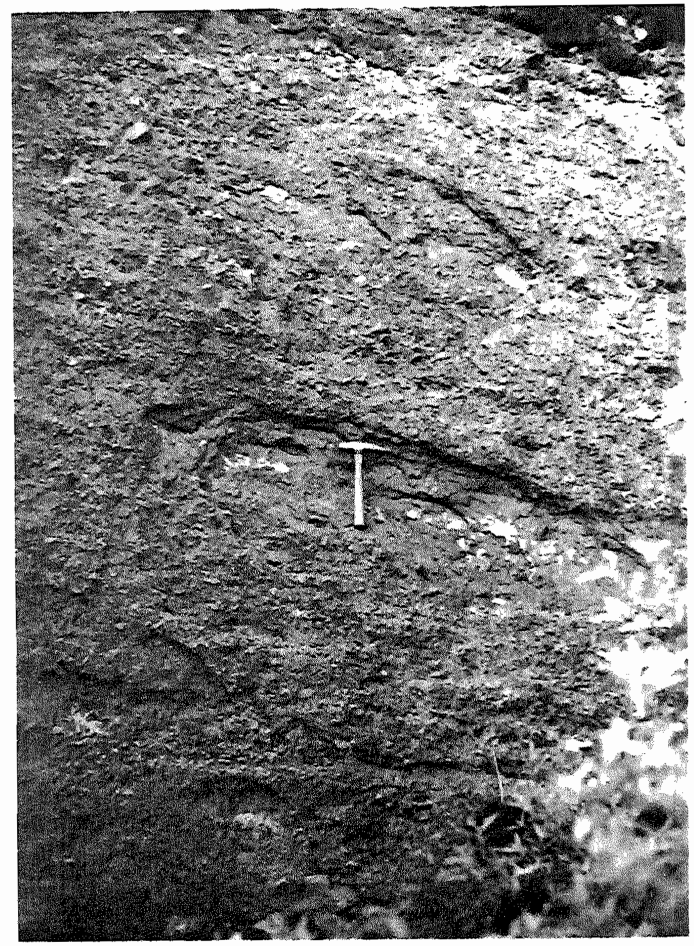


Figure 2.28. Well-sorted massive conglomerate (Gm) in the Rights River Formation (Location B, Fig.2.24). View is normal to the bedding. Hammer (34cm) for scale.

of medium- to coarse-grained sandstone (Fig.2.29). Weak stratification is generally accompanied by better sorting and rare primary current lineations. The sandstone is generally pebbly.

Mudstone (Fm) is red-coloured, poorly sorted, and generally has sand- to pebble-sized clasts (Fig.2.30). Sandstone and conglomerate lenses which range from 2-4 cm to 25 cm in thickness are common. The percentage of Fm varies considerably between the sections, with Section 7 containing 42 percent and Section 8, 14 percent.

A 0.5 m thick carbonate unit occurs just above the base of Section 8 (Fig.2.31). It consists of gray carbonate clasts in a red shale matrix and is mottled in appearance. The basal contact is irregular while the upper surface show poorly-preserved symmetrical ripple marks. Small lenses (2 cm thick) of granule-sized extraformational conglomerate are present. One of the carbonate clasts is laminated. Note that the unit has a distinct similarity to some of the carbonate units in the overlying Wilkie Brook Formation.

There are several characteristics which can be ascribed to the formation in general. (1) The conglomerate clasts are subangular to subrounded. (2) The major strata exhibit lateral continuity and a uniform thickness over distances of several metres. (3) Upper and lower contacts of the

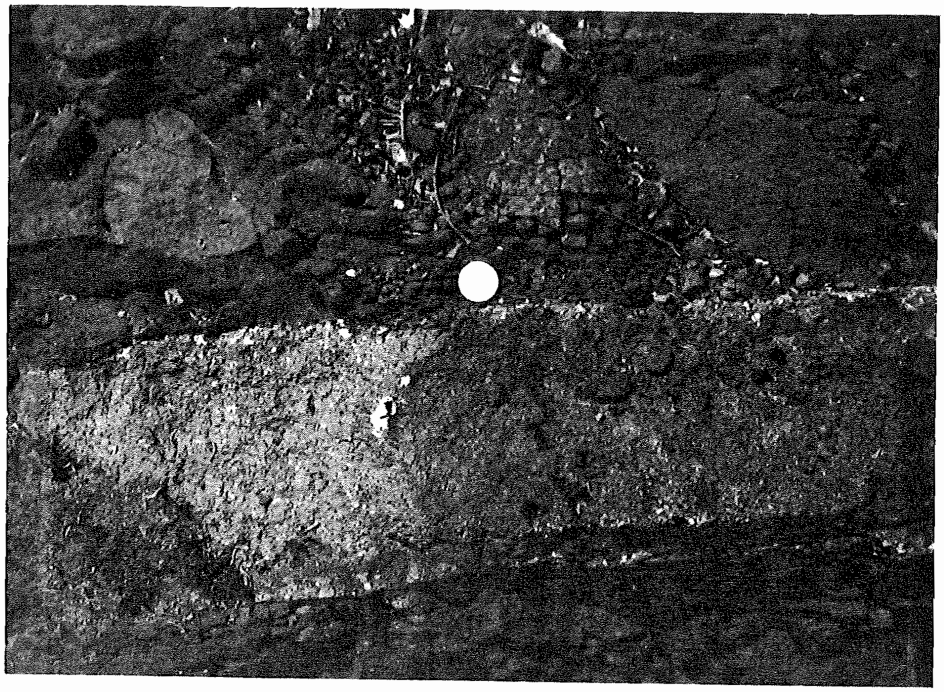


Figure 2.29. Massive coarse-grained sandstone unit (Shl) between mudstone units (Fm) in the Rights River Formation (Location A, Fig.2.24). Twenty-five cent piece for scale.

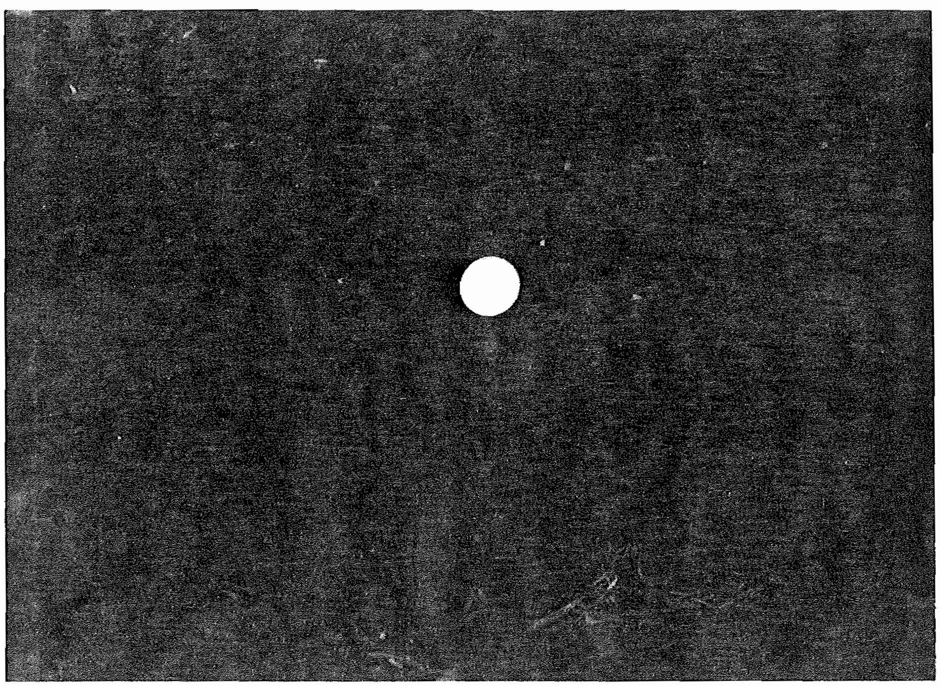


Figure 2.30. Pebbly mudstone in the Rights River Formation (Location A, Fig.2.24). View of bedding surface. Twenty-five cent piece for scale.

lithofacies are abrupt. (4) Calcrete nodules (Fig. 2.32) and reduction haloes are common. (5) Fossils are very uncommon. (6) Maximum grain size generally increases upsection in the formation (Fig.2.34).

Near the top of the Rights River Formation, and occurring between strata typical of it, is a 10 m sequence of reddish-brown sandstone and conglomerate (Fig.2.24, Location C). Interestingly it contains the only relatively mature sedimentary rocks found in the upper 75 percent of the formation. Its lower contact with the red conglomerates is irregular, with locations along it that are vertical to slightly overhanging. The precise upper contact is not exposed although strata immediately overlying it suggest a sharp contact with red conglomerates as well. The clast composition of this sequence is similar to rocks typical of the formation, but their much lower clay content gives them a "cleaner" appearance. The sequence varies laterally due to erosion and lensoid strata; however, it is generally composed of massive conglomerate, trough cross-bedded sandstone, and ripple cross-laminated sandstone.

The base of the Rights River Formation along the Rights River (Fig.2.24, Location D) consists of small, isolated outcrops with highly variable bedding attitudes. A detailed examination of these rocks was not conducted because of their poor exposure and structural complexity. However, in

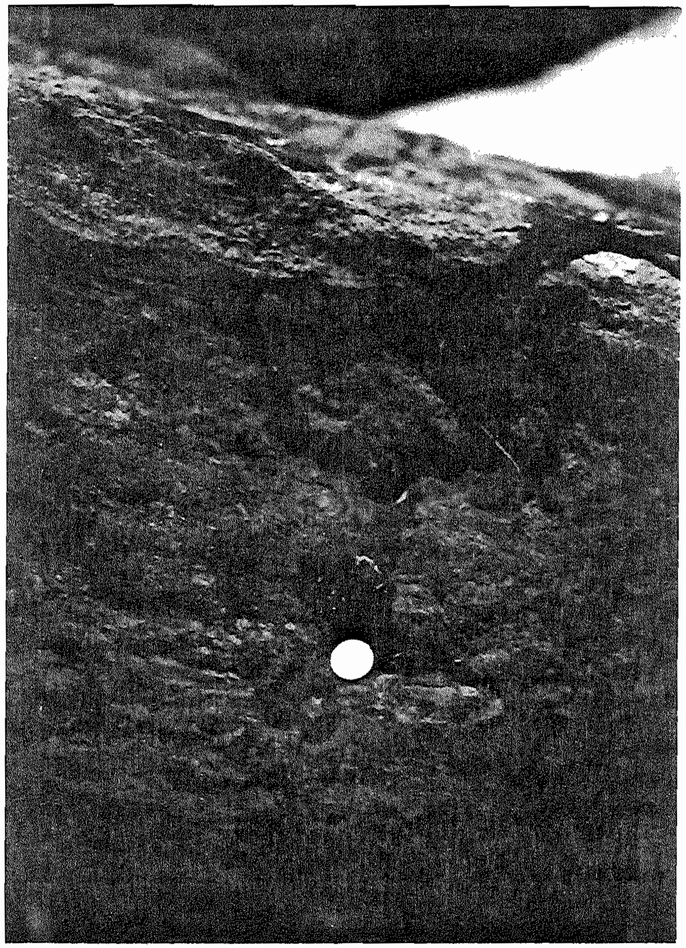


Figure 2.31. Carbonate unit in the upper part of the Rights River Formation (Location B, Fig.2.24). It consists of carbonate clasts in a red clastic matrix. Twenty-five cent piece for scale.

Figure 2.32. Bedding surface view of calcrete nodules in a trough cross-bedded sandstone unit of the Rights River Formation (Location B, Fig.2.24).

general they consist of conglomerates which are fine-grained (granule/pebble clasts) and commonly gray-coloured. They occur as interbeds with gray, calcareous sandstones and shales. Red planar-stratified sandstone and mudstone are also common. Small symmetrical ripple marks are common.

Depositional environment

The Rights River Formation consists predominantly of alluvial-fan deposits similar to modern-day analogues described by Blissenbach (1954), Hooke (1967) and Bull (1972).

The massive conglomerate lithofacies (Gm) is interpreted as low-viscosity debris-flow and stream-flow deposits. The poorly-sorted, clast-supported conglomerates represent low-viscosity debris flows. Normally, such deposits are matrix-supported. However, Blissenbach (1954) suggested that a continuum exists among the different types of depositional agents on an alluvial fan, and relatively small changes in flood intensity or sediment load could influence the texture of the deposits. Thus, low-viscosity debris flows could become sediment-choked sheet floods and vice versa so that their deposits would be difficult to distinguish in ancient deposits. The better-sorted conglomerates represent sheet flood deposits, formed in shallow distributary channels which migrated across the fan surface. Bull (1972) described sheet flood deposits as generally clean and well-sorted; however, in the Rights River Formation they exhibit a poorly-sorted texture which may reflect the composition of the sediments and/or the level of flood intensity. The mudstone and sandstone lenses in lithofacies Gm may represent: (1) the remnants of thin mudflow or sheet flood deposits that were vigorously eroded by successive flood events; or (2) drapes deposited during the waning stages of flooding on inactive terraces or in abandoned channels. Because these fine units are rarely well-sorted, it is unlikely that they settled out of suspension as drapes.

The massive to poorly-bedded sandstone lithofacies (Shl) is interpreted as both debris-flow and sheet flood deposits. The massive, poorly-sorted pebbly sandstones correspond to debris-flow deposits. These exhibit similar characteristics to mudflows described by Blackwelder (1928). The better-sorted, bedded strata correspond to sheet flood deposits which were deposited in rapidly-shifting distributary channels. Both the mudflow and sheet flood deposits are characteristic of major flooding and rapid deposition on the proximal regions of fans.

The mudstone lithofacies (Fm) represents mudflow deposits. The pebbly, massive texture and laterally continuous beds are characteristic of this type of deposit.

Lithofacies Shl and Fm could also be interpreted as floodbasin deposits of a separate fluvial system located more distally in the basin. This interpretation is unlikely for two reasons: (1) the abundant pebbles "suspended" in these fine-grained strata suggest that a relatively viscous transporting medium was present; (2) the coarse-grained and massive texture of the interbedded sheet flood and debris-flow deposits suggests alluvial deposition.

The sandstone and conglomerate lenses which occur throughout lithofacies Fm and Shl represent small channels. Similar to those in the Ogden Brook Formation, the channels may have resulted from (1) smaller flood events, or (2) dewatering following mudflow episodes.

The scarcity of trough cross-bedded conglomerate and sandstone strata in the sections is consistent with proximal alluvial-fan deposits. These lithofacies are deposited under lower flow regimes and usually within more stable streams (Miall, 1977). They were probably rarely formed in such proximal locations because of flood intensity. It would be expected that these lithofacies would increase in frequency distally.

The carbonate unit in Section 8 is an intraformational conglomerate. It may have formed either as (1) a channel lag derived from erosion of playa carbonates deposited elsewhere on the fan, or (2) a lacustrine or marine shoreline breccia at the edge of a standing-water body. Because it is an isolated bed and has an irregular erosional base, a channel deposit is favoured here.

The relatively mature sandstone and conglomerate sequence (Fig.2.24, Location C) was deposited in a fluvial system characterized by a lower flow regime than the surrounding alluvial fan deposits. The deep scouring and lensiod shape of the strata indicates deposition from channels that shifted readily and probably formed a braided pattern. These fluvial deposits resulted from either (1) an incised channel on the alluvial fan, or (2) intercalation of distal alluvial-plain deposits. Because of their similarity in clast composition to the conglomerates typical of the formation, an incised-channel origin is favoured here.

The presence of gray-colored conglomerates interbedded with calcareous sandstones/shales and red-colored sandstones near the base of the formation indicates that the alluvial fans were deposited initially on a fluvial-lacustrine plain located more centrally in the basin. This is consistent with prior depositional conditions in the underlying South Lake Creek Formation. The increase in maximum grain size of the fanglomerates upsection suggests that the alluvial fan system prograded across the basin floor through time. The disconformable contact of the coarse fanglomerates with the overlying Windsor marine carbonates indicates an abrupt termination of fan deposition. The contact may reflect a lateral facies change associated with a sudden marine invasion or a period of non-deposition and erosion prior to marine transgression.

The abundance of calcrete nodules and reduction haloes is evidence of chemical reactions with ground water and is generally associated with desiccation. Thus, the alluvial fans of the Rights River Formation probably were deposited under relatively arid conditions.

Paleocurrent Analysis

Axial data (seven primary current lineation readings, Fig.2.33, Appendix III), indicate a flow trend along a southwest - northeast axis. Directional data were restricted to one set of planar cross strata (074 degrees) and one imbricated bed (023 degrees), which suggests a northeasterly flow.

Provenance

The clasts of the Rights River Formation are of felsic metavolcanics, metasediments, and granitic rock types with each sample containing at least 60 percent of the combined volcanic and granitic clasts (Fig.2.34). The percentages of clast types remain relatively constant up through the

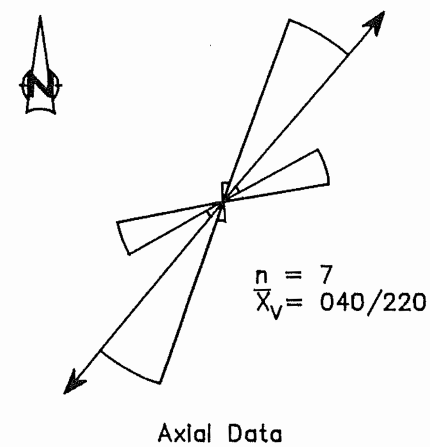


Figure 2.33. Paleocurrent trend in the Rights River Formation. Note the small sample size.

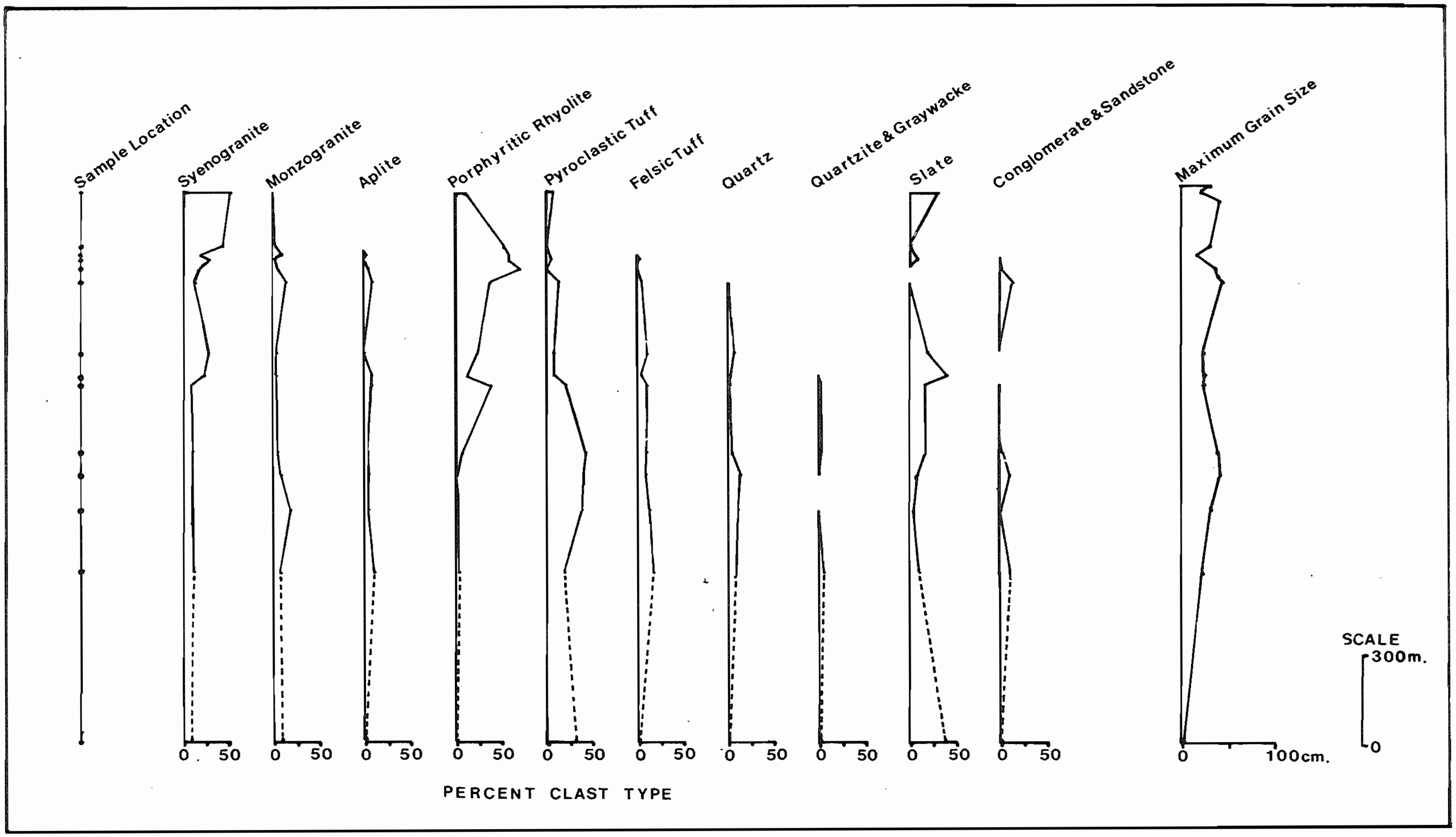


Figure 2.34. Clast composition of the Rights River Formation along Rights River (Locations B-D, Fig.2.24).

formation with the exception of the porphyritic rhyolite and syenogranite which increase quite sharply. The reason for these increases is unknown.

Comparison with clast assemblages in the Ogden Brook Formation indicates that both formations contain similar clast types. The Antigonish Highlands basement complex was probably the source for the Rights River Formation fanglomerates. This potential source area lies to the south and west of these sedimentary rocks. In the discussion of tectonics in the final chapter, it will become clearer how the Browns Mountain Massif shed sediment to the northeast.

The Rights River Formation was chosen to evaluate the variability in clast composition for samples within a relatively short stratigraphic thickness. The purpose is to assess the accuracy of diagrams such as Figure 2.34. Figure 2.35 demonstrates that the clast composition of three relatively closely spaced samples can vary considerably, with a very low confidence in similarity between any two of them. Thus, trends observed in Figure 2.34 are considered to be general at best.

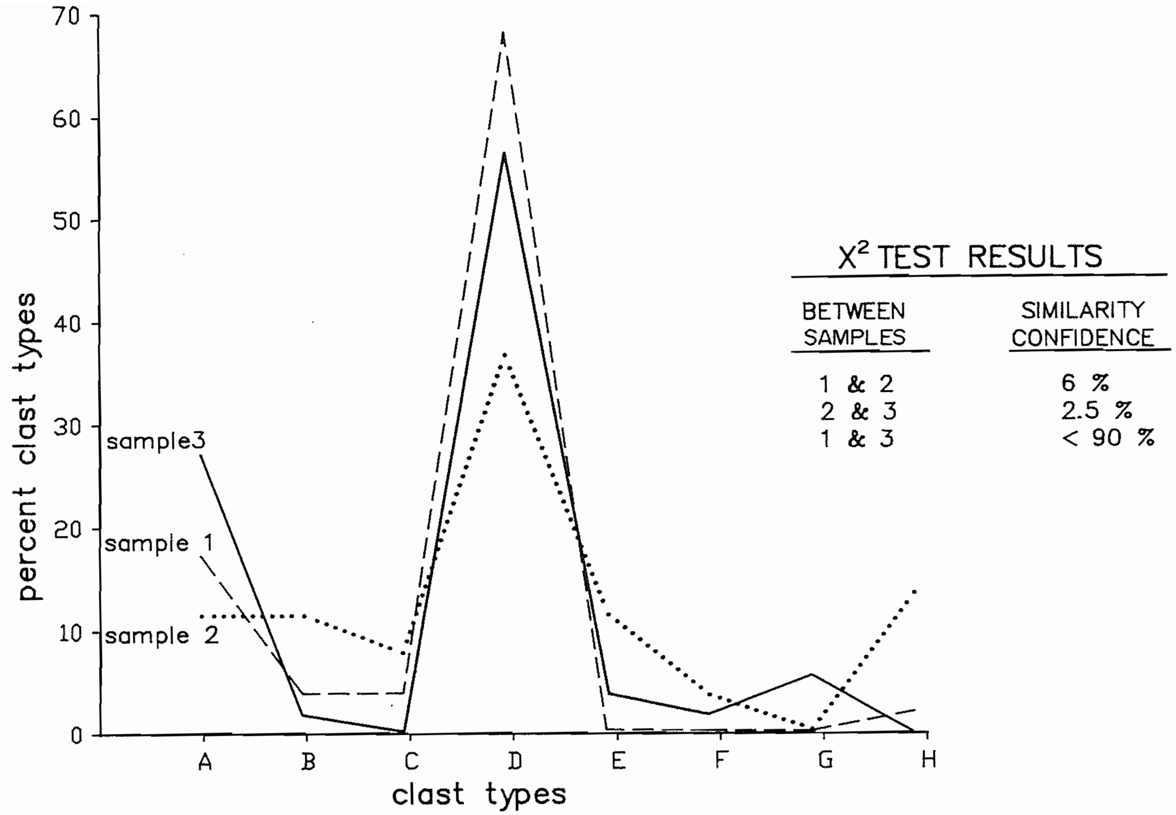


Figure 2.35. Graph showing variability between closely spaced point count samples in the Rights River Formation conglomerates. Samples are at 5 m stratigraphic intervals. Chi-squared test (from Folk, 1974) indicates considerable varibility between samples.

CHAPTER III

WILKIE BROOK FORMATION

The Wilkie Brook Formation (Fig.3.1) was first examined in detail by Kramer and Phinney (1953) and Kaminsky (1953). They proposed that the formation was equivalent in age to the lower part of the Windsor Group. Murray (1960) and Schenk (1969) developed facies models to show a lateral depositional relationship between the Wilkie Brook Formation and the Windor Group. Keppie et al. (1978) suggested that the ages of the two are quite different on the basis of palynomorphs extracted from the Wilkie Brook Formation. They assigned a Late Tournaisian age to the formation and included it in the Horton Group. Furthermore, there is disagreement as to the definition of the top of the formation (Murray, 1960; Keppie et al., 1978). As a result it is uncertain to which group the formation should be assigned. In this thesis, the Wilkie Brook Formation is tentatively included with the Horton Group. The reasoning for this decision is discussed at the end of the chapter.

The most recent work on the Wilkie Brook Formation was an honours thesis by MacBeath (1981). The type section was examined in detail; however, the focus of attention was the nodular limestone units.

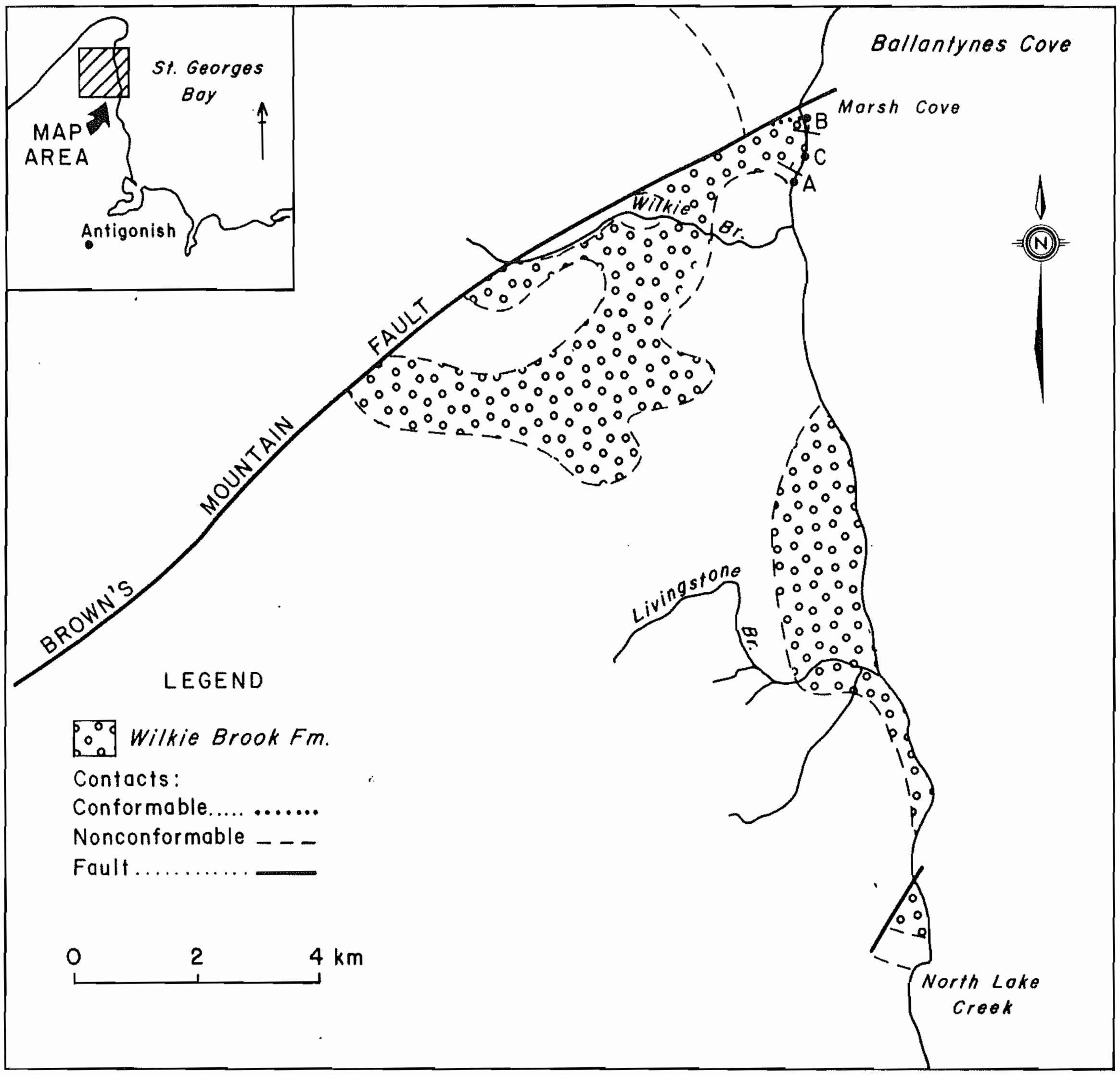


Figure 3.1. Location map showing Wilkie Brook Formation.

i) <u>Lithological Description</u>

The formation consists of interbedded polymictic clast - supported conglomerate, lithic graywacke, calcarenite, shale, and carbonate. The siliciclastics are predominantly red - coloured and infrequently green - gray.

ii) <u>Thickness</u>

The formation is 194 m thick at the type section based on measurements in this study.

iii) <u>Contact Relationships</u>

At the type section location the lower contact is an angular discordance with the underlying South Lake Creek Formation. The upper contact with the Marsh Cove Limestone (A1 limestone equivalent) of the Windsor Group (Keppie *et al.*, 1978) is covered with overburden; however, it appears to be a disconformity.

iv) <u>Age</u>

On the basis of palynological work by Barss (1977), Keppie *et al.* (1978) concluded that the age at the type section was Tournaisian to Early Visean.

v) Lithofacies Descriptions

The Wilkie Brook Formation type section (Section 9, Fig.3.2; Location AB, Fig.3.1) is a complex succession of sedimentary strata displaying an intricate interplay of lithofacies. Markov Chain analysis was not conducted on the section due to its complexities. Section 9 is subdivided into five distinct lithozones.

Lithozone 1 constitutes the basal 10 m of the section and lies in unconformable contact on the South Lake Creek Formation. It comprises red-coloured sedimentary rocks of lithofacies Gm, Sp, Sh2, and Fl. Lithofacies Gm (0-3 m) contains an imbricated clast framework. Lithofacies Sp consists of planar cross-stratified, pebbly-sandstone in a set of cross strata approximately one metre in thickness. Lithofacies Fl (7-8 m) contains symmetrical ripple marks of probable wave origin. Contacts between lithofacies are sharp.

Lithozone 2 (10-74 m) consists predominantly of shales interbedded with pebble/cobble, clast-supported conglomerate. The lithofacies includes Fs, Fl, Gml, Gp, Shl, and Sr. The colour of the strata varies from red to gray with some mottling. The lithozone can be subdivided into lower and upper subzones. The lower subzone (10-15 m) is composed of finely interbedded sandstone and fissile

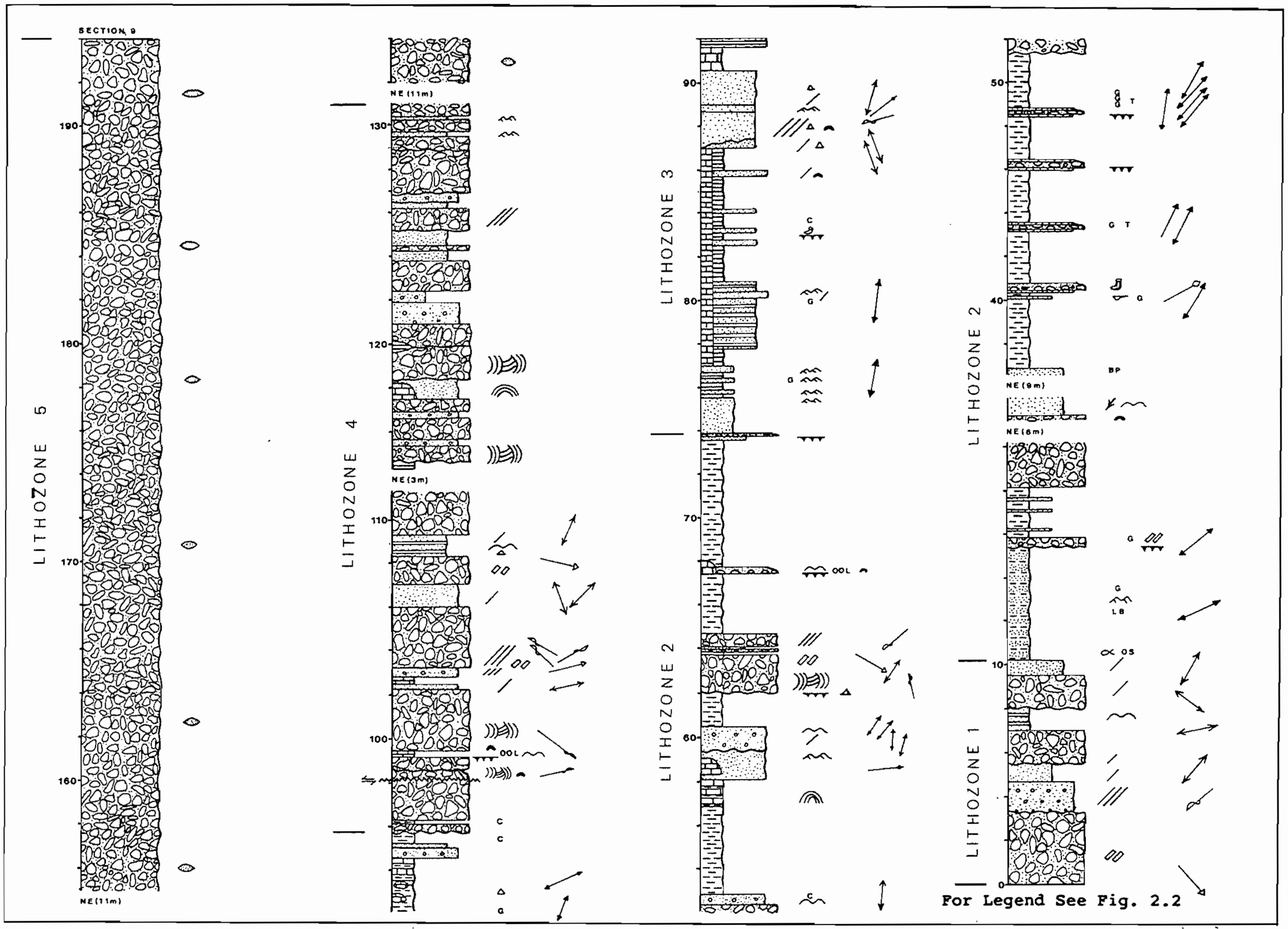


Figure 3.2. Type section on the Wilkie Brook Formation (Location AB, Fig.3.1).

shale (lithofacies Fl) (Fig.3.3). It contains minor lenticular bedding, groove marks, desiccation cracks, paleoniscid fish fragments, and ostracodes. The strata vary from red to gray-green in colour. The upper subzone (15-74 m) consists of pebble/cobble clast-supported conglomerate (lithofacies Gm, Gt, and Gp) separated by thick fissile shale strata (lithofacies Fs) (Fig.3.4). Lithofacies Fs constitutes 69 percent of the lithozone thickness and is characterized by lamination, scattered carbonate concretions, desiccation cracks, and a few thin sandstone beds. The strata vary from gray to red in colour. Abrupt contacts occur between Fs and the interbedded conglomerate. In general, two types of conglomerate strata occur in the upper subzone. One type consists of units 1-3 m thick of lithofacies Gml (e.g. 51-53 m); at 62-65 m it consists of lithofacies Gp overlying lithofacies Gt. The second type, averaging .5 m in thickness, consists of both Shl and Gml; it generally begins with lithofacies Shl at the base, followed by lithofacies Gm which consists of one or more fining-upward pebble conglomerate subunits (e.g. 43.5 m). The conglomerate strata contain intraclasts of shale. Desiccation cracks are common in lithofacies Fs.

One conglomeratic unit in the upper subzone (67.5-68 m) contains an isolated carbonate mound which extends through the upper half of the unit and into the overlying lithofacies Fm. The mound is 1 m thick, 1-2 m across,

Figure 3.3. Wilkie Brook Formation interbedded sandstone and shale (Fl) in Lithozone 2 of Section 9 (Fig.3.2). Note lenticular bedding approximately one metre above fieldbook.

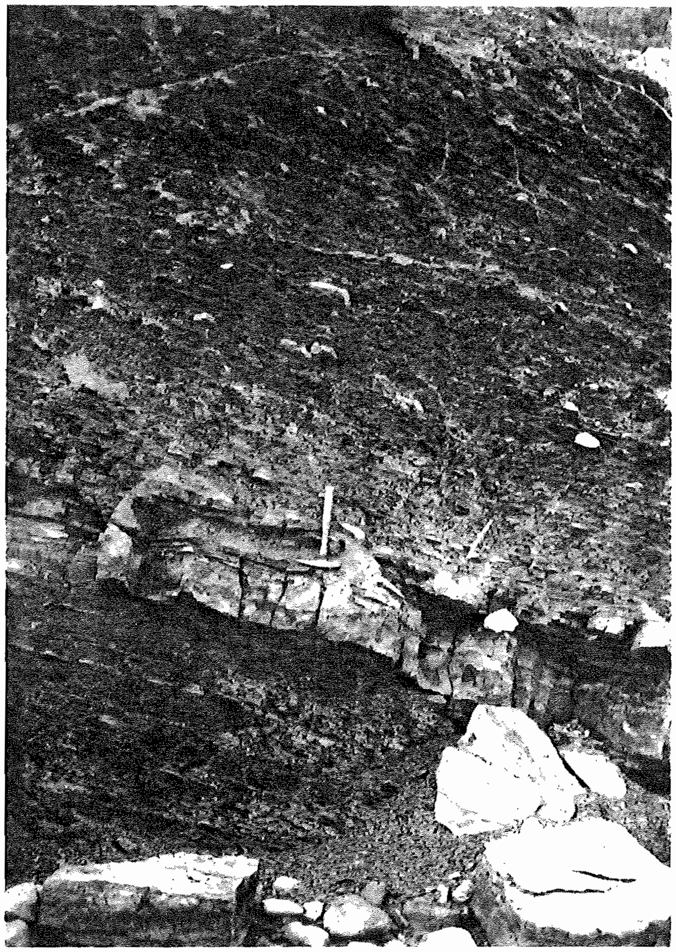


Figure 3.4. Thin conglomerate/sandstone unit in thick gray shale (Fs) of the Wilkie Brook Formation (Location C, Fig.3.1). Calcrete nodules are common in the shale.

unbedded and is strongly recrystallized. The unit also contains abundant carbonate "clasts" and is properly termed a calcarenite. Examined in thin section, the calcarenite generally consists of poorly sorted, angular siliciclastics (at least 50 percent), carbonate "clasts" and micritic matrix. The carbonate "clasts" range from .05-5 mm along their longest dimension. Their shape may be spherical, oval, rectangular, cylindrical, or irregular. They show concentric and/or radial textures or are completely micritized internally. Many of the "clasts" occur as broken fragments of larger clasts. Others consist of a cluster of smaller carbonate "clasts" or grapestone texture which collectively were abraided into a round shape. Some of the elongated "clasts" are parallel to the bedding planes. A few of the carbonate clast beds exhibit uniform grain size. Borings of algae or fungi are common in the clasts.

Other carbonate strata in Lithozone 2 (at 57-59 m) consist of rhythmically interbedded carbonate and red shale (Fig.3.5). The carbonate strata are finely laminated, locally pinching out or swelling laterally. Small mounds or clumps of carbonate locally interrupt the interbeds.

<u>Lithozone 3</u> (74-96 m) is a complex succession of interbedded red sandstone, mudstone, and carbonate. The upper and lower contacts are abrupt. From 78-87 m, carbonate strata crop out on the beach whereas laterally

equivalent strata in the cliff face are siliciclastics of lithofacies Fm, Sh, and Fl (Fig.3.6). This appears to be a lateral facies change. The carbonate is massive and irregularly surfaced (Fig.3.7), and consists of both mounds and laterally continuous strata (90.5-91.5 m). The mounds are generally less than one metre thick and several metres across. Although the mounds consist of completely recrystallized carbonate, recent erosion reveals small hemispherical shapes on their surfaces. The red siliciclastics consist of thick (0.5-1.5 m) mudstone units with thin (0.25 m) sandstone interbeds. One thick sandstone unit (87-91 m) consists of lithofacies St at the base overlain by lithofacies Sr and Sh2. Trace fossils in the form of burrows are found in the sandstone interbeds.

Lithozone 4 (95.5-131 m) consists predominantly of red, pebble-sized, clast-supported conglomerate of lithofacies Gm, Gt, and Gp. Sandstone lithofacies Sh, Sr, and Fl occur as minor interbeds. The conglomerate units (Fig.3.8) range from 1-3 m thick, the sandstone units, from 0.5-1 m thick. The contacts between the sandstone and conglomerate units are generally abrupt. At 108.5-109.5 m finely interbedded sandstone and shale (Fl) overlies lithofacies Gm with a sharp contact. Lithofacies Gp at 99.5-102 m consists of at least three sets of planar cross strata with varied dip directions, separated by erosional contacts.

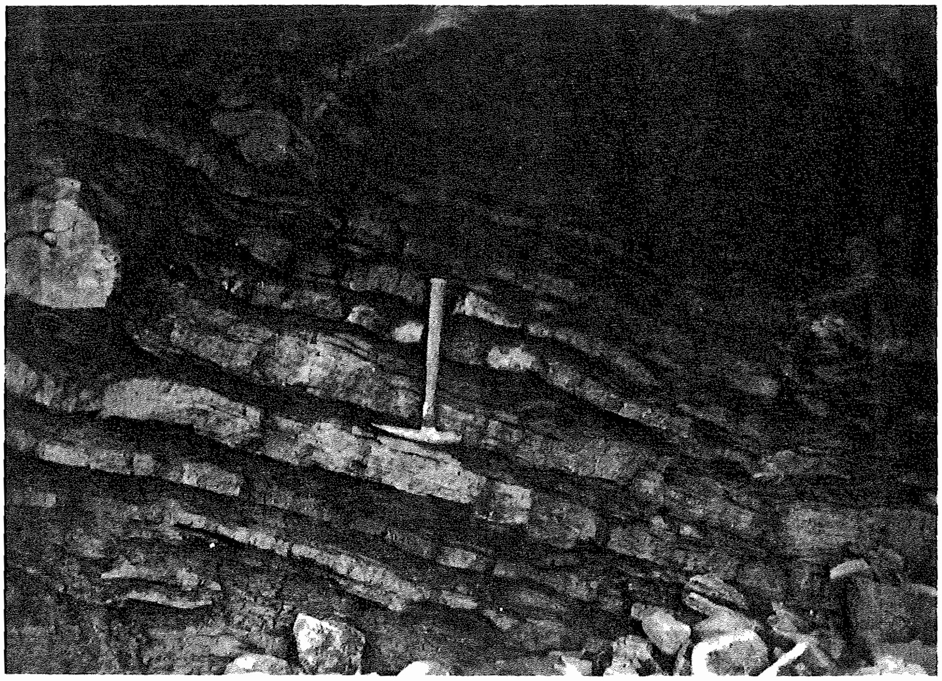


Figure 3.5. Interbedded carbonate and mudstone of the Wilkie Brook Formation (Location C, Fig.3.1). Note that carbonate mound to left of photo cuts across the strata.

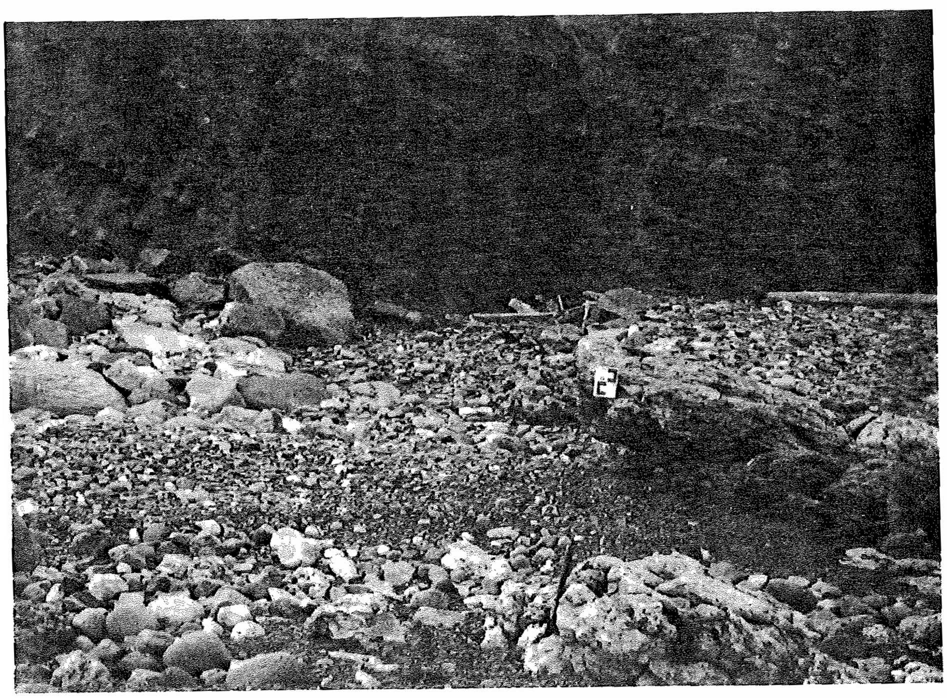


Figure 3.6. Carbonate mounds on the beach (identified by fieldbook and hammer) which disappear laterally into mudstone/sandstone strata in the Wilkie Brook Formation (Location C, Fig.3.1.).

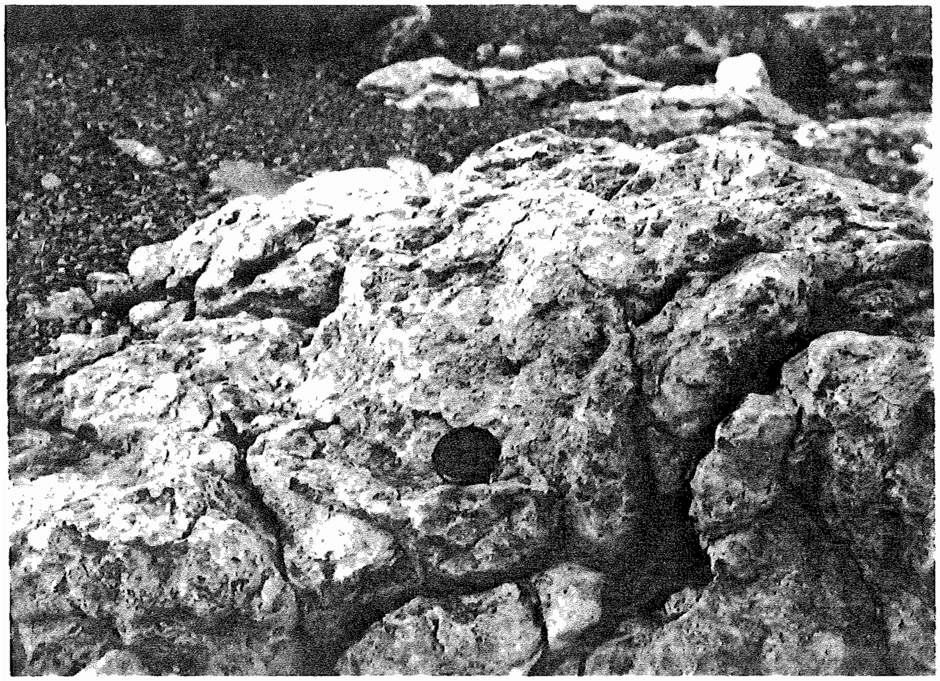


Figure 3.7. Detailed view of the carbonate mounds in Fig.3.6. Lens cap for scale.

Carbonate strata and mounds similar to those of Lithozone 3 occur scattered throughout Lithozone 4. A carbonate layer (at 99m), composed of carbonate "clasts" similar to Lithozone 2, contains symmetrical ripple marks. Calcite cement is common in the conglomerate lithofacies (Fig.3.9), indicating that some of the sedimentary rocks were deposited as openwork gravels.

Lithozone 5 (131-193 m) consists almost entirely of red, pebble-sized, clast-supported conglomerate of lithofacies Gm (Fig.3.10).

The nature of the lower contact with Lithozone 4 is not exposed. Lithozone 5 is distinguished by: (1) deeper red colour; (2) major decrease in sandstone and shale strata; (3)increased angularity of the clasts; and (4) the absence of carbonates. Sandstone and shale lenses are common. Imbrication is locally present. The upper contact with the Marsh Cove Formation carbonates (of Keppie et al., 1978) is covered; however, it appears to be a disconformity.

vi) Depositional Environment

The Wilkie Brook Formation provides the best example in a well exposed section of the complex depositional conditions that existed throughout the Middle-Late Devonian and Early Carboniferous in the Antigonish Basin. It

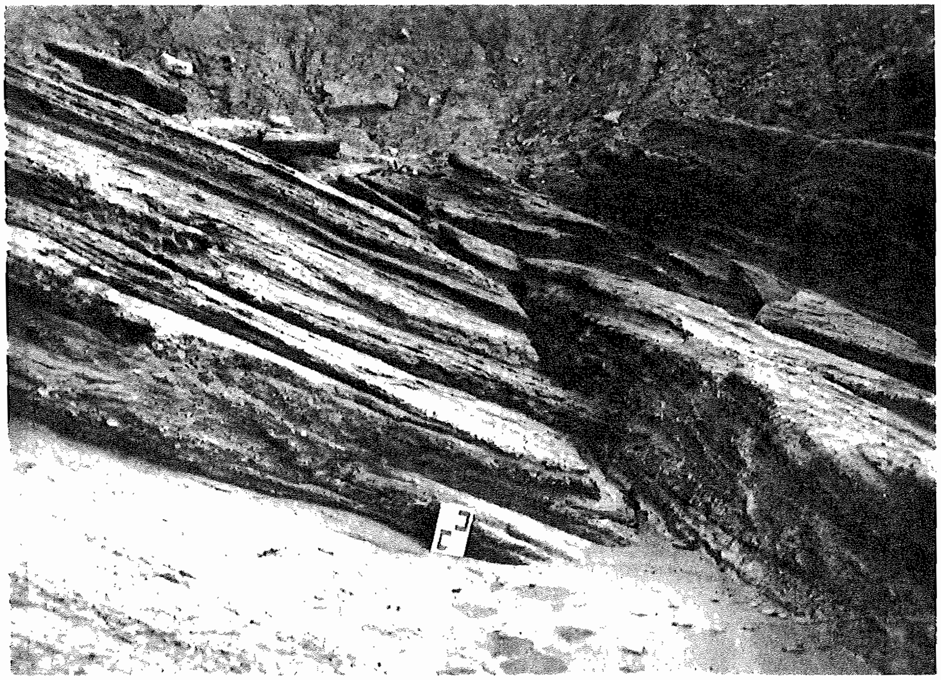


Figure 3.8. Well-stratified conglomerate (Gm) in the Wilkie Brook Formation (Location B, Fig.3.1).

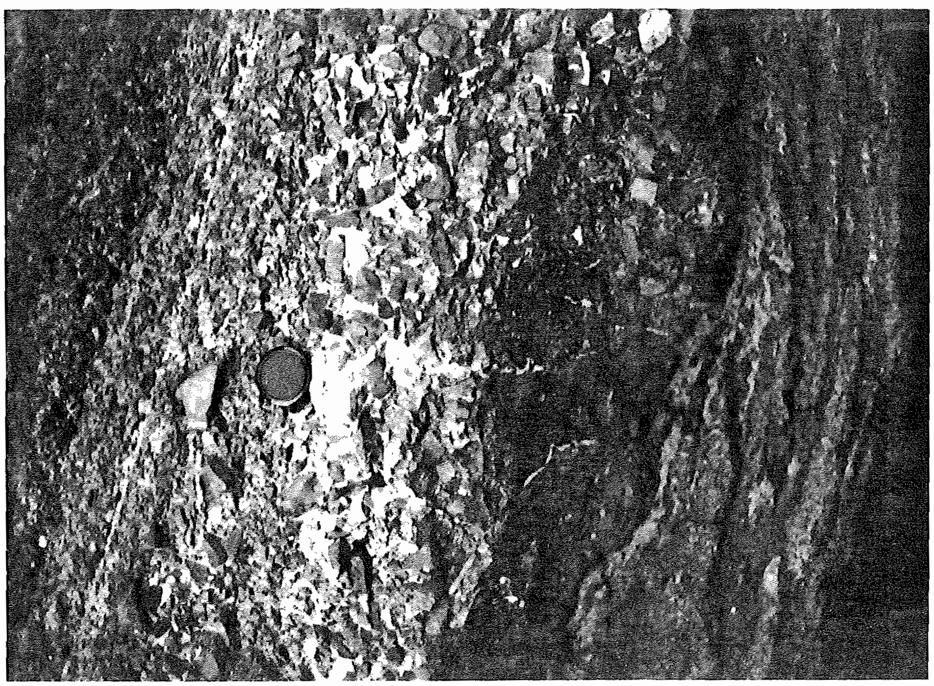


Figure 3.9. Calcite cement in conglomerate of the Wilkie Brook Formation (Location B, Fig.3.1). Lens cap for scale.

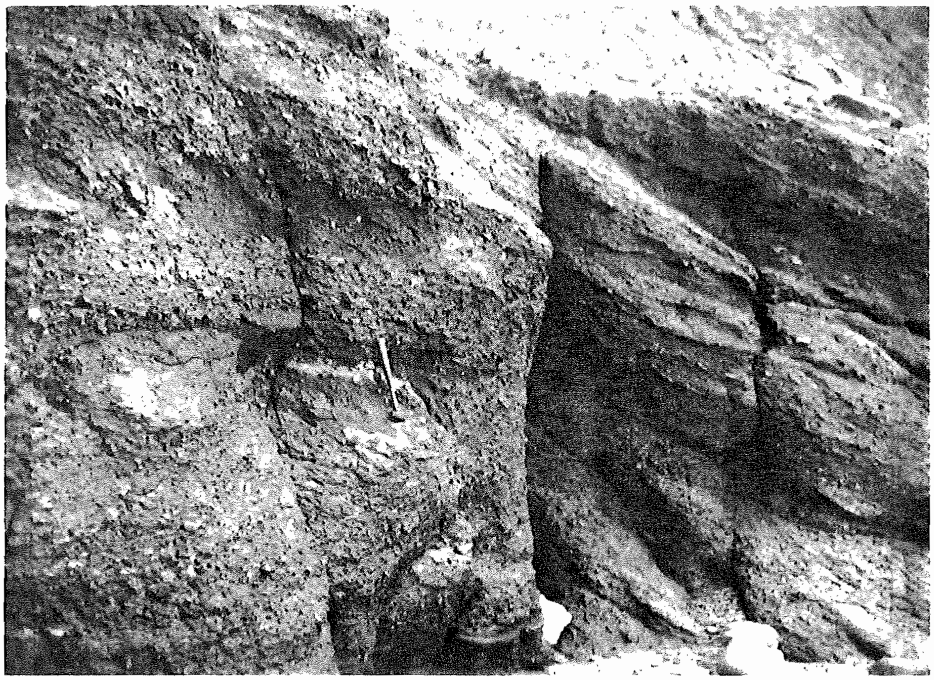


Figure 3.10. Clast-supported conglomerate characteristic of Lithozone 5 in the Wilkie Brook Formation type section (Location B, Fig.3.19).

represents the interplay of marginal alluvial fans with more central lacustrine/or marine environments.

<u>Lithozone 1</u> is interpreted as braided fluvial deposits, based on the relatively coarse-grained texture of the strata, the presence of planar cross-stratification, and the sharp erosional contacts between lithofacies (Miall, 1977). Where lithofacies Sp directly overlies lithofacies Gm (at 3-4.5 m) an in-channel bar is indicated overlying a channel lag (Miall, 1977). The preservation of planar cross-stratification usually is associated with reduced sediment discharge in more distal reaches of the braided river (Hein and Walker, 1977). The abrupt contact of lithofacies Fl with the underlying conglomerate lithofacies is characteristic of sedimentation in abandoned channels during the final stages of flooding. Lithozone 1 probably represents braided channels on the distal region of an alluvial fan system. Miall (1978) pointed out that the distinction between alluvial fans and braided rivers in the ancient record is often difficult to establish. It will become more apparent that this is an alluvial fan system when the upper part of the section is discussed.

<u>Lithozone 2</u> shows evidence for quiet-water deposition, interrupted by alluvial influxes. The standing-water bodies may be interpreted as lakes, floodbasin ponds or marginal oceans. The merits of each will be discussed later.

The lower part of the lithozone (10-15 m) represents a shallow standing-water environment. The evidence includes the rhythmic interbedding of sandstone and shale, fish fragments, ostracods, and minor lenticular bedding. Both fish and ostracods are commonly found in a marine or lacustrine setting (Picard and High, 1972). Lenticular bedding forms under conditions of meagre sand supply in alternating slack and turbulent flow conditions. They are usually attributed to tidal influences in intertidal or subtidal zones; but may also occur in nearshore lacustrine deposits (Reineck and Singh, 1980). Tidal deposits commonly show bipolar flow directions, whereas lacustrine deposits commonly show unipolar flow. The scarcity of paleocurrent data in the lower part of the lithozone makes identification of the environment uncertain; however, bipolar flow features were not identified.

The upper sublithozone (15-74 m) represents the interaction of a lacustrine/or marine environment with a braided river system. The thick, fine-grained, laminated units of lithofacies Fs suggests deposition from suspension in standing water. The calcrete nodules indicate a fluctuating water table and the desiccation cracks are characteristic of subaerial exposure. Thus lithofacies Fs represents quiet-water deposition where subaerial exposure frequently occurred, in a shallow marine or nearshore lacustrine environment.

The fines could also reflect a floodplain environment closely associated with the lacustrine/or marine carbonates. However, the absence of clearly identifiable crevasse splay deposits suggests that this is not the case (cf. Allen, 1965). The thin interbeds of conglomerate and sandstone may represent periodic pulsations of the braided river/alluvial fan system, as described for Lithozone 1. They may also represent crevasse splays; however, this is unlikely because of their coarse grain size and a clast composition similar to the braided river deposits. The thick conglomerate units of lithofacies Gml represent channel fill or channel bar deposits which occurred during periods of peak sediment discharge. Lithofacies Gp overlying lithofacies Gt (at 62-65 m) is interpreted as a transverse bar deposited within a major channel. The thinner multilayered conglomerate units, composed of lithofacies Shl at the base overlain by fining upward strata of lithofacies Gml (e.g. 43.5 m) also represent channels filled by multiflood events of varying intensities. The generally abrupt contacts of the coarse units with the fine units in the upper sublithozone indicate that deposition between the two was discontinuous, and that they may represent completely separate depositional systems.

The carbonate strata in Lithozone 2 are lacustrine/marine shoreline facies. This interpretation is based on their intercalation with alluvial deposits. The carbonate mounds have been referred to as algal reefs

(Murray, 1960; Boucot _et al_. 1974), but others suggest that the evidence to support this is lacking (Keppie _et al_., 1978; MacBeath, 1981). In spite of the strongly recrystallized texture of the mounds, they exhibit a domal shape and hemispherical outlines occur on some of the mound surfaces, both features characteristic of stromatolites. Thus they are considered to be of algal construction in this study.

The carbonate clast units are interpreted to be oolitic strata. They resemble the poorly-sorted, oddly-shaped oolitic sands of the lacustrine Green River Formation which formed along shorelines (Smoot, 1978). They could have formed also diagenetically as calcrete ooids due to soil-forming processes. A water-laid origin is favoured here because of the alignment of some of the grains parallel to bedding, the presence of grapestone, the fragmented nature of many ooids, and the well-sorted nature of some layers. Some of the carbonate clasts may be calcrete ooids which were reworked prior to induration, thus giving the appearance of water-laid ooid deposits (Read, 1976).

The interbedded carbonate and red shale (57-59 m) may represent algal mats or carbonate sediments rhythmically precipitated in a nearshore lacustrine/marine environment. Because the laminae pinch and swell laterally they may represent algal colonies. The presence of what appears to be domal stromatolites in the laminite further suggests an algal origin.

The question of whether the carbonate environment was marine or lacustrine cannot be definitely answered here. Picard and High (1972) pointed out that the distinction between these two environments is not always possible in the absence of key fossils. The fossils observed in the Wilkie Brook Formation by the author are restricted to unidentified ostracodes and paleoniscoid fish, both of which can occur in either setting. There have been at least two specimens of brachiopods identified. Kaminsky (1953) and Krammer and Phinney (1953) described the discovery of a single valve of a "Spirifer-type" brachiopod. Schenk (pers. comm., 1984) observed a single brachiopod valve in one of the algal mounds. Murray (1960) and Schenk (1975) developed facies models in which the Wilkie Brook Formation carbonates were considered to be marine shoreline deposits, proximal facies of the upper Windsor Group marine strata. However, the author feels that the Wilkie Brook Formation subaqueous deposits in Lithozone 2 represent a lacustrine environment for the following reasons. (1) The apparent absence of marine fossils based on this study. (2) The paleocurrent indicators show unipolar flow conditions. The apparent absence of bipolar paleocurrent patterns may be due to limited data. (3) The only chemically precipitated sedimentary rocks found in the section are carbonates, which are exceedingly difficult to precipitate in salt water. Furthermore, the absence of other precipitated sediments such as evaporites favours a low salinity lake environment. MacBeath (1981) also concluded that the carbonates are related to lacustrine environment, based primarily on the absence of a marine fauna.

Lithozone 3 is interpreted as floodplain deposits with interbedded shoreline stromatolites. The floodplain interpretation is based on the characteristic interbedding of lithofacies Sr and Fm which are typical of distal crevasse splays and floodbasin deposits, respectively (Turner, 1978). The relatively thick sandstone unit containing lithofacies St (87-91 m) may represent either a meandering channel or a proximal crevasse splay similar to deposits described by Turner (1978). The strongly oxidized red colouration and desiccation cracks indicate prolonged subaerial exposure probably in an arid to seasonally arid climate. The calcrete nodules are representative of a fluctuating water table.

These meandering river deposits may represent: (1) a high sinuousity extension of the braided river/alluvial fan (in Lithozones 1 and 2) during a period of reduced energy in the system, or (2) a second fluvial system on the basin floor unrelated to the braided river environment. The evidence is inconclusive; however, because the strata show a strong lithologic similarity (based on clast composition) to the underlying braided river deposits, it is suggested that the lithozone may represent a low-energy distal extension of the alluvial fan system. In either situation, fan activity was suddenly reduced to accomodate the temporary development of a floodplain environment at this location.

The carbonate mounds and strata are interpreted as algal stromatolites. The presence of the stromatolites associated with floodplain deposits indicates a shoreline environment. Storm waves reaching the floodplain presumably were responsible for stromatolite growth. Eardley (1938) describes similar algal mounds along the shoreline of Great Salt Lake. Likewise, the Ridge Basin has abundant stromatolites associated with lake shoreline siliciclastic lithofacies (Link and Osborne, 1978).

<u>Lithozone 4</u> is interpreted to be a proximal braided river deposit. This indicates renewed progradation of the alluvial fan system. The interbedding of cross-stratified and massive clast-supported conglomerates with sandstone strata is typical of a braided river with bar and channel deposits. The sequence is similar to the braided river deposits of the Scott outwash plain (Boothroyd and Ashley, 1975). Lithofacies Gt is indicative of channel fills whereas lithofacies Gml may represent either channel fills or longitudinal bars (Miall, 1977). Barface deposits are

suggested by the presence of planar cross-stratification (lithofacies Gp). The multiple planar cross-bedded unit (at 99.5-102 m) exhibiting reactivation surfaces is similar to Pleistocene examples described by Eynon and Walker (1974), who suggested that these deposits reflect delta-like growth from eroded bar remnants in deep channels. The abrupt contacts between conglomerate and sandstone units indicate that the sandstonelithofacies represent channel deposits which occurred during less violent flooding. Lithofacies Fl (at 108.5-109.5 m) represent drapes occurring in abandoned channels during the waning stages of flooding. This interpretation is based on the abrupt lower contact of these fines with underlying channel conglomerates. Lithofacies Fm and Sr were probably deposited in a similar manner.

The carbonate mounds are interpreted as algally-constructed bodies, and the oolitic strata (at 99 m) as water-laid ooid deposits. Symmetrical wave ripple marks in the oolitic strata suggest comparison with the margin of Great Salt Lake (Eardley, 1938). The abundant calcite cement in some of the conglomerates is common in modern arid settings, where evaporative pumping of ground water up through the fan causes massive precipitation of calcite cement (Hsu and Siegenthaler, 1969). In general, Lithozone 4 indicates periodic progradation of fans across a lacustrine shoreline.

Lithozone 5 resembles Lithozone 4 in consisting of alluvial-fan deposits. The predominance of lithofacies Gml is representative of sheet flood deposits formed during periods of high sediment discharge in rapidly-shifting, shallow distributary channels (Bull, 1972). The lenses of sandstone and mudstone represent accretion in abandoned channels (Miall, 1977). The lithozone represents the distal regions of the fans as debris-flow deposits are absent (Rust, 1978). The absence of shoreline carbonates indicates that the fans prograded onto the basin floor at this time, possibly accompanied by shrinkage of the lake/marine environment.

vii) Facies Model

Murray (1960) interpreted the Wilkie Brook Formation as a proximal deposit of the Windsor Group. Subsequently, Schenk (1969, 1975) developed a marine model to account for the shoreline facies of the Wilkie Brook Formation. A Persian Gulf/Shark Bay model was used to predict a Wilkie Brook-like deposit. However, similar depositional conditions have been described in the lacustrine Tertiary sediments of the Uinta Basin (Ryder et al., 1976). Figure 3.11 is a facies model illustrating the distribution of depositional environments observed in the Wilkie Brook Formation. They include the open lacustrine environment (distal), the marginal lacustrine environment (medial), and

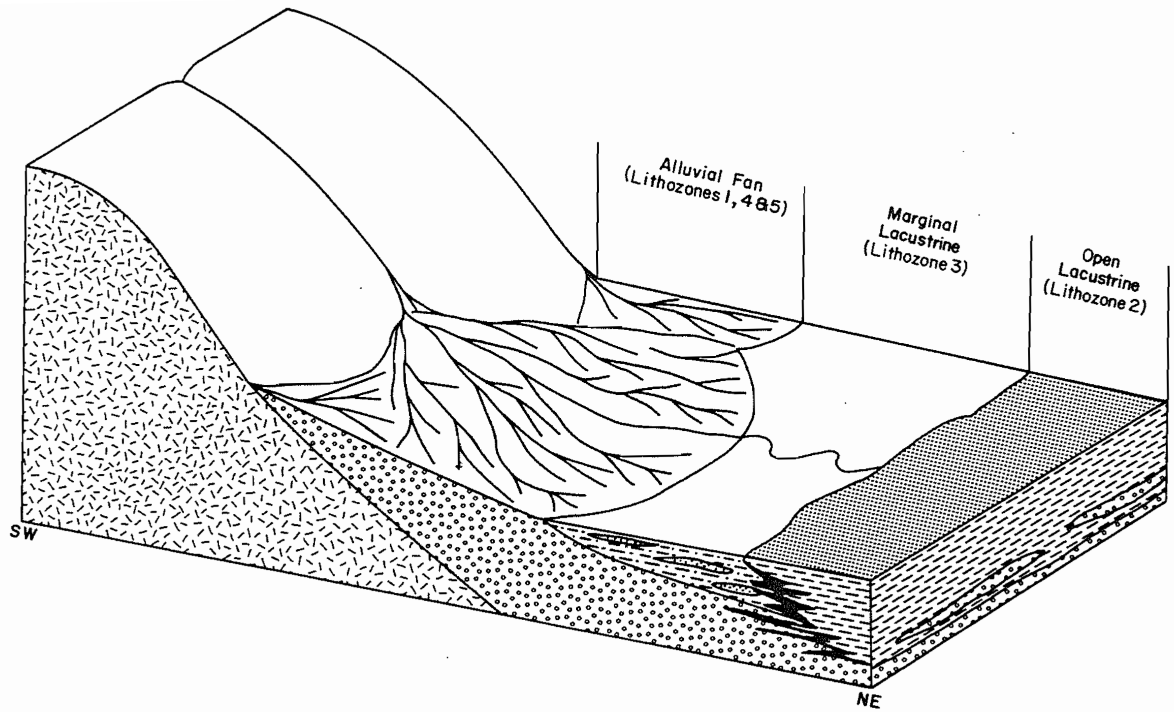


Figure 3.11. Depositional model for the Wilkie Brook Formation.

the alluvial fan environment (proximal). Lithozone 2 represents the nearshore fringe of the open lacustrine environment where rhythmically interbedded sandstone and shale and thick, relatively uninterrupted shales were deposited. The scattered presence of stromatolites, oolites, red oxidation colour, and desiccation cracks indicates that the lake was shallow and occasionally subaerially exposed. Ryder et al. (1976) interpreted the Uinta strata as being nearshore deposits periodically exposed during low stands of the lake. The presence of paleoniscoid fish fragments and apparent lack of evaporites suggests that the salinity was not extreme, nor the lake playa-like in nature. Lithozone 3 represents a marginal lacustrine environment, where algal colonies thrived on the borders of a meandering floodplain during a period of subdued alluvial fan activity. Lithozones 1,4, and 5 occurred in an alluvial fan environment and show strong similarity to the Lake Uinta fan deposits (Ryder et al. 1976). The presence of stromatolites and oolites indicates periodic marginal lacustrine conditions where the alluvial fan prograded into the lake.

In summary, Wilkie Brook Formation deposition began with the progradation of an alluvial fan system from the basin margin and the development of a lake system on the basin floor. Fan activity declined, accompanied by an expansion of the lake system and the appearance of a meandering floodplain. Finally, the alluvial fan system prograded once again, accompanied by a regression of the lake system.

It should be noted that the Albert Formation of the Moncton Basin compares quite favourably with the Wilkie Brook Formation, in terms of age and general lithofacies relationships. In the Albert Formation coarse fanglomerates at the basin margins interfinger with more distal, fine-grained lithofacies of fluvial-deltaic and lacustrine origin (Carter and Pickerill, 1985). The main differences are the presence of evaporites and abundance of oil shales in the Albert, both of which can be explained in terms of climatic conditions. These lithofacies may be present in the Wilkie Brook Formation as well, in an area of the Antigonish Basin which is not exposed. Precise correlation between stratigraphic units in the Horton Group and associated strata across Atlantic Canada is uncertain.

viii) <u>Paleocurrent Analysis</u>

The Wilkie Brook Formation contains a large variety of paleoflow indicators (Appendix III). Directional data show paleoflow to the northeast (Fig. 3.12). Axial data indicate a similar possible trend. Thus, the source area was to the southwest.

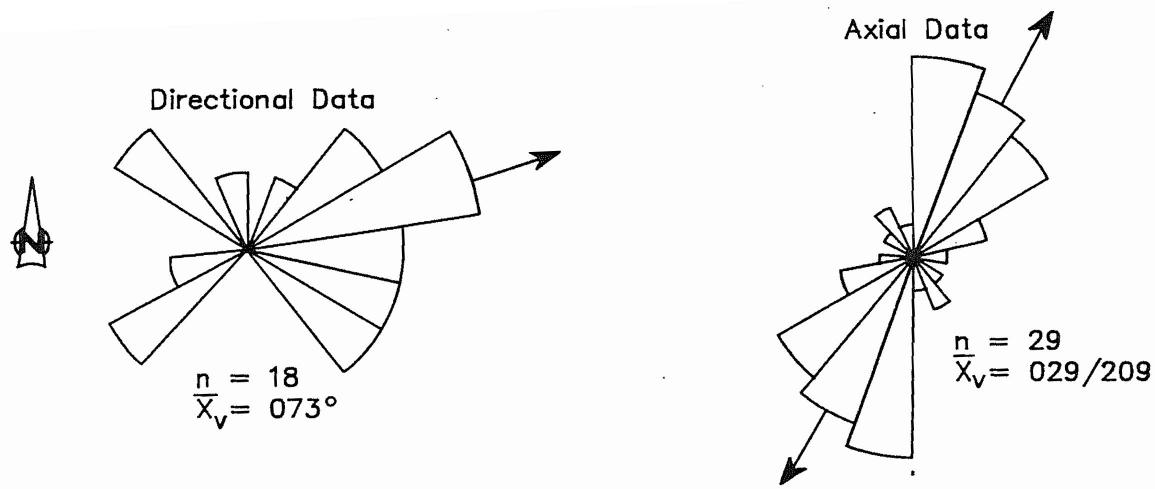


Figure 3.12. Paleocurrent trends for the alluvial deposits in the Wilkie Brook Formation.

The paleocurrent indicators are plotted along the stratigraphic column in Figure 3.2 to determine if there is a relationship between lithofacies type or depositional environment and paleocurrent direction. However, no obvious trends are apparent and the flow pattern seems to remain relatively consistent throughout. This would be expected if the entire stratigraphic section represents drainage and deposition from an alluvial fan system.

The greatest directional variance in the paleocurrent data occurs in the planar cross-stratified units which generally show a flow direction at an angle to the vector mean. This tendency is most pronounced in the stacked planar cross-stratified unit at 99.5-102 m where all three cross-stratified subunits indicate flow occurred in different directions, presumably within the same channel. This variance probably reflects the tendency for bar growth to occur on slip faces oriented at oblique angles to the general flow of the channel in a delta-like fashion. Cant (1978) demonstrated that transverse (oblique) bars in the Battery Point Formation and the South Saskatchewan River consistently deviate in a direction from the channel trough crossbeds.

ix) Provenance

Metasedimentary clasts predominate in the Wilkie Brook

Formation conglomerates although small percentages of metavolcanics and granitoid lithologies are also present (Fig.3.13). The clast assemblage and the vector mean for paleoflow are similar to those of the Ogden Brook Formation and the Rights River Formation. This is consistent with an Antigonish Highlands source area, as will be discussed in the final chapter.

The Wilkie Brook Formation differs from the Ogden Brook Formation and Rights River Formation in its higher percentage of metasedimentary clasts. This may be accounted for in several ways: (1) The basement rocks of the Antigonish Highlands (Fig.1.2) have a higher percentage of metasedimentary rocks to the north of James River Station than to the south (Murphy, pers. comm., 1983). If the northeast paleoflow direction is accurate and the source/depositional areas approximate their original positions, the predominantly metasedimentary highlands to the north would have been the primary contributor to the formation's deposits located along the northern flank of the basin. (2) The relatively fine-grained nature of the Wilkie Brook Formation fanglomerates indicates that they were deposited in a more distal location than those of the Odgen Brook or Rights River Formations. Thus the clast composition may simply reflect distance from the source. In the relatively distal deposits of the Wilkie Brook Formation, the resistant quartzites may have been preserved

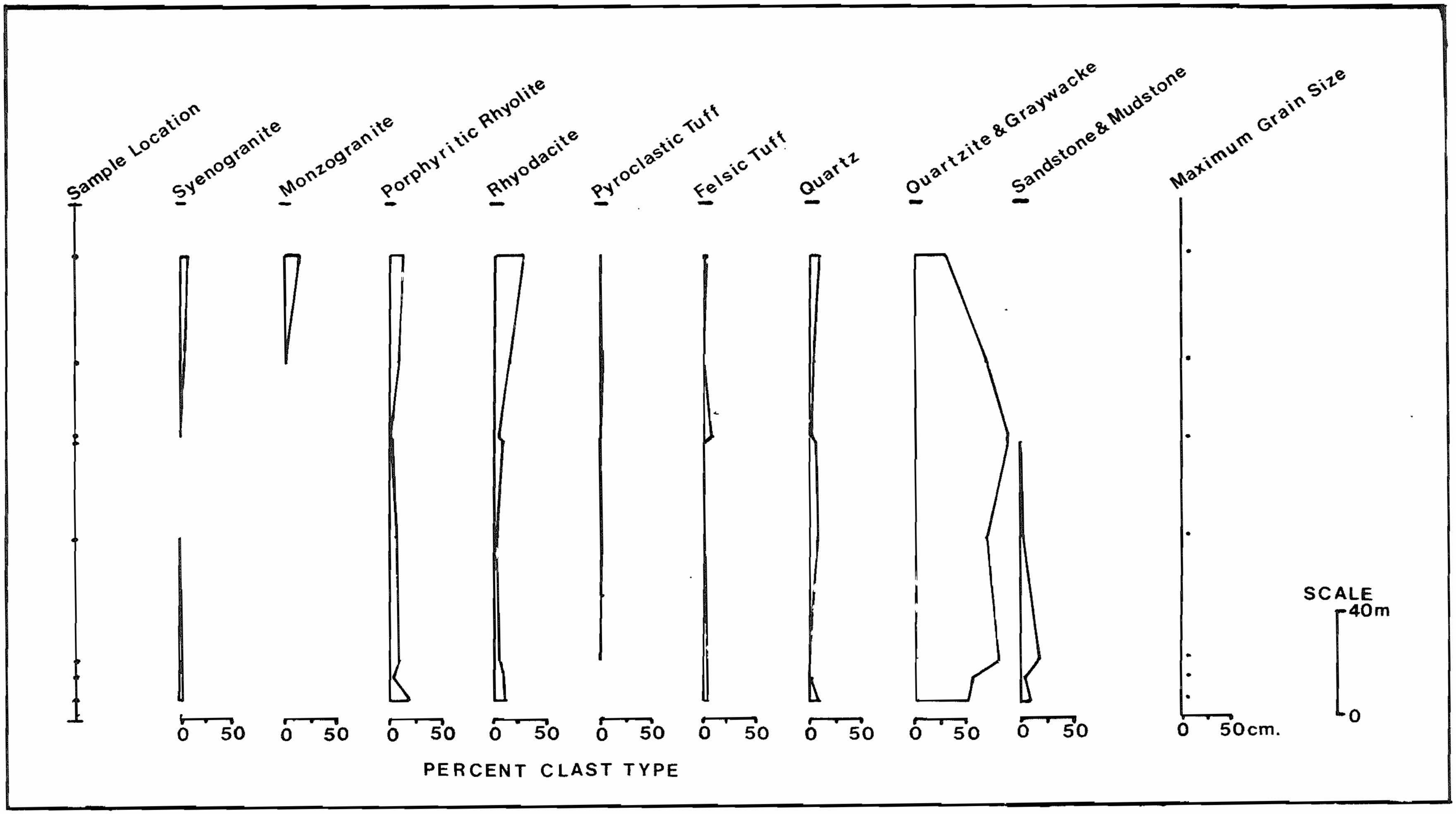


Figure 3.13. Clast composition of the Wilkie Brook Formation conglomerates (Location AB, Fig.3.1).

preferentially. However, there are white - gray quartzite clasts in the Wilkie Brook Formation that are not observed in the other two formations. This probably eliminates the possibility of a preferential disintegration of certain clast lithologies. One would expect to find these clasts in more proximal areas as well. Although white - gray quartzite is common in the Antigonish Highlands at present, there is not enough information on its geographic and stratigraphic distribution to determine why similar clasts are found only in the Wilkie Brook Formation. (3) Successive erosion of the Antigonish Highland source area may have exposed a predominantly metasedimentary basement at the time of Wilkie Brook deposition.

As first suggested by Boehner (pers. comm., 1983), the author feels that the Wilkie Brook Formation may be a lateral equivalent to the Rights River Formation. This is based on the following reasons: (1) the two formations are never found together in the stratigraphic column; (2) both formations are in contact with the underlying South Lake Creek Formation; (3) the uppermost conglomerates in both formations are in sharp contact with lithologically similar carbonates and evaporites generally recognized as part of the Windsor Group; (4) only Tournaisian spore assemblages are found in the formations; (5) both formations contain similar alluvial fan deposits of similar provenance and drainage.

The Wilkie Brook fanglomerates are less probably lateral equivalents of the Windsor Group. Spore assemblages in the Wilkie Brook Formation predate Windsor Group strata. However, this may simply mean that parts of the Wilkie Brook Formation represent earlier marine invasions.

CHAPTER IV

WINDSOR GROUP

i) Lithological Description

The Windsor Group in the Antigonish Basin consists of fine-grained siliciclastics, gypsum, anhydrite, rock salt, limestone, and dolostone. The rock types generally occur together as complete and incomplete cycles.

ii) Thickness

An accurate thickness for the strata in the Antigonish Basin is difficult to determine due to structural complexities, poor exposure, and abrupt lateral facies changes. Sage (1954) estimated a total thickness of 700-1000 m. Diamond drill core studies by Boehner (1980b) indicate a probable thickness of about 1000 m.

iii) Contact Relationships

The lower contact with the Horton Group varies from conformable to angularly discordant (Boehner, 1980b). The upper contact with the Canso Group is conformable (Belt, 1965; Boehner, 1980b).

iv) Age

Opinion has varied considerably as to the age of the Windsor Group within the province (e.g. Bell, 1929 and 1958; Belt, 1964; Globensky, 1967; Mamet, 1970). This appears to be largely due to the different methods employed to date the strata. Added to this is a lack of agreement in defining the group. The problems have been thoroughly reviewed by Kelley (1967) and Schenk (1969).

Bell (1929) originally subdivided the Mississippian Windsor Group of the province into two zones with five subzones based on marine fossils. He later assigned a Visean age to these rocks on the basis of the macrofauna (Bell, 1958). Globensky (1967) subsequently used conodonts to establish a Middle Visean-Early Namurian age. Mamet (1970) suggested a Late Visean-Early Namurian age based on foraminiferal studies. Palynological studies by Utting (1978, 1987) indicated a Middle - Late Visean age.

Work done by Sage (1954), and later confirmed by Boehner (1980b), indicates that all of Bell's (1929) subzones are present in the Antigonish Basin. Although the Windsor Group stratigraphy is complex and not well understood in the basin (see discussion of Boehner, 1980b), it appears that deposition was continuous here and typical of the Windsor Group elsewhere in Nova Scotia.

v) Lithofacies Descriptions

This thesis examines the siliciclastics of the Windsor Group. The carbonates and evaporites were not studied here as previous work by Schenk (1969) presented a detailed desription of these rock types. After an examination of several sections of the Windsor Group, a stratigraphic section at Monastery (Fig.4.1, Location A) was selected as a representative siliciclastic sequence.

Section 10 (Fig.4.2) consists of red siliciclastics with minor carbonates. The red siliciclastics (0-52.5 m) consist of mudstone, siltstone and fine-grained silty sandstone (Fig.4.3). Mudstone (Fm) is the most abundant lithofacies, occupying 42 percent of the total thickness. The mudstone commonly contains mottling and desiccation cracks. Interbedded siltstone and fine-grained sandstone units of lithofacies St, Sh2, Sr and Fl show two basic depositional patterns. One shows St overlain by Sr and/or Sh2 (e.g. 15.5-23.5 m and 42-44 m). The base of these units is generally erosional, mudclasts are present, and the units fine upward slightly. The other pattern consists of lithofacies Sr and/or Sh2 (e.g. 1-2 m and 40.5-41.5 m) and usually contains more and thinner units than the first pattern. Similar red siliciclastics underlie the base of Section 10, but occur as subcrop in the stream and were not measured in detail. Plant fossils were not observed in the

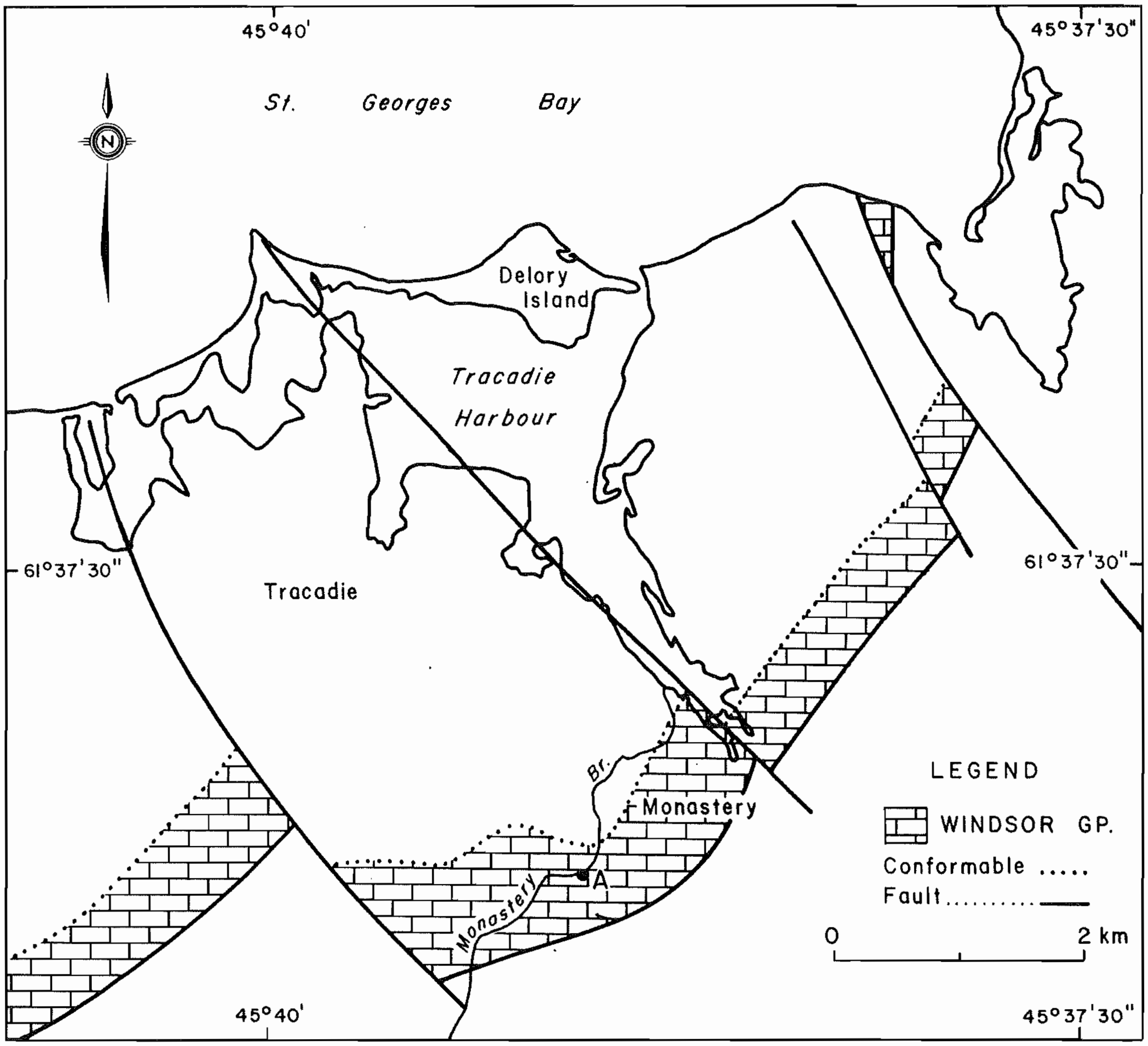


Figure 4.1. Location map of the Windsor Group in the eastern part of the Antigonish Basin (modified from Benson, 1970a).

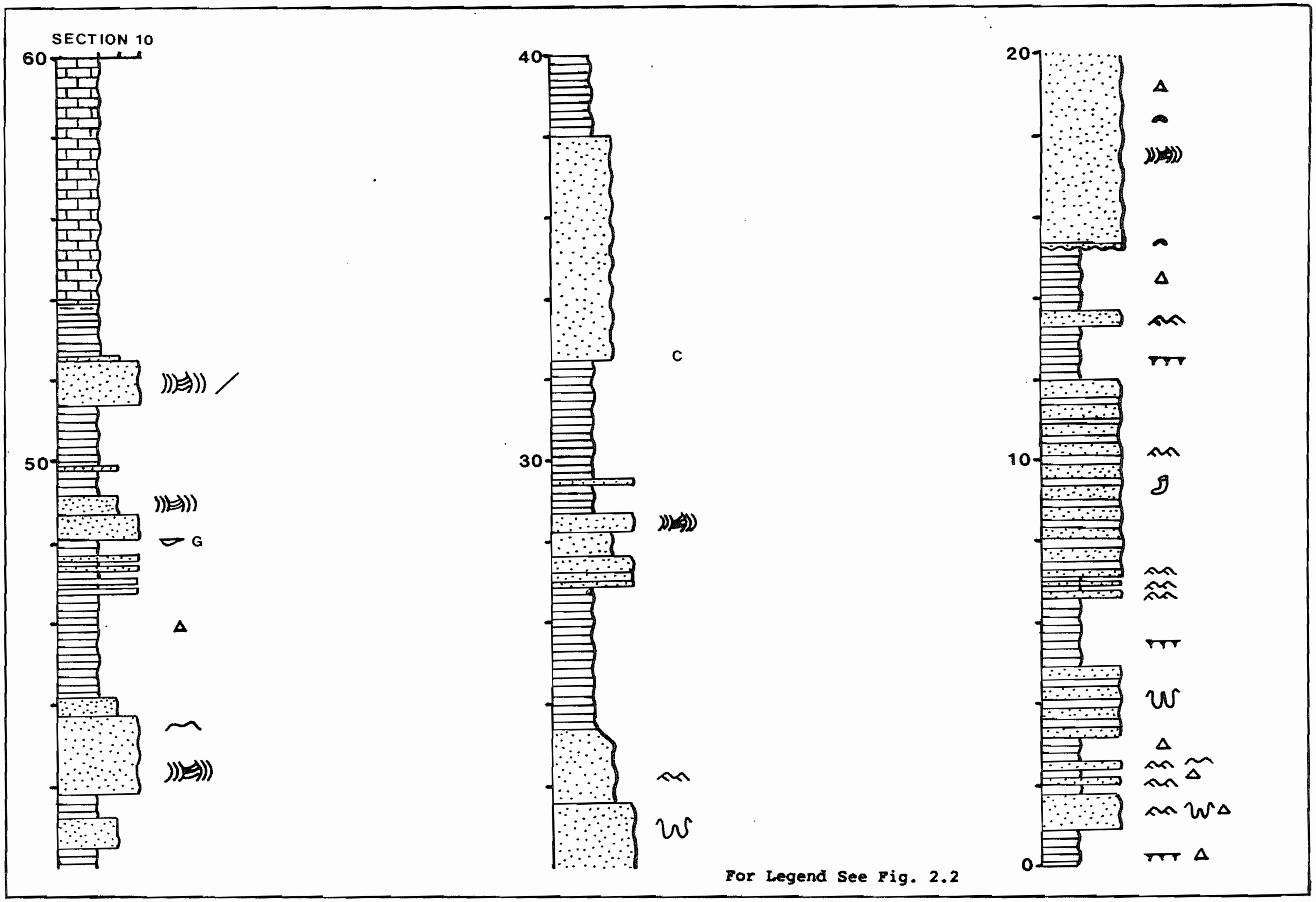


Figure 4.2. A typical section of the Windsor Group alluvial deposits at Monastery (Location A, Fig.4.1).

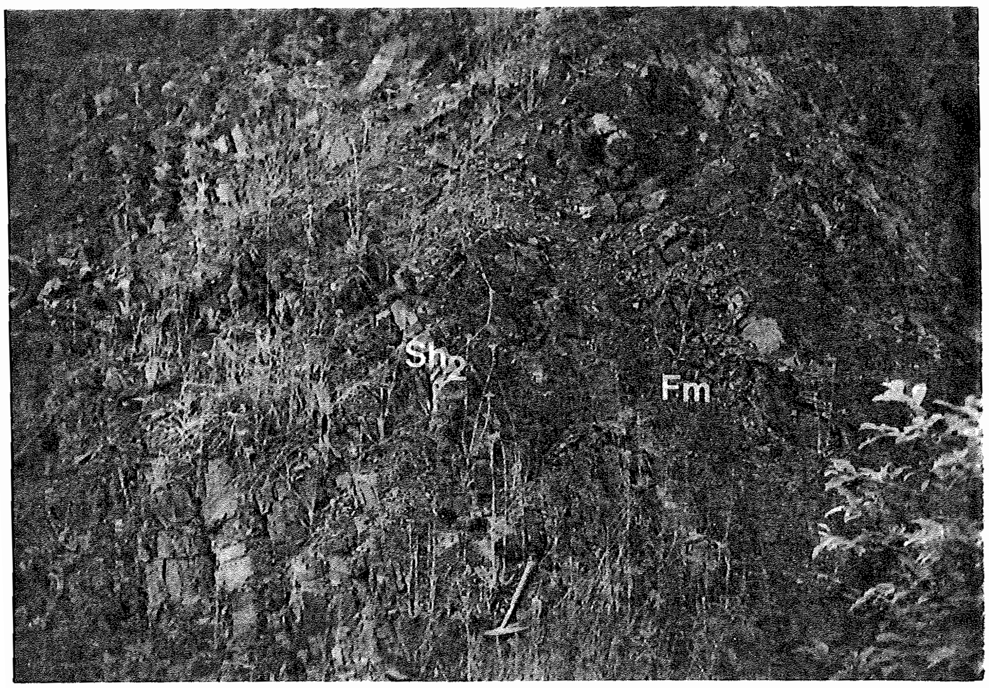


Figure 4.3. Interbedded mudstone and sandstone typical of the Windsor Group alluvial deposits (Location A, Fig.4.1).

red siliciclastics.

Overlying the red-beds is a 1.5 m thick gray-black unit consisting of mudstone (52.5-54 m) containing disseminated pyrite and devoid of any fossils. At the top of the section is 4 m of gray-brown dolostone which is massive and contains brachiopods.

vi) Depositional Environment

Section 10 consists of meandering river deposits (siliciclastics) overlain by marine deposits (carbonates). The fining-upward units of the first pattern in the siliciclastic succession display sedimentary structures that show an upward decrease in flow power, and are typical of meandering channel deposits (Allen, 1965). The thicker unit at 15.5-23.5 m probably represents a major channel with the upper strata resembling point bar deposits described by Reineck and Singh (1980). The thinner units at 42-44 m and 52.5-53.5 m may represent smaller channels or proximal crevasse splays. The second pattern of thinner sandstone strata are interpreted as distal crevasse splay deposits. Lithofacies Fm is typical of flood basin deposits.

The abundance of overbank deposits suggests a high sinuosity river (Allen, 1965). As the coarsest strata are fine-grained sandstone, energy and carrying capacity for the river was probably low. Based on the assumption that the depth of water in a river roughly corresponds to the thickness of its channel deposits, the channels in Section 10 were in the order of 2.0 to 6.0 m deep. Compared to the other fluvial deposits studied in this thesis, they were relatively small.

The overlying brachiopod-bearing dolostone is indicative of marine deposition and indicates a marine transgression. The intervening gray-black mudstone unit probably represents an interphase between the two major environments. Schenk (1969) suggested that similar zones represented either euxinic conditions at the onset of marine transgression or subsequent diagenesis due to a rapid rise of the water table associated with the transgression.

The fine-grained floodplain environment of Section 10, adjacent to the sea, could more accurately be termed coastal plain deposits (Reineck and Singh, 1980). They may have formed tidal mudflats prior to transgression.

Evidence of aridity and subaerial exposure is common throughout the section. The red colouration of the strata suggests oxidative low water table conditions, although an early diagenetic origin is possible. Desiccation cracks indicate subaerial exposure. Calcrete nodules and mottling resulted from chemical reactions with groundwater and are commonly characteristic of at least seasonal aridity. Halite casts are locally present in the strata near Antigonish (pers. comm., R.C. Boehner, 1987). The abundance of evaporites elsewhere in the Windsor Group indicates that a hypersaline environment was present in the Antigonish Basin, further evidence of at least seasonal or cyclical aridity. The absence of plant remains also suggests a harsh environment where vegetation was not abundant or was later destroyed by oxidation.

Marine/non-marine cycles have been recognized in the Windsor Group by many workers (Sage, 1954; Bell, 1958; Schenk, 1969; Giles, 1981). Schenk (1969) suggested that, following the marine invasion of the Antigonish Basin, at least twelve transgressive-regressive sequences occurred. He interpreted the sequences as shallow marine to supratidal cycles analogous to recent sequences at Shark Bay, Australia. Schenk (1969) further suggested that the mechanism responsible for the cyclicity was the fluctuation in the supply of terrigenous detritus during continuous subsidence; however, he acknowledged that isostatic and eustatic factors may have been important. Giles (1981) identified five major transgressive-regressive cycles in the Windsor Group in Nova Scotia. He suggested that they are bounded by time lines. Furthermore, he related Windsor cyclicity to worldwide sea-level changes and correlated them with European events.

The repeated interfingering of marine and non-marine environments further suggests that a delicate equilibrium existed in the Antigonish Basin. Hacquebard (1972) examined the relative thickness of marine/non-marine deposits in the Windsor Group of the province. He concluded that marine deposition was more active and widespread in the Fundy Basin during the Lower Windsor whereas terrigenous sedimentation was more active in the Upper Windsor. Marine environments disappeared from the region at the close of Windsor deposition.

vii) <u>Paleocurrent Analysis</u>

Paleocurrent data were not recorded in the Windsor Group.

viii) <u>Provenance</u>

A study of provenance was not conducted on the Windsor Group siliciclastics because of their fine-grained nature. Windsor Group conglomerate lithofacies were not encountered. The fine-grained nature of the red siliciclastics in the Antigonish Basin suggests a relatively distant source area and low energy transportation.

CHAPTER V

CANSO AND RIVERSDALE GROUPS

The youngest rocks preserved in the Antigonish Basin are mid Carboniferous in age. They comprise the Canso and the overlying Riversdale Groups. The Canso Group is the thickest succession of strata occurring in the basin, and consists of approximately 6 km of red and gray shale, mudstone, and sandstone (Belt, 1965). It includes two formations, the Hastings Formation and the overlying Pomquet Formation. The Riversdale Group represented by the Port Hood Formation is thin and poorly exposed, consisting of approximately 200 m of brown sandstone, conglomerate and mudstone at its maximum thickness (Belt, 1965), and is represented by the Port Hood Formation.

CANSO GROUP

Hastings Formation

i) Lithological Description:

The Hastings Formation is the "gray facies" of Belt's (1965) Mabou Group. It comprises gray, laminated shale, interbedded gray shale and sandstone, red shale, brown sandstone, and rare thin limestone/dolostone.

ii) Thickness

The Hastings Formation is 700 m thick along the Pomquet River (Belt, 1965), which represents the maximum continuous thickness observed in the Antigonish Basin.

iii) Contact Relationships

The lower contact with the Windsor Group is conformable. The upper contact with the Pomquet Formation is conformable and gradational.

iv) Age

The age of the Hastings Formation is generally accepted as Lower Namurian based primarily on megaflora and palynomorphs (Bell, 1944; Belt, 1965; Boehner, 1980b).

v) General Sedimentary Description

The type section for the Hastings Formation is found outside the study area along the Canso Strait; however, an excellent reference section occurs along the Pomquet River (Fig.5.1, Location AB). Based on the work of previous authors (e.g. Rostoker, 1960; Belt, 1968b) and observations in this study, the Hastings Formation is interpreted as predominantly lacustrine. The section was examined generally, as little provenance and paleocurrent information

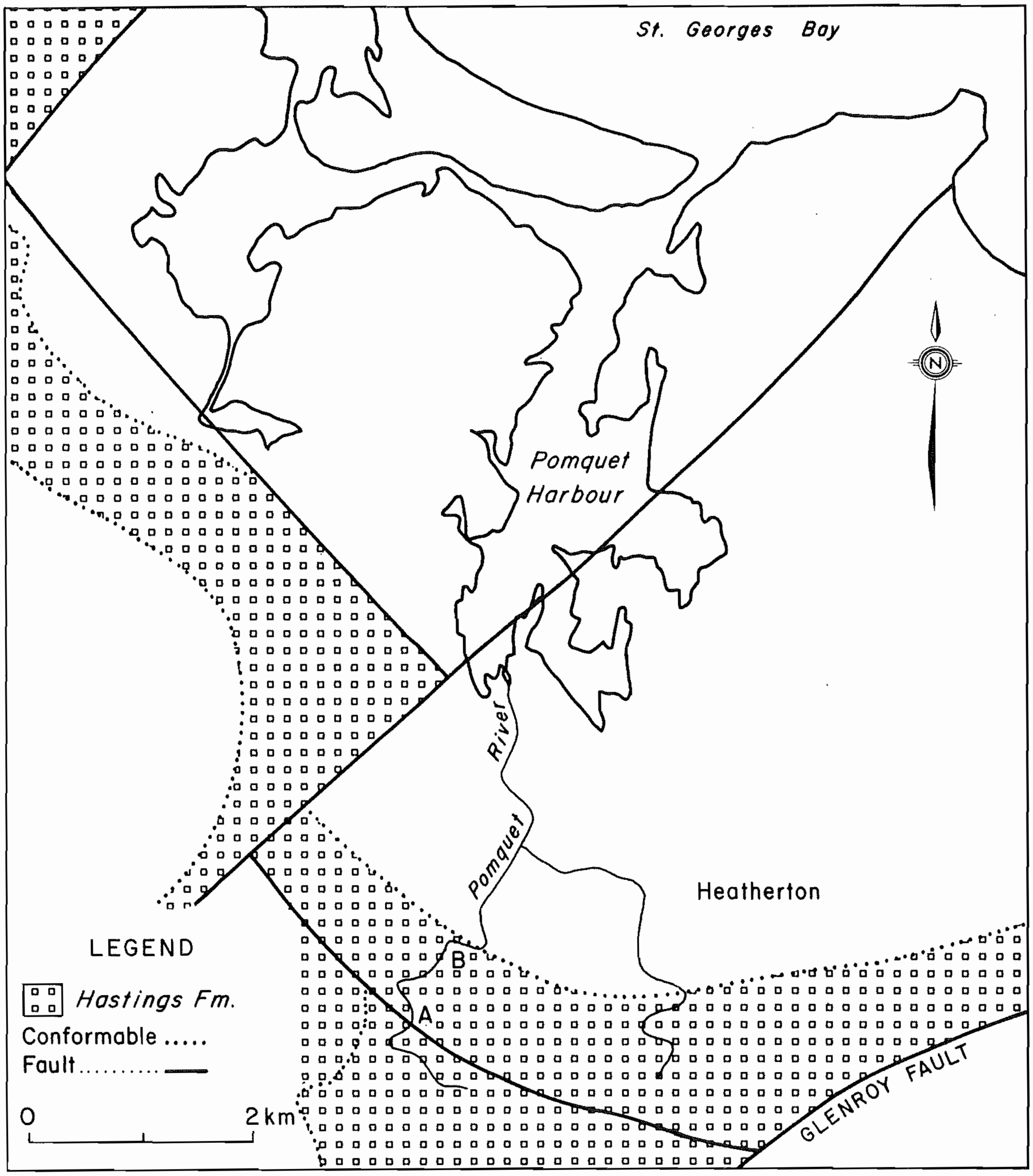


Figure 5.1. Location map of part of the Hastings Formation in the Antigonish Basin (modified from Boehner and Giles, 1982).

could be obtained.

The reference section is predominantly composed of gray strata. These strata consist of laminated shale which generally contains finely interbedded siltstone and sandstone (Fig.5.2). Sedimentary structures include symmetrical ripple marks, ripple cross-lamination, flutes, grooves, bounce marks, slump features, burrows, and plant fossils. Stromatolites described by Belt (1968b) occur in similar Canso strata along the shoreline just east of Delory Island (Fig.4.1). The gray strata are commonly calcareous and locally petroliferous. There are also rare thin limestone and dolostone units.

Interspersed in the gray strata are red to gray-brown shale and sandstone strata. The shales are fissile and often laminated, similar to those of the gray strata. The sandstone strata are present as both thick and thin units. The thick units, up to 6 m thick, are relatively rare. They occur as fining-upward successions with sedimentary structures which exhibit an upward decrease in flow power. The lower contact of the units is usually sharp and erosional with underlying lithofacies Fm. At the base is lithofacies St which is generally overlain by lithofacies Sr and Sh (Fig.5.3). The thin sandstone units vary from a few centimetres to one metre in thickness and are quite tabular. They are composed of lithofacies Sr and Sh, and occur as

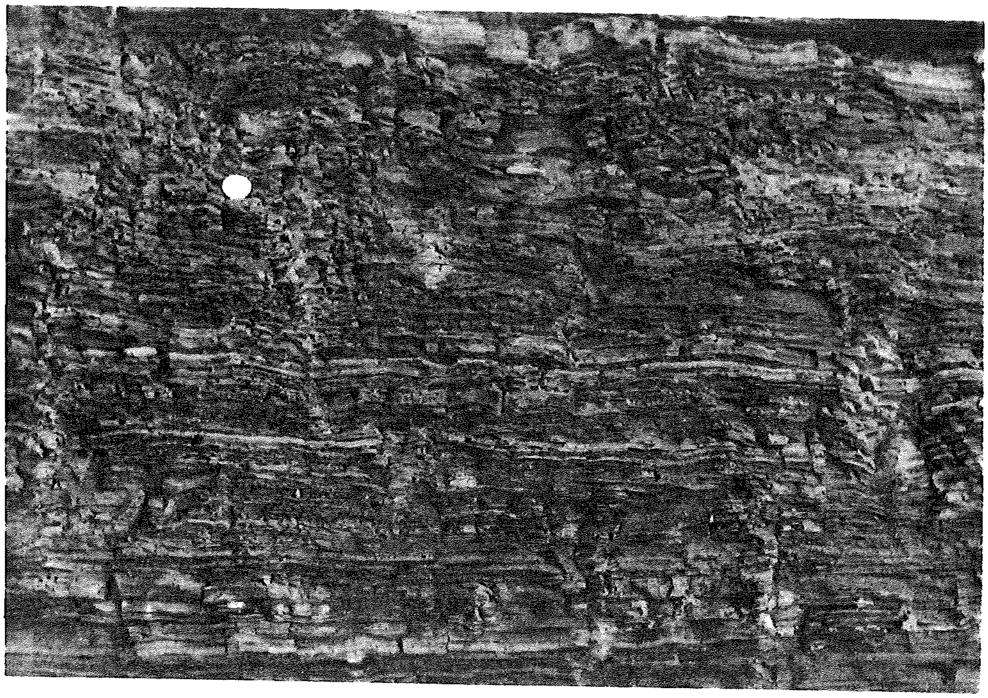


Figure 5.2. Laminated shale and sandstone in the Hastings Formation (Location B,Fig.5.1). Some of the light colored beds are very calcareous. Twenty-five cent piece for scale.

Figure 5.3. Thick sandstone body in shale of the Hastings Formation (Location A, Fig.5.1). St occurs from base of sandstone to top of hammer (arrow) and is overlain by Sr. Unit is approximately 4 m thick.

scattered interbeds throughout the thick shale strata (Fig.5.4) or as a closely spaced series of units separated by thin shale interbeds (Fig.5.5). Examination of exposures in other parts of the Antigonish Basin indicate that the rock types and lithofaices combinations remain quite consistent throughout the basin.

vi) Depositional Environment

The fine-grained nature of the deposits, the gray colour, the rhythmic interbedding of shale and siltstone/sandstone, the abundance of symmetrical ripple marks, and the stromatolites indicate deposition from standing water of a lacustrine or epicontinental marine environment (see criteria in Picard and High, 1972). Belt (1968b) interpreted the Hastings Formation as lacustrine primarily on the basis of fossil evidence which includes pelecypods, arthropods, vertebrates, and algal colonies, all of which were considered to be of freshwater origin.

The thick sandstone units represent fluvial strata deposited during low stands in lake level. They are interpreted as meandering river channels and point bar deposits on the basis of upward decrease in grain size and the vertical sequence of sedimentary structures (Allen, 1965). The relatively fine-grained nature of the channel deposits suggests a distal basinal location.

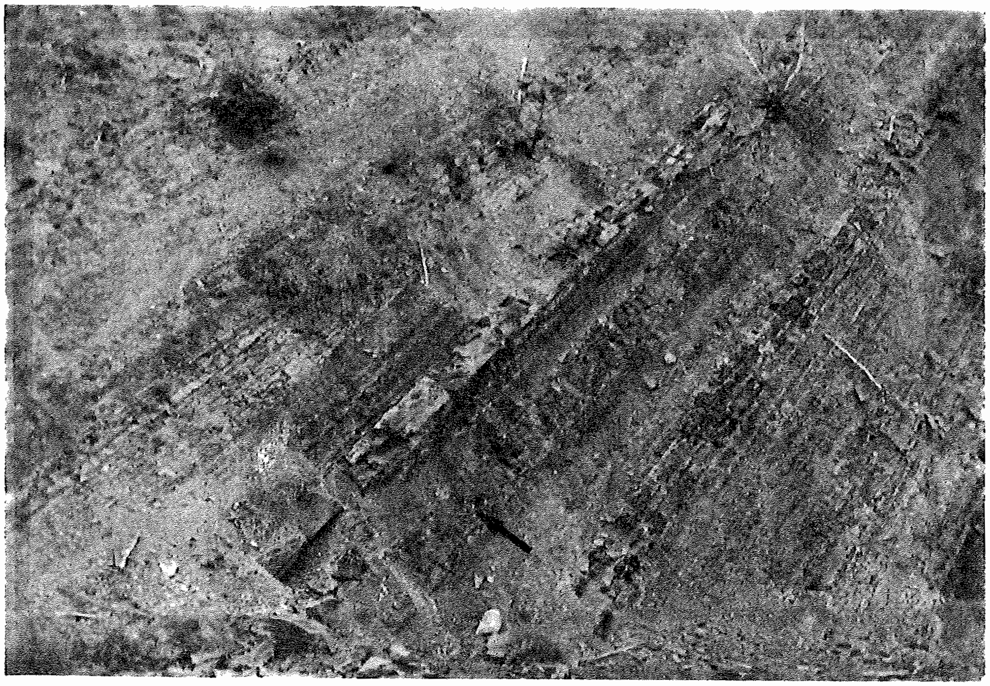


Figure 5.4. Tabular sandstone body (Sr) in thick shale sequence of the Hastings Formation (Location B, Fig.5.1). Hammer (arrow) for scale.

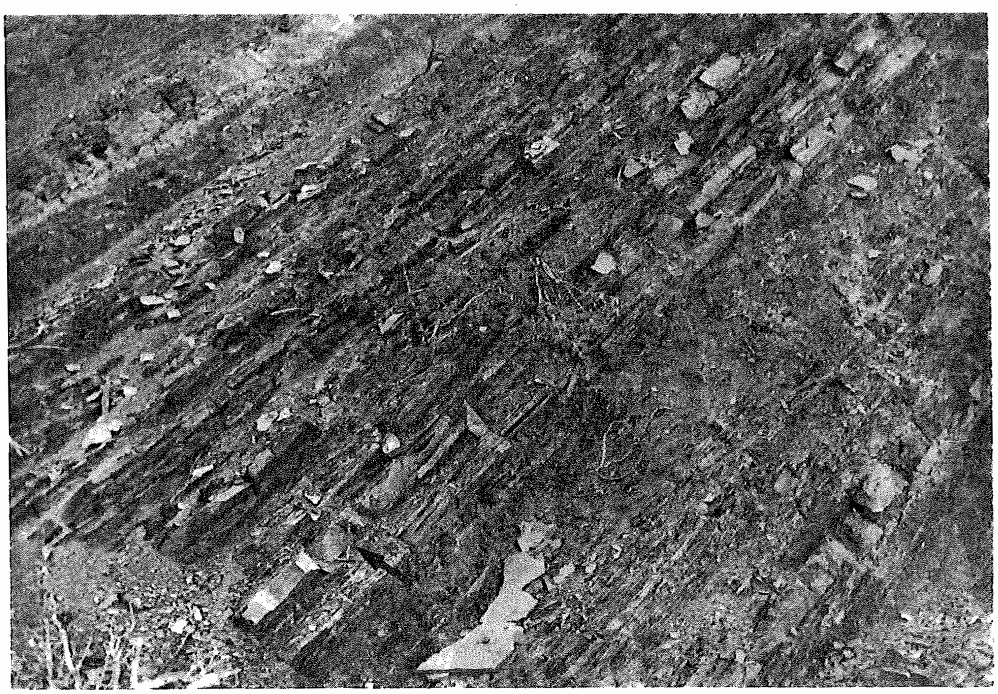


Figure 5.5. Interbeds of sandstone and shale in the Hastings Formation (Location B, Fig.5.1). Hammer (arrow) for scale.

The thin sandstone units are interpreted as crevasse splay deposits associated with the main channel. The shale strata associated with the sandstone are either flood basin deposits (Allen, 1965) or perhaps shallow lake-bottom sediments.

The thin red strata between otherwise thick gray strata are indicative of fluvial/lacustrine intercalations. They may have been subaerially exposed, or as suggested by Belt (1968b), they may have been deposited in shallow, well-oxygenated lake water. Evidence for subaerial exposure includes the calcrete nodules and desiccation cracks. The red pigmentation of the strata resulted from oxidation near the time of deposition; however, it is unknown if it is a primary or secondary process.

In summary, the evidence indicates that a large lake system covered the Antigonish Basin during depositon of the Hastings Formation. There is a stong similarity between these strata and mid - Carboniferous deposits found elsewhere in the Fundy Basin System (Belt, 1968b). Thus, the Antigonish lake probably existed as part of a larger interconnected system, occupying much of the Fundy Basin. The great thickness and relative consistency in lithofacies throughout the Antigonish Basin indicates that a finely balanced equilibrium existed between deposition and subsidence. Interruptions in lacustrine deposition occurred at times of lake contraction that allowed meandering river and floodplain deposits to inundate the basin floor. These fluvial deposits may also reflect periods of increased alluvial output from the hinterland and thus could indicate climatic or tectonic/source fluctuations.

vii) Paleocurrent Analysis

Only a small number of paleocurrent measurements were extracted from the Hastings Formation (Fig.5.6, Appendix III). The directional data indicates only a general flow direction ranging from northwest to east.

The line of flow data show much greater consistency with flow along a northwest/southeast axis (Fig.5.6); however, the vector mean varies substantially from that of the directional data, and a combined paleoflow direction is difficult to establish.

viii) Provenance

No extraformational conglomerates were observed in the formation. The fine-grained nature of the Hastings Formation indicates a distant source area, perhaps far beyond the present Antigonish Basin boundaries.

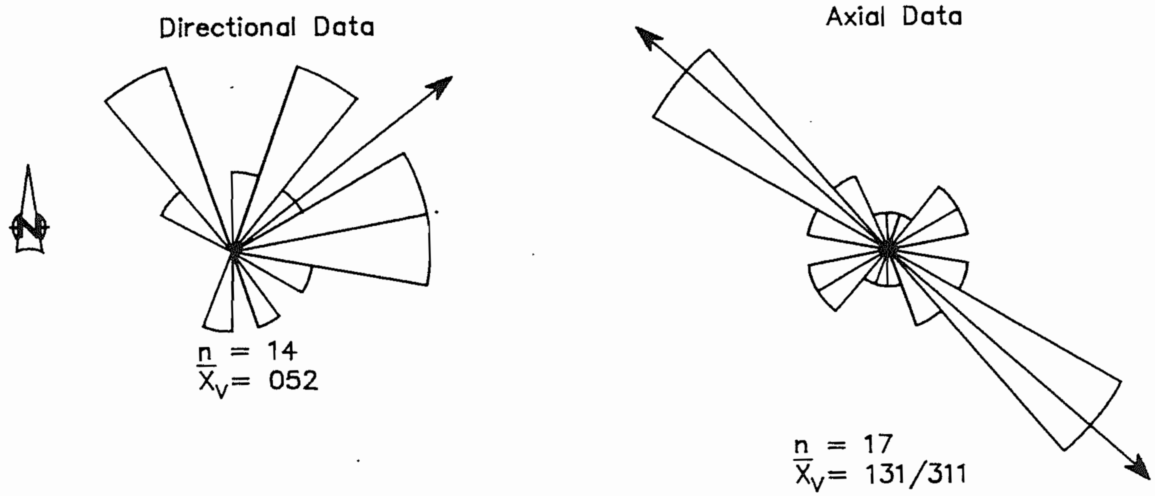


Figure 5.6. Paleocurrent trends in the Hastings Formation.

Pomquet Formation

i) Lithological Description:

The Pomquet Formation consists of red-coloured mudstone, siltstone, and fine- to medium-grained sandstone.

ii) Thickness

Belt (1965) determined the thickness of the formation as approximately 5400 m, the thickest formation of the Canso Group found in the Fundy Basin. This thickness may be over-estimated as it is interpolated across strike in an area of the Antigonish Basin that is cut by faults. Alternatively it may represent a lateral aggregate thickness.

iii) Contact Relationships

The lower contact with the Hastings Formation is conformable and gradational. According to Belt (1965), the upper contact with the Port Hood Formation near Monks Head is conformable; however, the abrupt lithological change observed here may indicate a disconformity.

iv) Age

Bell (1944) initially assigned the age of the formation to be Early Namurian. More recently he suggested that it extended into the Late Namurian (Bell, 1958). Studies by Barss (1961), Belt (1964), and Neves and Belt (1970) concluded that deposition extended from the Early Namurian to Westphalian A.

v) Lithofacies Description

Section 11 near Bayfield (Fig.5.7, Location AB; Fig.5.8) is representative of the Pomquet Formation, and contains sandstone, siltstone/silty sandstone and mudstone strata.

The sandstone units are generally thick and uncommon (e.g. 77-88 m and 136-140 m). The units exhibit a fining upward trend of grain size and form cycles 4-5 m thick (Fig.5.9). In general the cycles begin with an erosional base followed by an intraformational conglomerate of shale clasts (Gm2), overlain by finer grained strata of lithofacies St. The cycle is generally topped with interbeds of lithofacies Sr and Sh, as at 138-143 m, where a thick unit of lithofacies Sr, Sh and Fm overlies a fining upward sandstone unit. Markov Chain analysis demonstrates that these fining upward units show the transitional sequence Gm <--> St --> Sr --> Fm (Fig.5.10, Appendix II).

The siltstone/silty sandstone strata occur as thinner

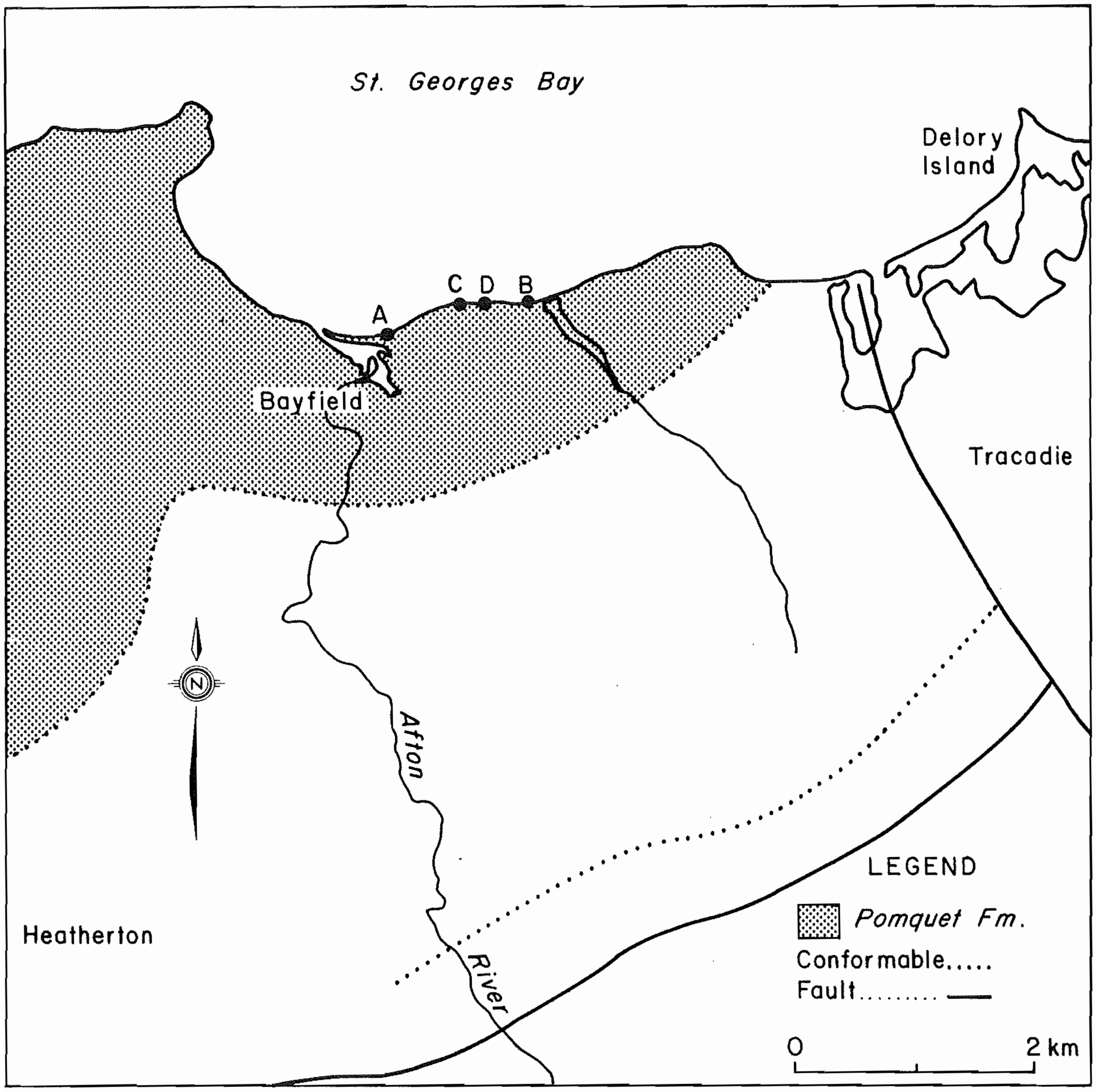


Figure 5.7. Location map of part of the Pomquet Formation (modified from Benson, 1970a).

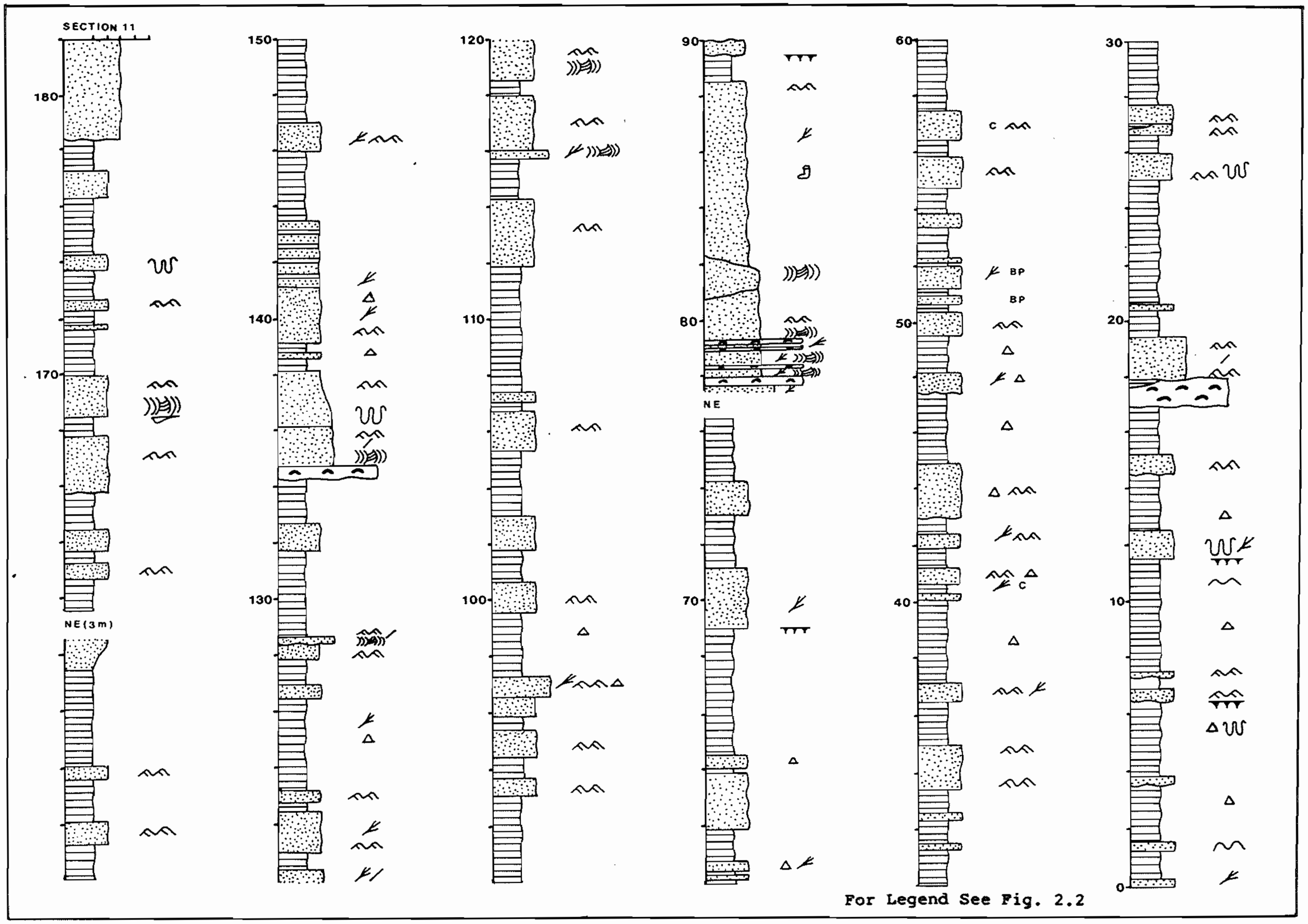


Figure 5.8. Section of the Pomquet Formation at Bayfield (Location AB, Fig.5.7).

Figure 5.9. Fining-upward sandstone sequence in the Pomquet Formation (Location C, Fig.5.7). Interbedded trough cross-bedded sandstone and intraformational conglomerate overlie mudstone at the base. Sequence is capped by ripple-laminated and planar parallel-bedded sandstone (upper third of the outcrop).

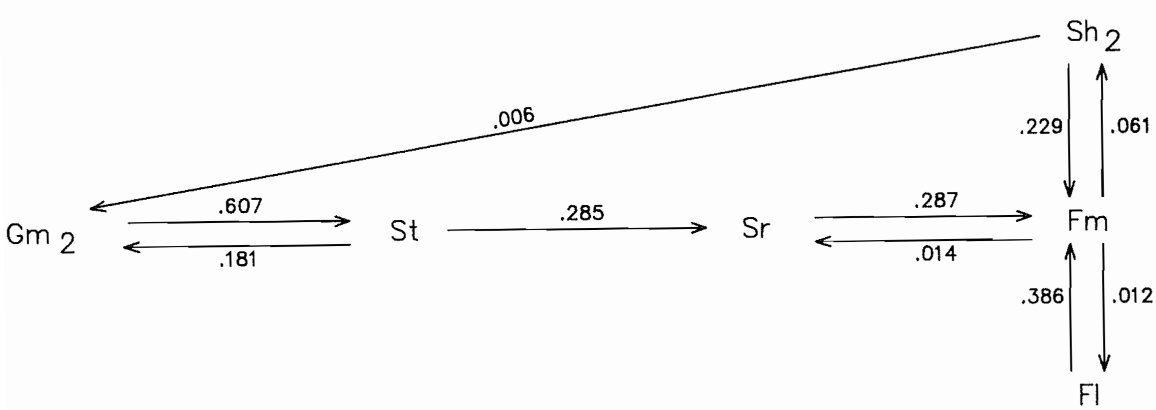


Figure 5.10. Markov Chain flow diagram for Section 11 of the Pomquet Formation (from Appendix II).

units within thick mudstone (Fig.5.11) and are relatively abundant. Small fining upward cycles are common (e.g. 17-19.5 m and 168.5-170 m), beginning with an erosional base followed by lithofacies Gm or St, with lithofacies Sh and/or Sr at the top. Also present are thin units with lithofacies Sr, Sh and/or Fl interbedded (e.g. 33.5-35 m and 25-26 m). At 157.5-158.5 m a silty sandstone unit exhibits a coarsening upward tendency.

The mudstone (Fm) is generally massive or poorly bedded and commonly silty, with scattered calcrete nodules, reduction mottling, and desiccation cracks. It forms 55 percent of the strata.

Plant fragments are rare in the sandstone and intraformational conglomerate beds. Although not observed in the present study, Sage (1954) and Belt (1965) reported a 0.3 m coal seam in the upper Pomquet Formation at Antigonish Harbour.

vi) Depositional Environment

The Pomquet Formation was generally described by Belt (1962) as being of fluvial origin. In the present study, this interpretation has been refined by suggesting that the sequence fits Allen's (1965, 1970) meandering stream model.

The thick sandstone units (e.g. 79-88 m and 136-140 m) represent deposition in high-sinuosity river channels, following the model of Allen (1965). The transitional sequence Gm2 <--> St --> Sr --> Fm within the sandstone units is characteristic of fining upward, laterally accreted point bar successions overlying coarser channel lag deposits. Reineck and Singh (1980) pointed out that the ideal point bar sequence is not always seen in the geological record and the Pomquet Formation is no exception. Ripple cross-lamination occurring between strata of lithofacies St at 77-88 m suggests fluctuations in discharge or multistacking during separate erosional/depositional events. The thick unit of silty sandstone strata of lithofacies Sr and Fl (138-143 m) overlying the point bar sequence at 134-138 m is interpreted as a levee or possibly a bartop deposit.

The fine-grained silty sandstone units are interpreted as crevasse splay deposits similar to those of the Upper Permian Beaufort Group (Turner, 1978). The thin fining upward units (e.g. 17-19.5 m and 168.5-170 m) are interpreted as proximal crevasse splays, differing from channel deposits in their small thickness, lateral persistence, and fine grain size (Coleman, 1969). The thin units of lithofacies Sr or Sh2 (e.g. 36.5-37 m) represent distal crevasse splay deposits and predominate in the section. The coarsening upward unit from 157.5-158.5 m is similar to crevasse splays observed by Turner (1975).

Lithofacies Fm is characteristic of vertical accretion as overbank sediment that settled out of suspension in the flood basin. The high percentage of fines observed suggests that the meandering river system(s) occupied stable positions (Reineck and Singh, 1980) or that the deposits occurred at a distal location in the system. The presence of red color, mottling, calcrete nodules, and desiccation cracks, and the scarcity of plant material collectively suggest at least a seasonally semi-arid climate, certainly one with periodic prolonged exposure of the sediments. The coal seam in the upper part of the formation suggests the onset of the more humid climate evident in the overlying Riversdale Group.

vii) Paleocurrent Analysis

An abundance of paleocurrent data was obtained in the Pomquet Formation (Fig.5.12, Appendix III). The results indicate a stong correlation between axial and directional data and a northeasterly paleoflow.

viii) Provenance

As no extraformational conglomerates were found, a provenance study was not conducted. The fine grain size and distal location in the depositional system of the succession

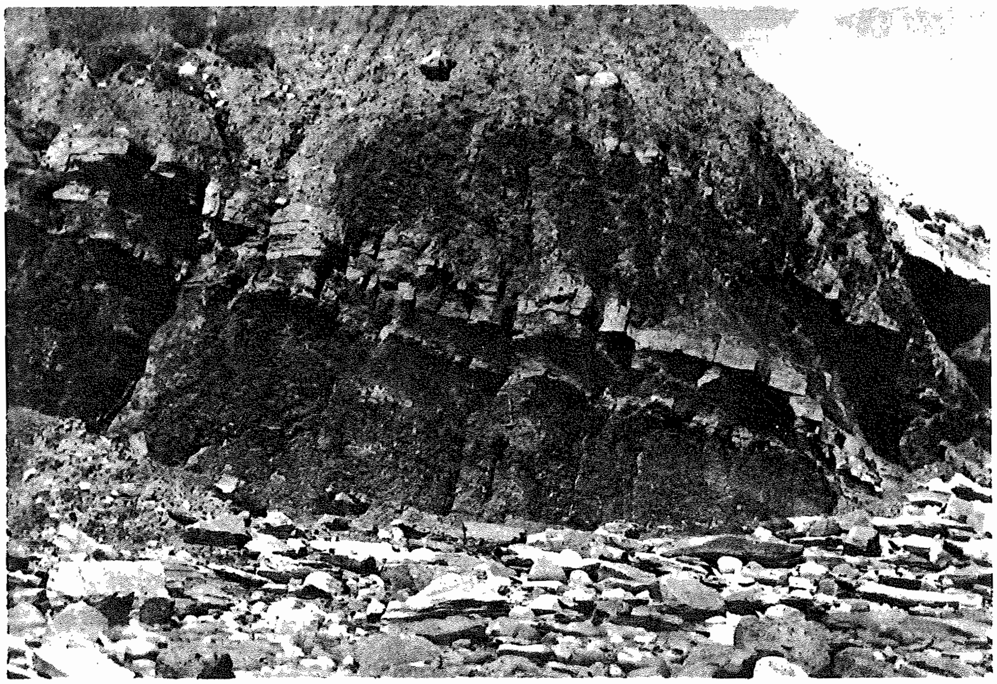


Figure 5.11. Relatively thin tabular sandstone units (Shl) within thick mudstone of the Pomquet Formation (Location D, Fig.5.7). Hammer (centre) for scale.

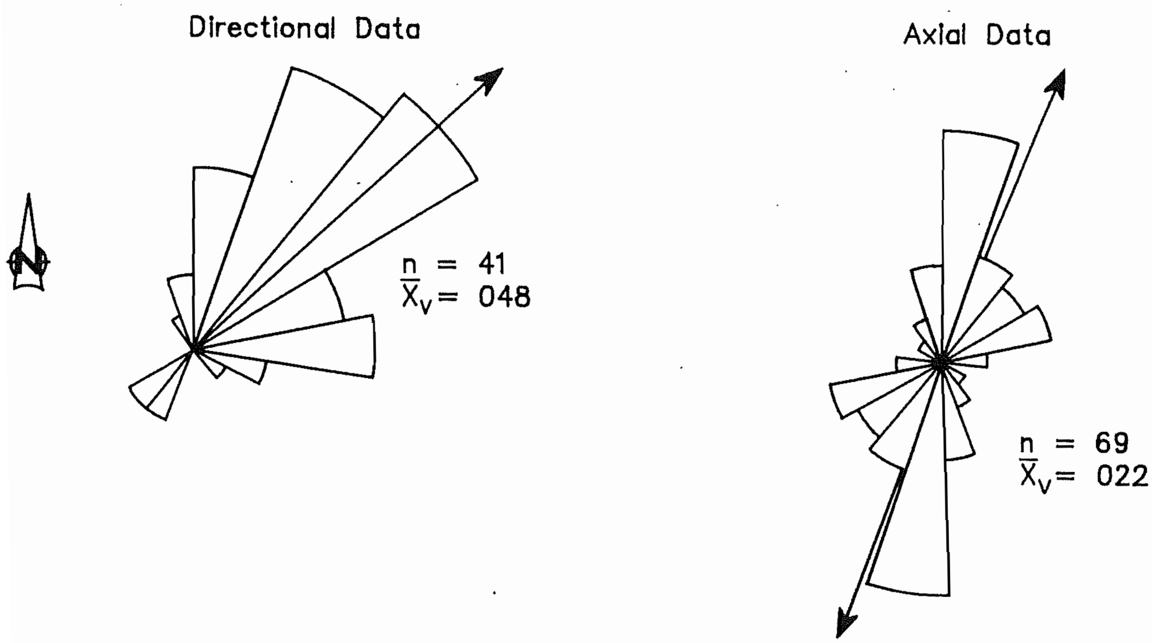


Figure 5.12. Paleocurrent trends in the Pomquet Formation.

suggest that the source area lay at a considerable distance to the southwest.

RIVERSDALE GROUP

Port Hood Formation

The Riversdale Group is represented in the Antigonish Basin by the Port Hood Formation (Fig.5.13). The formation was originally defined in southwestern Cape Breton Island by Norman (1935). In Bell's (1944) description of the formation only the type area was considered. Bell (1958) and Belt (1965) expanded the formation to include Riversdale Group rocks in the Antigonish Basin which occupy the same stratigraphic position and contain similar strata.

The Port Hood Formation is the uppermost Carboniferous unit in the Antigonish Basin. Two small coastal exposures several kilometres apart were the only strata found (Fig.5.13, Locations A and B).

i) Lithological Description

The Port Hood Formation consists of light brown sandstone and clast-supported conglomerate. The sandstone is lithic arenite and ranges from medium- to coarse-grained. The conglomerate has well-rounded clasts of granule/pebble size.

ii) Thickness

Approximately 200 m of Port Hood Formation strata is

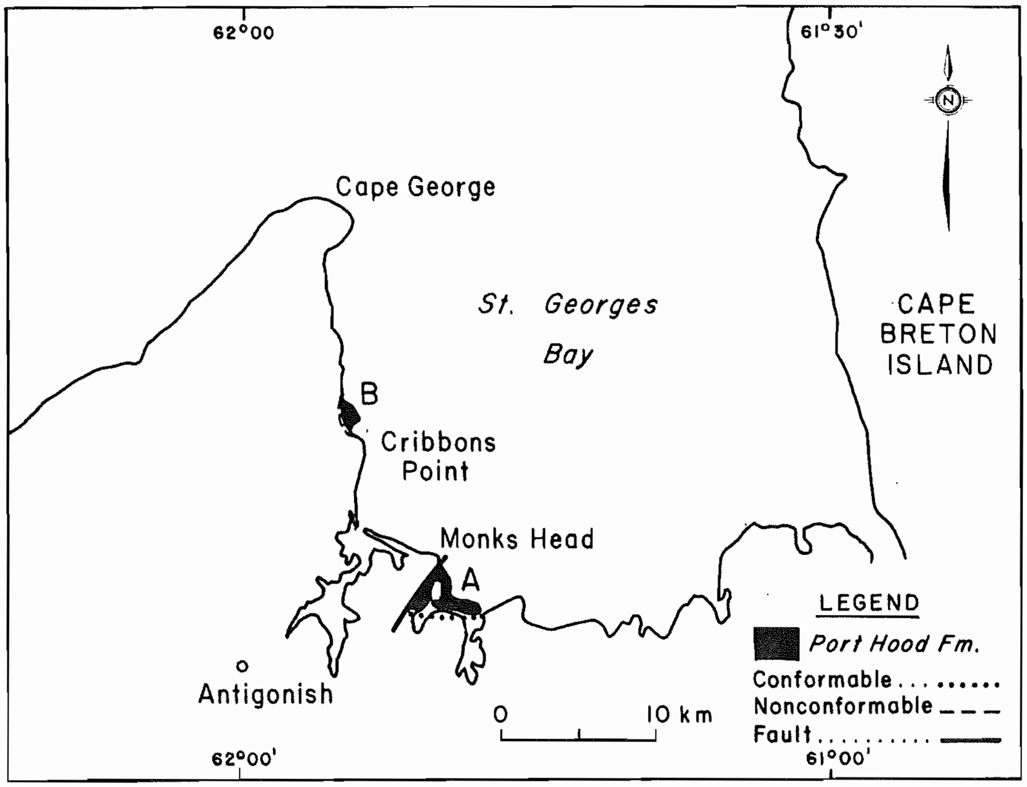


Figure 5.13. Location map of the Port Hood Formation in the Antigonish Basin.

present at Monks Head (Belt, 1965).

iii) Contact Relationships

At the Monks Head exposure (Fig.5.13, Location A), the lower contact with the Pomquet Formation is conformable to disconformable (Belt, 1964). At Cribbons Point (Fig.5.13, Location B), the Port Hood Formation lies in unconformable contact on basement rock and in angular discordance with the Ogden Brook Formation and the South Lake Creek Formation (Murray, 1960). The upper contact of the formation is a regional erosional surface with Pleistocene glacial deposits.

iv) Age

The Port Hood Formation is generally considered to be Westphalian A in age (Bell, 1944; Hacquebard, 1960; Belt, 1964) based on megaflora and palynomorphs.

v) Lithofacies Descriptions

At Cribbons Point the limited outcrop consists entirely of light brown medium- to coarse-grained pebbly sandstone of lithofacies St, Ss, and Sh. Sedimentary features include large-scale trough cross-stratification (Fig.5.14), abundant erosional surfaces, primary current lineations, and mudstone intraclasts. Large (1-3 m long) plant fragments commonly occur as lag in the sandstones (Fig.5.15). Fine-grained lithofacies were not observed.

At Monks Head, the strata consist of light brown medium-grained sandstone, coarse-grained pebbly sandstone and pebble conglomerate (Fig.5.16). The exposure is composed of short sections of strata interrupted by beach gravel. Lithofacies St, Sh, Gml, and Gt are present. Plant fossils are uncommon. Fine-grained lithofacies were not observed.

vi) Depositional Environment

Deposition of the Port Hood Formation probably occurred in a distal braided river enviromnment. Evidence supporting this interpretation includes (1) the predominance of upper flow regime lithofacies, (2) the occurrence of clast-supported pebble conglomerate, (3) the lack of fining-upward sequences, and (4) the absence or scarcity (no outcrop) of fine-grained lithofacies. These features suggest a low-sinuosity fluvial system exhibiting high sediment discharge within rapidly shifting channels. The Monks Head strata were probably deposited more proximally as suggested by the coarser grade. Although the exposures at Monks Head and Cribbons Point occur at the base of the formation, lateral equivalency is not implied here. Documented onlap in the basin during earlier stages of

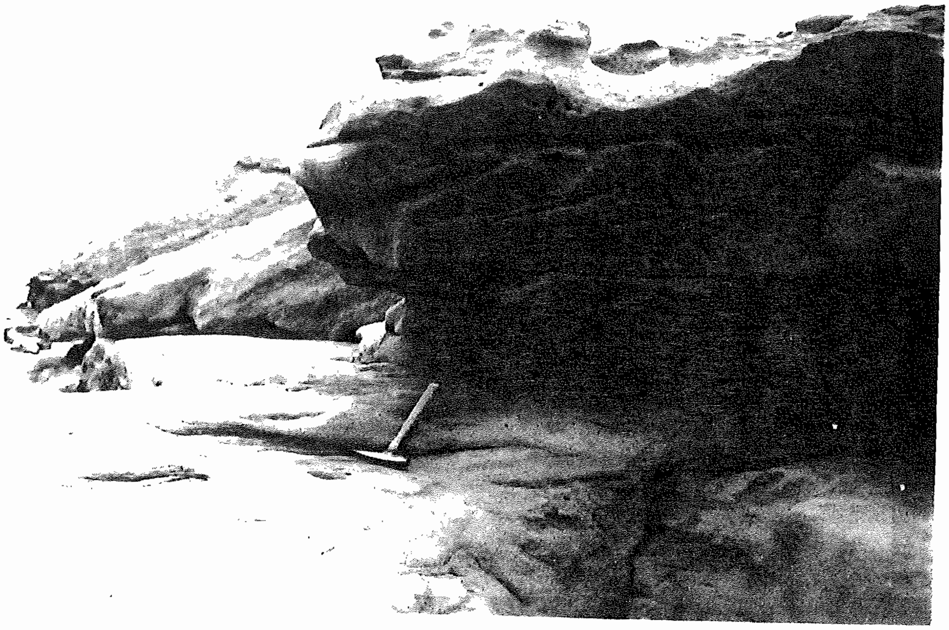


Figure 5.14. Trough cross-bedded sandstone of the Port Hood Formation at Cribbons Point (Location B, Fig.5.13).

Figure 5.15. Large plant fragments as lag in a channel sandstone of the Port Hood Formation at Cribbons Point (Location B, Fig.5.13).

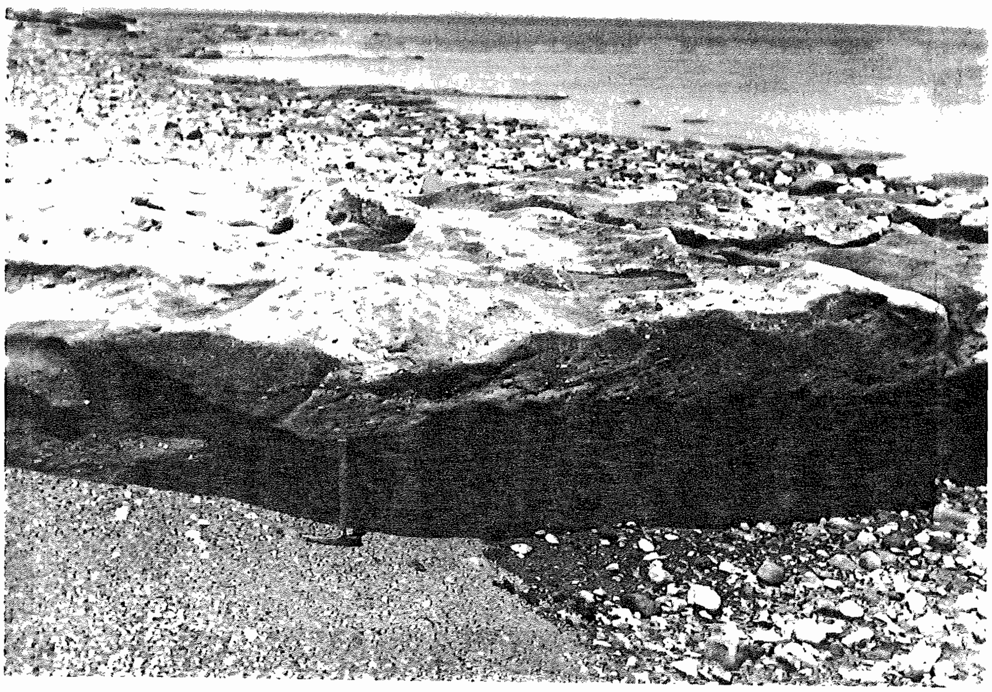


Figure 5.16. Trough cross-bedded pebble congomerate in the Port Hood Formation at Monks Head (Location A, Fig.5.13).

deposition (Boehner, 1980b) may have continued into Riversdale time. Consequently, the strata at the two exposures may have been deposited at very different times.

The abundance of large plant fossils and the pale brown color of the strata suggest that oxidation was of relatively low intensity. Thus climatic conditions were probably more humid and the water tables higher than during Pomquet Formation deposition.

vii) Paleocurrent Analysis

Paleocurrent data from the Port Hood Formation is limited to a few measurements of trough cross-bedding and primary current lineation from the Cribbons Point exposure. A northeasterly paleoflow direction is suggested. Gersib and McCabe (1981) report paleodispersal data from the upper part of the formation at Port Hood which indicates a paleoslope from west to east. However, it is uncertain whether the Port Hood strata were part of the same depositional system as those strata described in this thesis.

vii) Provenance

Detailed sampling of the formation's conglomerates was not possible due to poor exposure; however, a sample of 200 clasts at Monks Head was examined to establish the lithological composition (Fig.5.17). The results indicate the presence of quartzite, sandstone, mudstone, and vein quartz. In addition, small amounts of red granite (less than one percent) were observed outside of the sample locations. Some sandstone clasts which are buff-coloured and poorly indurated appear similar in colour and composition to the Port Hood Formation sandstones and may represent reworking. Other sandstone and quartzite clasts are well indurated and unlike any Carboniferous strata observed in the basin. Devono-Carboniferous strata (from Keppie, 1979) to the south and southeast of the basin contain similar rock types, including white quartz veins. However, a major fault (the Glenroy Fault of Boehner and Giles, 1982) separates these rocks from the basin and it is uncertain if the two areas were juxtaposed during Early Westphalian deposition. The presence of granitoid clasts indicates that at least a portion of the source area consists of basement rocks. The quartzite clasts may pre-date the Devono-Carboniferous rocks as well, although the evidence is inconclusive. In conclusion, a source area cannot be clearly identified for this clast assemblage.

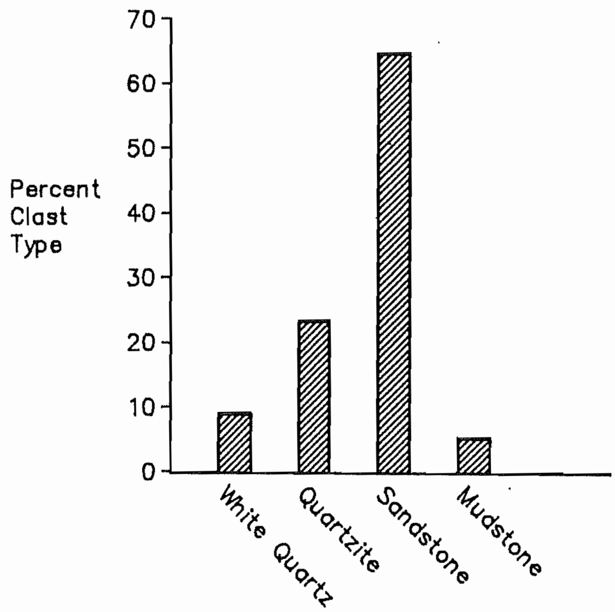


Figure 5.17. Clast composition of the Port Hood Formation at Monks Head (Location A, Fig.5.13). Sample consists of 200 clasts.

CHAPTER VI

SEDIMENTARY TECTONICS

Structure

The structural framework of the Antigonish Basin includes two major elements, the highland blocks and the major faults (Fig.6.1).

The highlands consist of basement rocks of Hadrynian to Silurian age (Murphy, 1984). To the west and northwest of the Antigonish Basin lie the Antigonish Highlands or Browns Mountain Massif of Belt (1968a). To the north of Antigonish and within the basin margins is a small outlier of the Antigonish Highlands, the Morristown Block (Keppie, 1982a). Both of these basement blocks are in unconformable and fault-bounded contact with basin strata (Murray, 1960; Murphy, 1984). Where the contact is unconformable, the strata indicate a progressive onlap.

Two major fault systems, the Chedabucto and Hollow Faults, border the Antigonish Highlands to form a wedge-shaped massif where the faults converge to the west and splay to the northeast (Fig.6.1). The history of activity along the faults is uncertain due largely to poor exposure; however, it is presented in general terms below.

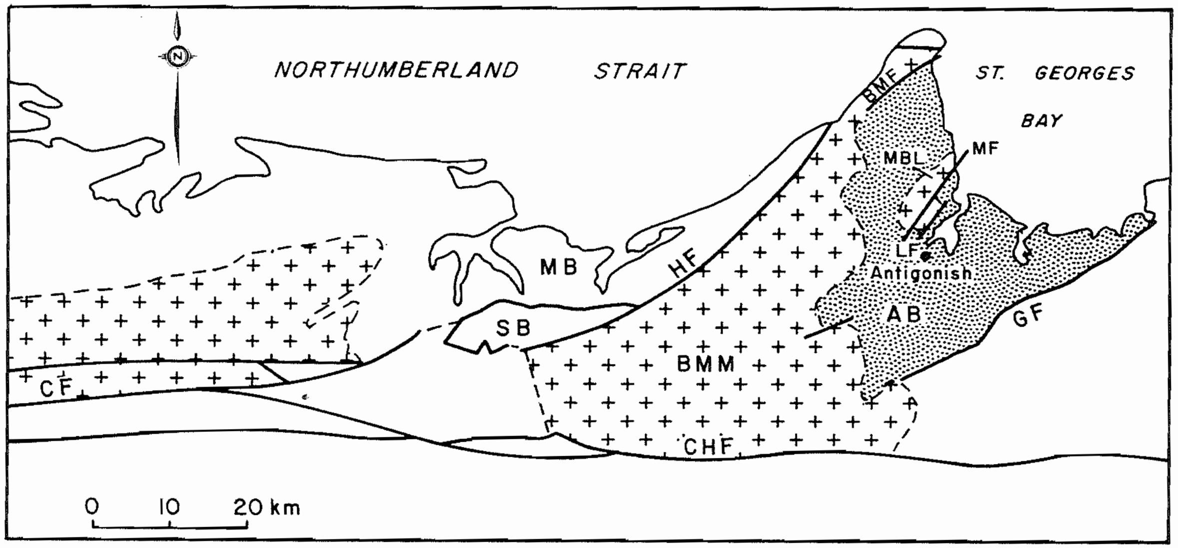


Figure 6.1. Structural features related to the tectonic development of the Antigonish Basin (AB): Cobequid Fault (CF); Chedabucto Fault (CHF); Hollow Fault (HF); Browns Mountain Fault (BMF); Glenroy Fault (GF); Morristown Fault (MF); Lanark Fault (LF); Browns Mountain Massif (BMM); Morristown Block (MBL). Nearby basins influenced by the same structure include the Stellarton Basin (SB) and the Merigomish Basin (MB).

The Chedabucto Fault is an easterly-trending fault zone along which evidence for vertical and horizontal movement has been observed (Eisbacher, 1969; Benson, 1974; Keppie, 1982). However, the major evidence indicates that the fault system is fundamentally of strike-slip origin (Eisbacher, 1969; Yeo, 1985; Mawer and White, 1987). Thus it can be concluded that the Chedabucto Fault is a wrench fault system. It occurs as the easterly component of the Cobequid - Chedabucto Fault System and thus forms part of the boundary separating the Meguma and Avalon Terranes (Keppie, 1982b). Early movement along the fault was primarily dextral (Keppie, 1982b). Fault activity appears to have been initiated in the mid-Devonian (e.g. Keppie, 1982b), with significant phases of activity during the Late Devonian - Early Carboniferous and in the Late Carboniferous (Keppie, 1982b; Yeo, 1985). According to Keppie (1982b) later sinistral movements occurred well into the Mesozoic, apparently related to the opening of the Bay of Fundy. Mawer and White (1987) could not find evidence of major sinistral movement along the Chedabucto Fault System.

The Hollow Fault is a northeasterly trending wrench fault system thought to be related to the Cobequid Fault (Belt, 1968; Eisbacher, 1969; Benson, 1974; Fralick and Schenk, 1981). It separates the Browns Mountain Massif to the east from the Merigomish Basin to the west. Its southwesterly continuation forms the southern margin of the

Stellarton Basin (Yeo and Ruixiang, 1986). Movement along the fault was predominantly dextral with apparent displacement of 20 to 35 km (Yeo and Ruixiang, 1986). Three major episodes of fault activity have been identified. The initial stage occurred in the Middle to Late Devonian with the deposition of the McAras Formation conglomerates and volcanics (Fralick and Schenk, 1981). A second stage in the Late Visean resulted in the deposition of the Hollow Conglomerate and the Lismore Formation (Fralick and Schenk, 1981). The final stage in the Late Westphalian corresponds to the development of the Stellarton Basin, a pull-apart basin filled with deltaic-lacustrine deposits (Fralick and Schenk, 1981; Yeo and Ruixiang, 1986).

Several other high-angle faults are located between the major wrench faults in the Browns Mountain Massif (Murphy, 1984). They run parallel to subparallel to the major faults in a northeast to east direction with movement at least as late as the Devono-Carboniferous (Murphy, 1985). The faults can be traced into the Antigonish Basin (Boehner and Giles, 1982) and include the Browns Mountain, Morristown, Lanark, and Glenroy Faults (Fig.6.1).

<u>Sedimentary History</u>

Table 6.1 summarizes the stratigraphy and sedimentology of the Antigonish Basin. Its history may be divided into

	APPROXIMATE AGE	FORMATION	APPROXIMATE THICKNESS (M)	DEPOSITIONAL[2] ENVIRONMENT(S)	PALEOFLOW DIRECTION	SOURCE AREA	LOCAL TECTONISM
	WESTPHALIAN A	PORT HOOD	200	BRAIDED FLUVIAL	UNKNOWN	UNKNOWN	
CARBONIFEROUS	NAMURIAN	POMQUET	5400	MEANDERING FLUVIAL	NE	UNKNOWN[4]	TECTONIC
CARBONIFEROUS	NAMURIAN	HASTINGS	700	LACUSTRINE, MEANDERING FLUVIAL	NW TO E[1]	UNKNOWN[4]	
CARBONIFEROUS	VISEAN	WINDSOR (GROUP)	1000	MARINE, MARGINAL MARINE, COASTAL PLAIN	UNKNOWN	UNKNOWN[4]	QUIESCENCE
CARBONIFEROUS	—?—?—?—?—	WILKIE[5] BROOK	200	ALLUVIAL FAN BRAIDED FLUVIAL MEANDERING FLUVIAL LACUSTRINE	ENE	BROWNS MOUNTAIN MASSIF	
CARBONIFEROUS	TOURNAISIAN	RIGHTS[5] RIVER	>1200	ALLUVIAL FAN RIVER[3] LACUSTRINE[3]	NE	BROWNS MOUNTAIN MASSIF	TECTONICALLY
	MIDDLE -LATE	SOUTH LAKE CREEK	500	BRAIDED, EPHEMERAL MEANDERING LACUSTRINE VOLCANICS[1]	WNW[1]	UNKNOWN	ACTIVE
	DEVONIAN	OGDEN BROOK	2000	ALLUVIAL FANS	NE	BROWNS MOUNTAIN MASSIF	

1. EVIDENCE INCONCLUSIVE
2. NO SEQUENCE IMPLIED WITHIN GROUPS/FORMATIONS
3. MINOR COMPONENT
4. PROBABLY WELL BEYOND BASIN MARGINS
5. MAY BE LATERAL EQUIVALENTS

Table 6.1. A summary of Late Paleozoic deposition in the Antigonish Basin.

two stages, an initial period of predominantly coarse clastic deposition associated with the basin margins (Middle Devonian to Tournaisian) and a later period characterized by generally fine-grained deposition related to more regional tectonic events (Visean to Early Westphalian).

Sedimentation began in the Middle to Late Devonian with the deposition of the Ogden Brook Formation alluvial-fan deposits. Approximately 2 km of coarse clastics were deposited along the basin margin at this time. Based on paleocurrent data and clast lithology, the source of these sedimentary rocks was the Browns Mountain Massif, an uplifted block which shed sediments to the northeast. This block was to become the major source of detritus at the Antigonish Basin margins. A fining upward of the Odgen Brook alluvial-fan deposits was accompanied by late stage intertonguing with fluvial sediments of the South Lake Creek Formation. This indicates a retreat of the alluvial-fan environment, probably in conjunction with subdued relief and/or decreased uplift of the Browns Mountain Massif.

The Late Devonian South Lake Creek Formation may represent a period of relative tectonic quiesence when braided and meandering rivers and lakes covered the basin floor with at least 0.5 km of sediment being deposited. The provenance of the South Lake Creek is unknown; however, the paleocurrent data suggest a flow transverse to the alluvial fans, probably as a trunk river system. It is speculated that this drainage system was also present in the central regions of the basin throughout the deposition of the Ogden Brook Formation and the overlying Rights River Formation; therefore, it may not necessarily represent tectonic stability as suggested but may be a feature of varying paleogeography. The limited amount of interbedded volcanics in the South Lake Creek Formation observed by Murray (1960) probably came from dilation zones associated with the major faults.

In the Tournaisian the Rights River Formation dominated the basin margins with renewed alluvial-fan activity in conjunction with another episode of uplift of the Browns Mountain Massif. Progradation of the fan system continued throughout deposition of the Rights River Formation with at least 1 km of sediment being deposited. The upper contact with the overlying Windsor Group marine carbonates is abrupt and may reflect either continuous deposition during a rapid marine transgression or a period of non-deposition and/or erosion prior to marine incursion.

The Wilkie Brook Formation may or may not represent a third stage of uplift and fan deposition prior to or during the marine invasion (see Murray, 1960; Schenk, 1975; previous discussion in this thesis). If it is laterally continuous with the Rights River Formation, as suggested here, its 0.2 km thickness and northeast position relative to the Rights River Formation exposures would be consistent with a pinching out of the Rights River alluvial-fan system at a distal location along the paleoslope. Irrespective of its stratigraphic position, the Wilkie Brook Formation indicates that high sinuosity rivers and saline lakes were present toward the basin centre. The Rights River and Wilkie Brook Formations mark the final stage(s) of coarse clastic deposition in the Antigonish Basin. Correspondingly, uplift and unroofing of the Browns Mountain Massif appear to have ceased after this time.

In the Visean, the Windsor Group marine/nonmarine strata mark the beginning of a period during which predominantly fine-grained siliciclastic sediments and marine evaporites were deposited in the basin, a trend which continued into Early Westphalian. A shallow sea invaded the basin, repeatedly transgressing across a coastal floodplain, perhaps as many as a dozen times and depositing at least a kilometre of sediment. The cyclicity of these deposits suggests a delicate equilibrium between sediment supply and subsidence, possibly in combination with eustatic rises in sea level (Schenk, 1969; Giles, 1981). Exclusion of the marine environment from the basin occurred in the Namurian with the deposition of the Hastings Formation. The low areas formerly occupied by the shallow seas became a natural site for saline lakes to develop. Thus, the Hastings

Formation represents an extensive lake system covering most of the basin and bordered by floodplains, the two types of deposits interfingering over a thickness of 0.7 km. This cyclicity may have been the result of expansion/contraction of the lake system due to climatic changes or possibly more regional tectonic events which periodically produced increased clastic output from the hinterland. Because the cyclicity in the Hastings Formation immediately followed that of the Windsor Group, it is suggested here that the same mechanism may have been responsible for both. The regional tectonism accompanied by periodic increased clastic output and continuous subsidence was probably the major cause for the cyclicity.

During the Late Namurian/Early Westphalian, the lakes were succeeded by a meandering river/floodplain system when as much as 5 km of sediment were deposited as the Pomquet Formation. This may represent a period of regional tectonism and increased clastic output from the hinterland similar to suggestions by Belt (1965). The result was the deposition of one of the thickest fluvial sequences known in the Fundy Basin, probably in conjunction with rapid, continuous subsidence.

The final episode of deposition in the basin occurred during Westphalian A when a braided river system deposited more than 0.2 km of sediment (the Port Hood Formation). The abrupt contact with the underlying Pomquet Formation records a dramatic change in deposition which may or may not indicate an intervening period of non-deposition and/or erosion. The source of these coarse sandstones and pebble conglomerates, the clasts of which are composed mainly of sandstones and quartzites, is uncertain; they may represent reworking within the basin in part or a source beyond its margins. Belt (1965) suggested a regional mechanism whereby uplifted platforms around the Fundy Basin were responsible for this deposition.

Because the rock record is incomplete due to erosion, it is uncertain whether deposition in the Antigonish Basin continued beyond the early Westphalian. Some of the other basins in the Fundy Basin System, however, exhibit deposition at least until the end of the Carboniferous (e.g. Fralick and Schenk, 1981; Yeo, 1985). Thus sediments in the Antigonish Basin may have continued to accumulate but were subsequently eroded. Evidence is lacking to support or refute this.

Stratigraphic Thickness

Table 6.1 indicates that the cumulative thickness for the strata in the Antigonish Basin is 11 km. This is very large for a sedimentary basin, although fills of 10 km in thickness are observed elsewhere (e.g. Link and Osborne, 1978; Trevena and Clark, 1986). The author suggests that the true thickness may be substantially less than indicated here, based on the following reasons: (1) The unit thicknesses shown in Table 6.1 are maximum thicknesses in the basin and it is unlikely that they would be found together in a vertical succession. (2) Some of the units (e.g. Rights River Formation and Wilkie Brook Formation) may be lateral equivalents. (3) Authors who reported the measured thicknesses did not have good structural control in the measured areas, thus the extensive faulting observed in the basin (see Boehner and Giles, 1982a) may have resulted in the duplication of strata in the calculations. (4) Some of the observed thicknesses may be apparent due to lateral opening and shifting depocentres similar to the Hornelen Basin where 25 km of strata are observed (Steel, 1976).

It should be noted that although the basin thickness is probably less than indicated in Table 6.1, there may be older strata deeper in the basin which are not exposed that would add to the total thickness.

Tectonic Development

The tectonic history of the Antigonish Basin may be generally divided into two stages corresponding to sedimentation patterns: (1) an initial period of tectonic activity accompanying prolonged movement along the major faults; and (2) a subsequent period of tectonic quiescence when the major faults were relatively inactive.

Initial basement faulting and differential movement of basement blocks to form the Antigonish Basin occurred in the Middle to Late Devonian. This time frame corresponds to regional northwest - southeast compressional stress patterns (Yeo and Ruixiang, 1986) which developed immediately following continental collision and the peak of orogenic activity during the Acadian Orogeny (Bradley, 1983; Faill, 1985; Tankard, 1986). The Hollow and Chedabucto Faults, or related adjacent, parallel faults, probably formed the basin margins, producing a splay system which defined the Browns Mountain Massif and the newly formed Antigonish Basin. Evidence for similar splayed faults systems in the Fundy Basin occurs on Cape Breton Island (Bradley and Bradley, 1986; Gibling et al., in press). The northwest - southeast compression which was responsible for these wrench faults also produced zones of compression and extension between them. Where the faults converged, a zone of northwest-southeast compression resulted in uplift of the Browns Mountain Massif. This compression was noted by Murphy (1985) who described these highlands as being caught in a "vice". Where the faults diverged to the northeast, a zone of extension resulted in downwarping accompanied by the development of a sedimentary basin, the Antigonish Basin. Note that the median direction between the two major faults in the direction of splay is roughly northeast (Fig.6.1) which compares favourably to the major drainage direction as determined by the paleocurrent data. Compression and uplift continued into the Tournaisian or Early Visean with continued pulses from the alluvial-fan system. This activity declined in the Visean, probably corresponding to a period when only the Hollow Fault was in motion (Yeo, 1985). The result was a period of tectonic quiescence extending from the Visean to the Westphalian A. During this time steady basinal subsidence predominated, accompanied by continued deposition. The Antigonish Basin probably ceased to exist as a structural entity. Former source areas remained worn down although topographic relief was still significant. Distant source areas became dominant over local sources, resulting in more regional trends in sedimentation. The subdued local topography, the distant source areas and similar trends in sedimentation in some of the other basins at this time suggests that the component basins of the Fundy Basin were probably interconnected and fed sediment by the same regional fluvial systems.

Tectonic Model

The most recent studies of the Fundy Basin indicate that it developed within a wrench fault regime (e.g. Belt, 1968a; Fralick and Schenk, 1981; Hyde and Ware, 1981; Bradley, 1982; Bradley and Bradley, 1986; Yeo and Ruixiang, 1986; Mawer and White, 1987; Gibling et al., in press). Therefore, it makes sense to use wrench fault models to explain the tectonic development of the Antigonish Basin. Studies by Crowell (1974a, 1974b, 1976) provide many possible models to explain uplift and subsidence for wrench fault basins and therefore form the basis for interpretations presented in this thesis.

The only previous attempt to explain the tectonic development of the Antigonish Basin was by Fralick (1980), who briefly discussed a rotated block model based on his study of the adjoining Merigomish Basin. According to this model the Browns Mountain Massif became a positive area and the Antigonish Basin a negative area through compression/extension and the rotation of a single basement block caught between major wrench faults. Based on source area location and drainage directions in the Antigonish Basin as determined in this thesis, the author considers this model to provide a suitable mechanism for its development. However, based on modelling by Crowell (1974) and the geometry of the Antigonish Basin, the fault-wedge model is favoured here.

The fault-wedge model is specifically associated with anastomosing fault systems within strike-slip fault regimes (Crowell, 1974b; Reading, 1980). Using Crowell's (1974b) model (Fig.6.2), a basin develops between splayed wrench faults. Where the splay converges, a zone of compression and uplift such as the Browns Mountain Massif occurs (Fig.6.3). Where the splay diverges, extension and downwarping causes a depression such as the Antigonish Basin. More recent examples of fault-wedge basins in a strike-slip regime are observed in Haiti (Mann and Burke, 1982) and California (Crowell, 1976). Although the Pliocene basins described by Mann and Burke (1982) are much smaller than the Antigonish Basin, they do contain a similar sedimentary fill consisting of conglomerates that fine into lacustrine/floodbasin muds in a direction where the basin widens.

The stratigraphic onlap observed against the Browns Mountain Massif should occur using this model. The implication of the onlap is that the massif was progressively buried under its own detritus as uplift and downwarping continued.

There are problems associated with using the fault-wedge model for the Antigonish Basin. Firstly, there

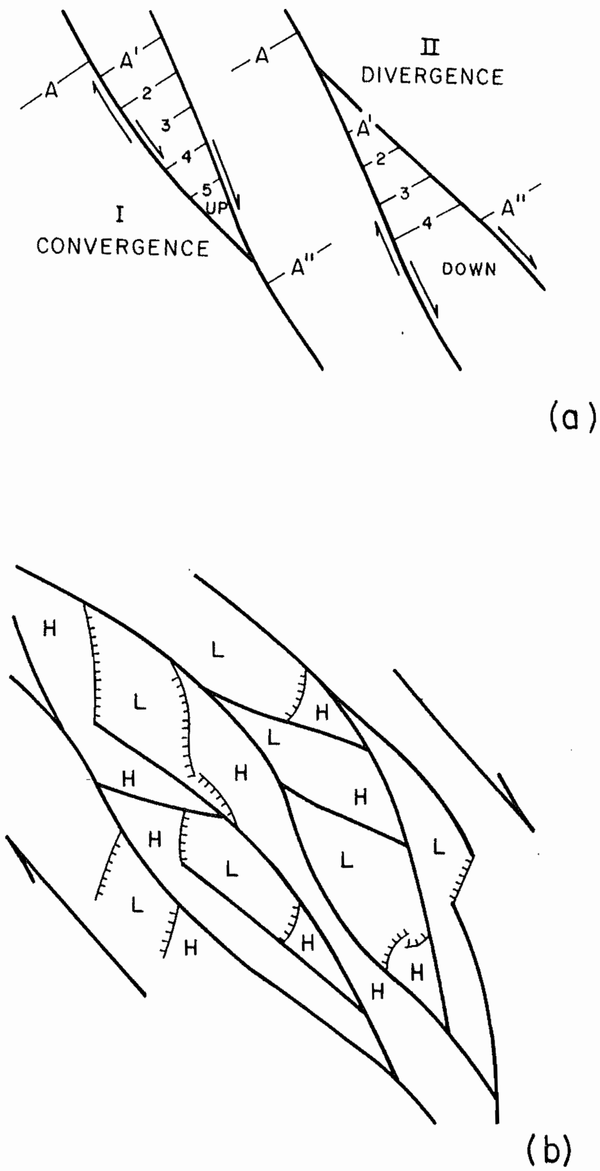


Figure 6.2. (a) Fault-wedge basin development between splaying dextral strike-slip faults. Uplift occurs where faults converge; subsidence where faults diverge (Crowell, 1974b). (b) Coexistence of tipped fault-wedge and pull-apart basins within an anastomosing strike-slip fault system (Crowell, 1974b).

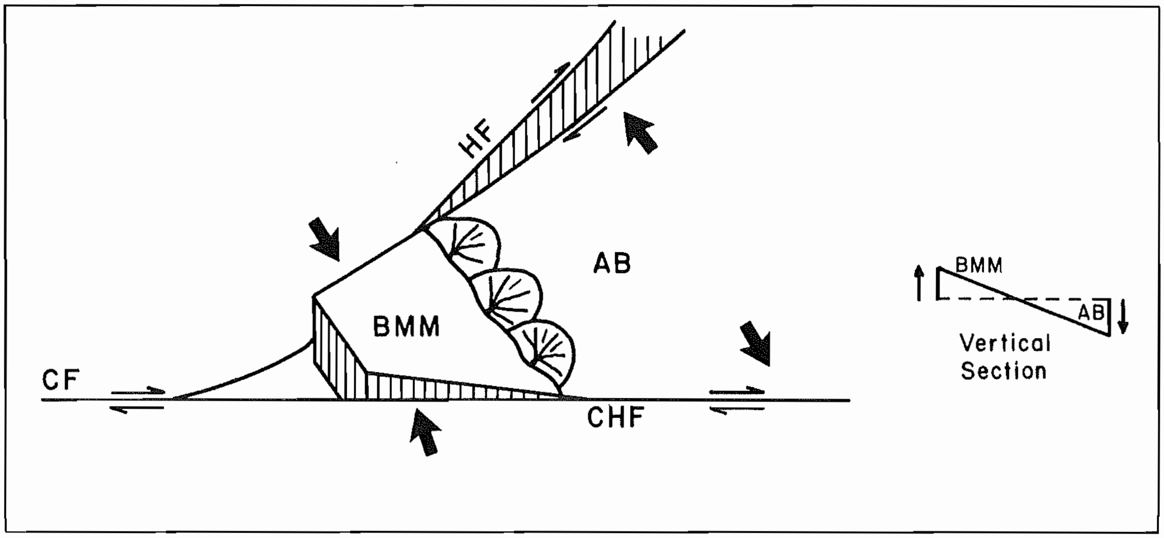


Figure 6.3. Application of Crowell's (1974b) fault-wedge model to the Antigonish Basin (AB). Arrows indicate zones of compression and extension between splaying faults. Cobequid Fault (CF); Chedabucto Fault (CHF); Hollow Fault (HF); Browns Mountain Massif (BMM).

is scale. The few fault-wedge basins which have been described (e.g. Crowell, 1976; Mann and Burke, 1982) are very small by comparison. Larger fault-wedge basins do exist in California; however, few studies are available for reference. Secondly, there is a problem of volume in sediment transfer from a relatively small uplift (the Browns Mountain Massif) to a large deep basin. It is unlikely that the highlands could have supplied the large sediment pile which accumulated in the basin early in its history. One explanation is the possible existence of large trunk river systems which may have filled the more central regions of the basin but now occur beyond the limits of exposure. The South Lake Creek Formation may be evidence for such deposition. In conclusion, this is a simple model for the basin and stands up as far as our information goes.

The division of the Antigonish Basin into two stages of development roughly fits Bradley's (1982) extensional rift model of Fundy Basin subsidence based on McKenzie's (1978) model. The Antigonish Basin's tectonically active period (Middle Devonain to Tournaisian) corresponds well with Bradley's initial stretching phase which was fault controlled with local sources, rapid subsidence and periodic volcanism. Sedimentation in the Antigonish Basin was rapid at this time with an abundance of alluvial fan deposition related to local source areas. It can be traced to the activity of major wrench faults during rifting. The minor interbedded volcanics described in the basin (Fletcher and Faribault, 1887; Murray, 1960) occurred during the tectonically active period as well and fit with a mechanism of extension and thinning. The basin's later stage of tectonic quiescence (Visean to Early Westphalian) corresponds to Bradley's gradual thermal subsidence phase, when deposition expanded to cover the basin margins. Alluvial plain sedimentation related to regional sources predominated, implying a waning of tectonism in the Visean.

There are also problems associated with a comparison of the Antigonish Basin and Bradley's (1982) model which are discussed as follows. (1) The Canso Group succession is a very thick sedimentary pile by comparison with other sedimentary basins in the Atlantic region. This implies that, in contrast to the gradual subsidence indicated by Bradley's model, active subsidence was occurring in the Antigonish Basin at this time. (2) The Riversdale Group is substantially coarser than the underlying Canso Group with a sharp contact occurring between the two. This suggests that some renewed tectonic activity may have occurred in Early Westphalian time. Both problems indicate that tectonism may not have waned entirely in the area, thus they may represent some of the complications in the model discussed by Bradley (1982). Gibling et al. (in press) expressed similar reservations with Bradley's model based on a study of the Sydney Basin. They provide evidence which suggests that the period of thermal subsidence may have been more complex than Bradley indicated, probably in association with increased tectonism.

The Morristown Block (Fig.6.1) appears to have been a positive structure thoughout much of the evolution of the Antigonish Basin, as indicated by the unconformities between major stratigraphic units in the vicinity of the block (see Boehner, 1982b) and thinning of major stratigraphic units such as the Rights River Formation against the block (e.g. Murray, 1960). Furthermore, rock types observed by the author in the block are similar to the clast types in the alluvial-fan deposits. Therefore, the block may have been a source for some of these sedimentary rocks. Two high-angled, northeasterly-trending faults at the southern margin of the block, the Morristown and Lanark Faults (Fig.6.1), may provide evidence for the mechanism of uplift, if they were active during the Late Devonian-Early Carboniferous. Using the fault-wedge model within a strike-slip fault zone, two major compressive forces would be applied to the basement block caught between the splay faults: north/south compression due to the wrench faults and northeast/southwest compression as the block encountered resistance at its ends during the rotation-like movement. This would induce strain release through faulting, probably in a direction similar to the Morristown and Lanark Faults. The result would be fragmentation of the wedge block and localized uplift in the basin such as observed in the Morristown Block. This may have the implication that the Horton and Windsor Groups were deposited in smaller depocentres between uplifted blocks; however, evidence substantiating this is lacking.

Regional Implications

Nova Scotia consists of two distinct tectonolithologic terranes, the Avalon and Meguma Terranes, separated by the Cobequid - Chedabucto Fault System. To the north is the Avalon Terrane, a Late Precambrian - Early Paleozoic microcontinent characterized by volcanic and metasedimentary rocks. To the south is the Meguma Terrane, characterized by a thick Cambro - Ordovician continental margin/turbidite sequence (Schenk, 1971). Both terranes are considered to be formerly a part of Gondwana (Schenk, 1981). During the Acadian Orogeny in the mid - Devonian, the Meguma and Avalon Terranes were accreted to the North America plate (Bradley, 1983). The Acadian Orogeny represents part of the much larger collision between cratonic North America and the Gondwana continent (Tankard, 1986) which continued until suturing of the plates was completed in the Late Carboniferous to Permian (Keppie, 1985). The Acadian Orogeny was responsible for regional folding, metamorphism, and igneous intrusion in Atlantic Canada. In addition to this main collision (in the mid- Devonian), there was later shearing along a major northeast - southwest fault system (during the Devonian - Carboniferous). Examination of the penetrative deformation associated with part of this shear system by Eisbacher (1969) indicates a primary compressive stress oriented in a northwest southeast direction. Early work by Webb (1967) and Belt (1968a) suggested that the shearing was part of a transcurrent fault zone largely controlled by wrench faults. Subsequent work by Yeo and Ruixiang (1986) and Mawer and White (1987) provides strong evidence of a strike-slip history within the fault zone. Belt (1968a) proposed that strike-slip movement along the shear was responsible for the development of the interconnected fault-bounded basins forming the Fundy Basin System in which thick Devonian - Carboniferous strata were deposited. Although the term "rift" was inappropriately applied to this system by Belt (Fralick, 1980), the transform fault mechanism was an important advance in the understanding of the Carboniferous of eastern North America. Since that time evidence supporting a transpression/trantension regime has been mounting with several strike-slip related basins being identified (McMaster et al., 1980; Fralick and Schenk, 1981; Bradley, 1982; Hyde, 1984; Yeo, 1985; Bradley and Bradley, 1986; Gibling et al., in press). The Antigonish Basin, as a fault-wedge basin, fits well within this framework. Both pull-apart and fault-wedge basins are commonly found in strike-slip fault zones (Reading, 1980). The Cenozoic wrench fault system found along the San Andreas Fault System in southern California has generated numerous pull-apart and fault-wedge basins (Crowell, 1974b).

The initial basement fragmentation and sedimentation in the Antigonish Basin corresponds in time to the initial development of the Fundy Basin. The northwest-southeast compression experienced in the Antigonish Basin is also consistent with the more regional trend in the Fundy Basin System. As for a comparision with the adjoining basins, the early development of the Antigonish Basin compares favourably with that of the Merigomish Basin to the west (Fig.6.1). Both contain abundant fanglomerates which were deposited in the Devonian (see Fralick and Schenk, 1981). Although there is a scarcity of volcanics in the lower stratigraphy of the Antigonish Basin as compared to the Merigomish Basin, this may reflect distance from a potential source (e.g. a dilated fault zone) or that the volcanics exist deeper in the sedimentary pile in the Antigonish Basin where they are not exposed (e.g. under St. George's Bay). Deviations in sedimentary histories of the two occur mainly after the Devonian, when the Hollow Fault exerted greater influence on the Merigomish Basin. The adjacent Stellarton Basin (Fig.6.1) had its beginnings in the Visean with the greatest volume of sediments occurring after deposition had apparently ceased in the Antigonish Basin. Although the Chedabucto and Hollow Faults were active concurrently during much of the Westphalian (Yeo, 1985), there is no evidence of this activity in the Antigonish Basin. The variation in development seen in these three basins represents a very local scale. On a regional scale, variation in basin style is equally pronounced as illustrated in an examination of the northern Appalachians (Table 1 of Bradley, 1982). Differences in basin size, thickness, and stratigraphic composition, as observed in the Fundy Basin System both locally and regionally, are typical of wrench fault systems which are dynamic regimes where zones of transpression and transtension are constantly shifting (e.g. Howell et al., 1980).

Areas For Future Study

This study represents a general view of the southwestern portion of the Antigonish Basin based on limited stratigraphic and structural control. In conclusion, the author would like to suggest areas for future consideration where this model may be tested. They are listed below.

(1) The northeast drainage direction in the basin suggests that the more central regions of the former depositional basin underlie St. George's Bay. This area should contain a thickening sedimentary pile composed of fine-grained basin floor deposits. Because oil shale and coal are locally present in the basin, this area should be carefully examined

for future economic potential.

(2) The precise paleomargins of the depositional basin are unknown; however, the fault-wedge model would predict locallized alluvial-fan development along the sinking margins of the splay faults. Devono-Carboniferous strata occur in abundance both north of the study area between the Browns Mountain and Hollow Faults and south between the Glenroy and Chedabucto Faults. A preliminary examination of these rocks by the author suggests that they are significantly different from the stratigraphy presented in this thesis. Thus, it would be interesting to study these rocks to determine their relationship with the Antigonish Basin.

(3) The fault-wedge model predicts that the splayed faults within an anastomosing fault system eventually converge or are truncated by another fault (Crowell, 1974b). The transform faults at the margins of the Antigonish Basin may converge or be truncated by another fault on southwestern Cape Breton Island adjacent to the Craignish Hills. Fault patterns observed in this area (Keppie, 1982a) suggest a predominant northwest - southeast to north - south shear direction. However, evidence of a fundamental fault is not observed, possibly due to burial. The relationship between the Antigonish Basin and the Ainslie area of Cape Breton is far from clear, although the two have been interpreted as portions of a component basin (Bell, 1958). An examination

of the Devonian and Carboniferous strata in southwestern Cape Bretion Island is important to determine if this area can be correlated with the Antigonish Basin and whether it fits a fault-wedge setting.

APPENDIX I

LOCATION DESCRIPTIONS OF STRATIGRAPHIC SECTIONS

Sections consist of all outcrop exposure at described location unless otherwise indicated. The base or top of the sections is indicated where necessary.

Section 1: (45 degrees 43'57''N, 61 degrees 55'07''W)
Ogden Brook Formation. Crystal Cliffs area; along Ogden Brook 1800 m upstream from intersection of brook and Route 337.

Section 2: (45 degrees 43'51''N, 61 degrees 56'20''W)
Ogden Brook Formation. Crystal Cliffs area; along Ogden Brook 3900 m upstream from intersection of brook and Route 337.

Section 3: (45 degrees 43'31''N, 61 degrees 57'11''W)
Ogden Brook Formation. Crystal Cliffs area; along Ogden Brook 5500 m upstream from intersection of brook and Route 337; downstream 100 m from major fork of brook.

Section 4: (45 degrees 51'12''N, 61 degrees 55'24''W)
South Lake Creek Formation. Cape George area; along shoreline 300 m north of mouth of Wilkie Brook below unconformity (= top); continues south along shoreline to Graham Brook.

Section 5: (45 degrees 46'17''N, 61 degrees 54'37''W)
South Lake Creek Formation. Lakevale area; along shoreline at first appearance of outcrop immediately north of beach at South Lake Creek (= base); continues north along shoreline

approximately 800 m to first major point of land; top of described section arbitrary point as exposure continues up section.

Section 6: (45 degrees 41'00''N, 62 degrees 01'41''W)
South Lake Creek Formation. North Grant area; approximately 1600 m north of North Grant and 250 m east of Highway 245 along Rights River at Arsenault's sandstone quarry.

Section 7: (45 degrees 38'07''N, 62 degrees 01'00''W)
Rights River Formation. Northwest of the Antigonish town limits; begins on downstream side of bridge where Highway 245 intersects with South Rights River (= top); continues downstream to intersection of river and railway bridge.

Section 8: (45 degrees 38'21''N, 62 degrees 01'18''W)
Rights River Formation. Northwest of the Antigonish town limits; on Rights River 360 m upstream from fork with South Rights River (= top); includes all outcrop on river bank upstream from this point.

Section 9: (45 degrees 51'12''N, 61 degrees 55'24''W)
Wilkie Brook Formation. Same location as South Lake Creek Formation Section A but above unconformity (= base); continues NNE along shoreline 400 m to prominent point of land, then NNW 300 m along shoreline; top of section occurs near thick, vuggy, brecciated limestone.

Section 10: (45 degrees 36'06''N, 61 degrees 38'04''W)

Windsor Group. Monastery area; at St. Augustine Monastery 100 m downstream from intersection of bridge and Monastery Brook (= top).

Section 11: (45 degrees 38'01''N, 61 degrees 43'20''W) Pomquet Formation. Bayfield area; first appearance of continuous outcrop along shoreline west of Rileys Beach between Bayfield and Quarry Point (= base).

APPENDIX II

MARKOV CHAIN ANALYSIS

An excellent discussion of Markov Chain analysis has been provided by Miall (1973); however, a summary of the technique as it is applied to this study is presented here. In brief, Markov Chain analysis is a statistical tool for determining repetitive processes, in this case cyclicity in sedimentary successions. The technique involves the examination of lithological transitions between a given lithofacies and the adjacent overlying one within a stratigraphic column. Miall (1973) described two methods for sampling the column. Method 1 involves the counting of all transitions between different lithofacies within the section, regardless of the thickness of the lithofacies unit. It presents the actual sequence of lithofacies as they were deposited. Method 2 samples the section at regular fixed intervals, providing a better measure of the frequency of the lithofacies present, but disregarding the actual sequence of depositional events.

Method 1 is used in this study. It consists of five steps, designated in the computed results which follow using corresponding numbers.

(1) A transition count matrix is constructed in which all transitions between different lithofacies in a stratigraphic section are recorded and tabulated. The individual elements in the matrix are referred to as f_{ij},

<u>where</u> i = row number

j = column number

(2) A random probability matrix determines the probability of a given transition occurring randomly (rij) based on the proportion of lithofacies present.

formula rij = sj/t

where sj = sum of fij for the jth column

t = total number of lithofacies units in the section

(3) An actual probabilities matrix shows the actual probablity (pij) of a given transition occurring in the section.

formula pij = fij/sij

where sij = sum of fij for the ith column

(4) A difference matrix determines which of the transitions in the section occur with a greater frequency than when generated randomly. This is calculated by finding the difference (dij) between the actual probability and the random probability of a transition occurring.

formula dij = pij - rij

The positive entries in the difference matrix are used to construct a flow diagram illustrating relationships among lithofacies.

Transitions between lithofacies separated by a fault or a gap in the section are not included in the calculations. The analysis is applied only to those sections where the technique appeared beneficial. It should be noted that

Reading (1978) presents valid criticisms of the Markov process but points out that the problems can be largely overcome by inspection of the raw data after the statistical computation.

SECTION 4

(1)

	GM1	GT	ST	SH2	SR	FM	TOTAL
GM1		--	3	8	--	3	14
GT	--		--	--	--	2	2
ST	--	--		2	1	3	6
SH2	--	--	1		4	11	16
SR	1	--	1	2		1	5
FM	13	2	2	4	--		21
TOTAL	14	2	7	16	5	20	64

(2)

	GM1	GT	ST	SH2	SR	FM
GM1		--	.214	.571	--	.214
GT	--		--	--	--	1.000
ST	--	--		.333	.166	.500
SH2	--	--	.063		.250	.688
SR	.200	--	.200	.400		.200
FM	.619	.095	.095	.190	--	

(3)

	GM1	GT	ST	SH2	SR	FM
GM1		.040	.140	.320	.100	.400
GT	.225		.112	.258	.081	.323
ST	.241	.034		.276	.086	.345
SH2	.292	.042	.146		.104	.417
SR	.237	.034	.119	.271		.339
FM	.326	.047	.163	.372	.116	

(4)

	GM1	GT	ST	SH2	SR	FM
GM1		-.040	.074	.251	-.100	-.186
GT	-.225		-.112	-.258	-.081	.677
ST	-.241	-.034		.057	.080	.155
SH2	-.292	-.042	-.083		.146	.271
SR	-.037	-.034	.081	.129		-.139
FM	.293	-.048	-.068	-.182	-.116	

SECTION 5

(1)

	GM2	SS	ST	SH2	SR	FM	TOTAL
GM2		--	2	1	--	1	4
SS	--		--	1	--	--	1
ST	1	--		5	2	6	14
SH2	2	1	4		3	3	13
SR	--	--	--	4		1	5
FM	1	--	8	1	--		10
TOTAL	4	1	14	12	5	11	47

(2)

	GM2	SS	ST	SH2	SR	FM
GM2		--	.500	.250	--	.250
SS	--		--	1.000	--	--
ST	.071	--		.357	.143	.429
SH2	.154	.077	.308		.231	.231
SR	--	--	--	.800		.200
FM	.100	--	.800	.100	--	

(3)

	GM2	SS	ST	SH2	SR	FM
GM2		.023	.326	.279	.116	.256
SS	.087		.304	.261	.109	.239
ST	.121	.030		.364	.152	.333
SH2	.118	.029	.412		.147	.324
SR	.095	.024	.333	.800		.261
FM	.108	.027	.378	.324	.135	

(4)

	GM2	SS	ST	SH2	SR	FM
GM2		-.023	.174	-.029	-.116	-.006
SS	-.087		-.304	.739	-.109	-.239
ST	-.050	-.030		-.007	-.009	.096
SH2	.036	.048	-.104		.084	-.093
SR	-.095	-.024	-.333	.514		-.061
FM	-.008	-.027	.422	-.224	-.135	

SECTION 11

(1)

	GM2	ST	SR	SH2	FL	FM	TOTAL
GM2		4	1	1	--	--	6
ST	2		5	2	--	--	9
SR	--	1		5	1	32	39
SH2	2	1	6		--	27	36
FL	--	--	1	--		4	5
FM	2	3	27	26	4		62
TOTAL	6	9	40	34	5	63	157

(2)

	GM2	ST	SR	SH2	FL	FM
GM2		.666	.167	.167	--	--
ST	.222		.555	.222	--	--
SR	--	.026		.128	.026	.821
SH2	.056	.028	.167		--	.750
FL	--	--	.200	--		.800
FM	.032	.048	.435	.419	.065	

(3)

	GM2	ST	SR	SH2	FL	FM
GM2		.059	.265	.225	.033	.417
ST	.041		.270	.230	.034	.426
SR	.051	.076		.288	.042	.534
SH2	.050	.074	.331		.041	.521
FL	.039	.059	.263	.224		.414
FM	.063	.095	.421	.358	.053	

(4)

	GM2	ST	SR	SH2	FL	FM
GM2		.607	-.088	-.058	-.033	-.417
ST	.181		.285	-.008	-.034	-.426
SR	-.051	-.050		-.160	-.016	.287
SH2	.006	-.046	-.164		-.041	.229
FL	-.039	-.059	-.063	-.224		.386
FM	-.031	-.047	.014	.061	.012	

APPENDIX III

PALEOCURRENT ANALYSIS

Where data are sufficient, an analysis of paleocurrent orientation is presented using methods described by Curray (1956) and Potter and Pettijohn (1977). The application of these statistics is useful in determining if there is a preferred direction for the paleocurrent indicators, the magnitude of this preferred orientation, and the probability that the orientation is other than random.

To determine the preferred direction of the directional indicators, the "grouped data" method described by Potter and Pettijohn (1977) is used. The observations are grouped into 20 degree class intervals with Xi being the midpoint azimuth in the ith interval. Xi can then be considered in terms of a vector which consists of a north-south component (V) and an east-west component (W), each class interval being weighted according to the number of observations (Ni) occurring in it. The components can then be summed to produce a resultant vector (XV). Three equations achieve this result:

$$V = Ni \quad \cos Xi$$

$$W = Ni \quad \sin Xi$$

$$XV = \arctan \quad W/V$$

The magnitude (R) of the resultant vector is then calculated using the following equation:

$$R = (V)(V) + (W)(W)$$

This magnitude can then be expressed in terms of a percent (L) using the total number of observations (N):

$$L = (R/N)100$$

This method cannot be used for axial data because each Xi would be, in effect, plotted and calculated twice in opposite directions. This would have a cancelling effect producing a resultant vector of zero. To remedy this, the interval vector direction (Xi) is doubled in the calculations above. For a detailed discussion of this method, refer to Curray (1956).

To test the significance of the distributions calculated here, the Rayleigh test (Curray, 1956) is used. The method compares the vector magnitude (L) against the total number of observations (N) to establish the probability (P) of obtaining a greater amplitude in a given distribution by randomness. This is accomplished using a graph illustrated by Curray (1956). The critical level of significance used by Curray is P = .05. This means that an empirical distribution is not considered different from a random distribution unless there is less than a 5 percent chance of the distribution being generated randomly.

FORMATION	DATA TYPE	(N)	(XV)	(L)	(R)	(P)	FREQUENCY
PORT HOOD	—	—	—	—	—	—	—
POMQUET	DIRECTIONAL	41	048	64.4	26.41	<.00001	XL(13), PXB(10), TXB(9), FC(8), CC(1)
	AXIAL	69	022/202	43.1	29.71	<.00001	PCL(59), TM(9), FC AXIS (1)
HASTINGS	DIRECTIONAL	14	052	41.3	5.78	>.05	XL(4), PXB(4), FC(3), TM(3)
	AXIAL	17	128/308	29.0	4.92	>.20	TM(8), PCL(7), FC AXES (2)
WINDSOR GP.		—	—	—	—	—	—
WILKIE BK.	DIRECTIONAL	18	073	35.3	6.36	>.05	PXB(7), IMB(5), XL(2), BM(2), TXB(1), FC(1)
	AXIAL	29	029/209	55.1	15.99	<.001	PCL(17), TM(12)
RIGHTS R.	AXIAL	7	040/220	75.2	5.26	—	PCL(7)
S.LAKE CK.	DIRECTIONAL	46	279	35.4	16.27	<.01	TXB(27), PXB(9), XL(7), FC(3)
	AXIAL	135	041/221	7.5	10.15	>.40	PCL(128), TXB AXES(3), FC(2), TM(2)
OGDEN BK.	DIRECTIONAL	4	055	95.9	3.83	—	IMB(3), TXB(1)

XL = RIPPLED CROSS LAMINATION, PXB = PLANAR CROSS-BEDDING, TXB = TROUGH CROSS-BEDDING, FC = FLUTE CASTS, TM = TOOL MARKS, PCL= PRIMARY CURRENT LINEATIONS, IMB = IMBRICATION, BM = BRUSH MARKS, CC = CURRENT CRESCENT CASTS.

APPENDIX IV

CLASSIFICATION OF CONGLOMERATE CLAST TYPES

Syenogranite

Hand Specimen: deep red to pink; coarse-grained; uniform texture with no alignment of grains.

Thin Section: quartz content 30-60%; more quartz in pink rocks; quartz commonly is vermicular with micrographic texture; 40-50% K-feldspar; 10-20% plagioclase; 2% opaques; generally subhedral crystals; minor alteration to chlorite and epidote.

Monzogranite

Hand Specimen: white with black flecks; often with red and/or green tinge; medium- to coarse-grained; no preferred orientation of grains.

Thin Section: 50% free quartz; 30% feldspars; 10-20% micas (chlorite); crystals subhedral to euhedral; feldspars are sausseritized with inclusions of epidote; chlorite occurs as large laths which have a relict texture; alteration products of epidote and chlorite.

Quartz Biotite Schist

Hand Specimen: pink to white; medium-grained; distinct banding or layering with fracturing occurring along these planes.

Thin Section: 60% free quartz; minor vermicular quartz with micrographic texture; 20% K-feldspar; 10% plagioclase; 5-10% opaques; 5% chlorite; schistose texture with chlorite occurring in discontinuous layers; chlorite is probably alteration product of biotite; subhedral crystals; feldspars strongly fractured, altered, with quartz inclusions; opaques occur in fractures; alteration products are chlorite and epidote.

Quartz-rich Aplite

Hand Specimen: light green-brown to orange-brown, fine- to medium-grained; no preferred alignment; mafics give rock speckled appearance.

Thin Section: 70-80% quartz; 20% interstitial muscovite or sericite; minor garnet and hornblende; generally equigranular with some samples containing oversized porphyroblasts; subhedral crystals; minor epidote and chlorite alteration; hematite staining along fractures.

Porphyritic Rhyolite

Hand Specimen: light to deep red, gray or brown; porphyritic crystals in a very fine-grained matrix; flow banding common.

Thin Section: large quartz and feldspar porphyroblasts in fine-grained or glassy groundmass; groundmass may or may not have microlites which often show an alignment; porphyroblasts are generally strongly fractured and altered; pseudomorphs of quartz, epidote, muscovite, and opaques have entirely replaced feldspars in some specimens; calcite in fractures; spherulites of cristobalite rare.

Rhyodacite

Hand Specimen: light to dark green, fine- to medium-grained; generally porphyritic.

Thin Section: feldspar-rich (70%); both plagioclase and K-feldspar; 30% quartz; medium- to coarse-grained laths of feldspar in a fine-grained or glassy groundmass which contains microlites of feldspar; some samples are equigranular rather than prophyritic; angular crystal fragments quite common; flow banding common; some crystals highly fractured; other crystals exhibit wavy extinction; alteration products of chlorite, calcite, and epidote abundant; zircon and apatite rare.

Note: The above rock type is actually a combination of intermediate volcanic lithologies including crystal tuffs and porphyritic flows, with some clasts showing a contact between both types. Because of the fine texture of this group, it could not be accurately subdivided in the field according to mineralogy or texture.

Rhyodacitic Pyroclastic Tuff

Hand Specimen: green, yellow, brown, or purple; angular coarse-grained clasts in a very fine-grained matrix; some specimens are massive; others banded; welding uncommon.

Thin Section: angular felsic lithoclasts and quartz/feldspar crystals in a fine- to medium-grained groundmass; microlites and clasts commonly aligned with flow banding; often altered by chlorite and epidote; rhyolitic to rhyodacitic composition; quartz content quite variable.

Felsic Tuff

Hand Specimen: green, gray, brown, red or purple; very fine-grained; massive or banded; hard; rare soft earthy look and texture.

Thin Section: very fine-grained to glassy groundmass with uncommon small angular fragments of quartz and feldspar; chlorite and epidote alteration profuse, generally masking texture; minor banding; may be a volcanic sediment.

Vein Quartz

Hand Specimen: white; commonly observed in contact with other lithologies in the clasts; vein product.

Graywacke (Metamorphosed)

Hand Specimen: green or gray; usually quite coarse-grained with clasts ranging from 0.5-10 mm; massive; well indurated.

Thin Section: clasts of quartz, feldspar, and felsic volcanic rock fragments; clasts vary from generally angular to infrequently well-rounded; bedding not observed; poorly-sorted; silt/clay matrix; clast- or matrix-supported; minor epidote alteration. Perhaps can be classified as volcanic wacke.

Quartzite (Metamorphosed)

Hand Specimen: green, red, white, brown, or gray; very hard; generally fine-grained; may or may not contain visible individual grains; 80-90% quartz; minor feldspar; some epidote and chlorite alteration; one specimen in the Wilkie Brook Formation contained brachipods.

Slate

Hand Specimen: pale to medium green; very fine-grained; low specific gravity; laminated; generally soft with talcy feel; may have fractures along bedding planes; metamorphosed.

Thin Section: finely laminated; well-graded; fining upward from silts to clays; some lenticular layers of silt-sized quartz grains with possibly starved ripples; alteration by chlorite and epidote.

Paraconglomerate

Hand Specimen: light red; matrix-supported; coarse sand matrix and pebble-sized clasts of volcanics and quartzite; no bedding observed; probably intraformational.

Sandstone

Hand Specimen: red, green, brown, or gray; generally quite well-indurated except for clasts which appear to be intraformational in origin; frequently gradational with quartzites; fine- to medium-grained; compositionally quite variable and depends on the formation; massive, laminated or cross-bedded.

Shale

Hand Specimen: red, green, or gray; laminated or massive; generally quite friable; may be intraformational.

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