GEOLOGY OF THE FROZEN OCEAN LAKE - NEW BAY POND AREA, NORTH - CENTRAL NEWFOUNDLAND

A thesis presented to the Faculty
of the State University of New York
at Albany
in partial fulfillment of the requirements
for the degree of
Master of Science

School of Arts and Sciences
Department of Geological Sciences

Timothy M. Kusky
1985

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ABSTRACT

Rocks of the Frozen Ocean Group outcrop in the Frozen Ocean Lake - New Bay Pond Area, Newfoundland, and are here divided into four formations. The Lewis Lake Formation forms the base of the Frozen Ocean Group, and is composed predominantly of mafic volcanic flows; this is conformably overlain by the Blue Star Formation which is entirely sedimentary in nature. The Blue Star Formation is in turn conformably overlain by the Bursey Point Formation, which is a mixed volcanic and sedimentary unit. The top of the Frozen Ocean Group is marked by the Lynx Pond Formation, a mixed silicic- and mafic-volcanic formation, with minor sedimentary intercalations.

The Frozen Ocean Group is everywhere in fault contact with structurally underlying, medial to late Ordovician, rocks of the Shoal Arm Group and Point Leamington Formation: structural analysis of this fault zone reveals that the present juxtaposition is a result of an early Silurian back-thrusting event, although several later episodes of deformation have modified the original geometry. The back-thrusting event is believed to be a result of continued, post-Taconic convergence between the Taconic-modified margin of North America, and the remaining, open part of the Appalachian Ocean. The later deformation episodes which have affected rocks of the area include right-lateral strike-slip faulting associated with pull-apart basin formation, upright regional folding,

batholith intrusion, and a second generation of dextral strike-slip faulting.

ACKNOWLEDGEMENTS

I would especially like to thank Bill Kidd for suggesting this project, for encouragement and advice throughout its preparation, and for his field support. Special thanks also goes to Sharon Poissant, who acted as a strong-willed field assistant and remained interested in the project throughout the season, despite heavy rains, bear and bug attacks, not to mention numerous other bizarre adventures. Dex Hoffe, Bill Farrell, Knobby, and the rest of the Price Motorcycle gang of Newfoundland provided initial disbelief and later field evacuation operations, and their efforts are greatly appreciated. Bud James of Noranda Exploration Company, from Gander, Newfoundland, contributed extensive amounts of information about previous geologic surveys in the area. Fossil identification was performed by John Riva of Universite Laval, Quebec. Discussions with W.D. Means, D.C. Bradley, and Kevin Burke were extremely helpful and Pam Stella, Bruce and Katrina Idleman each contributed in some way to the success of this project. Financial support for this thesis was provided by grants from the Geological Society of America, Sigma Xi, as well as personal grants and loans from Bill Kidd and my parents. K. Treiber is thanked for building a drafting table.

TABLE OF CONTENTS

CHAPTER I
INTRODUCTION

CHAPTER II
STRATIGRAPHY OF THE FROZEN OCEAN LAKE -
NEW BAY POND AREA, NEWFOUNDLAND

CHAPTER III
STRUCTURE OF THE FROZEN OCEAN LAKE -
NEW BAY POND AREA, NORTH CENTRAL NEWFOUNDLAND

CHAPTER IV
INTRUSIVE ROCKS

CHAPTER V
REGIONAL METAMORPHISM

CHAPTER VI
REGIONAL STRATIGRAPHIC CORRELATIONS

CHAPTER VII
TECTONIC HISTORY OF NORTH - CENTRAL NEWFOUNDLAND

LIST OF FIGURES

LIST OF PLATES

(in back pocket)

"The beauty of the scene presented by the land upon all sides is very impressing; yet at the same time a conviction will almost inevitably arise that, after all, such beauty, in a material sense, is a delusion, and that the whole region is nothing more than a vast inhospitable desolation". (Alexander Murray, in: Report for 1873, Geological Survey of Newfoundland).

CHAPTER I

INTRODUCTION

Purpose and Objectives of Study

The Frozen Ocean Group is a volcanosedimentary sequence that occurs in the east-central part of the Exploits Tectonostratigraphic Zone, Newfoundland (Figure 1.1). The present study was undertaken because rocks of the Frozen Ocean Group (F.O.G.) were stated by Dean (1977, 1978) to conformably overly Caradocian black cherts, argillites and a flysh sequence generally known as the Sansom or Point Leamington Graywacke. If Dean's claim that rocks of the Frozen Ocean Group conformably overly these Caradocian and younger sediments were to be proven true, then the New Bay Pond area would be the only place in central Newfoundland's Exploits Zone where Ordovician (and early Silurian) volcanism demonstrably post-dates the deposition of these Caradocian black shales (Figure 1.2).

Elsewhere in the Exploits Zone of central Newfoundland rocks record early Ordovician island-arc and back-arc basin volcanism and sedimentation, with the cessation of volcanism in the medial Ordovician (Caradocian), followed by the deposition of Caradocian black argillites. Medial through late Ordovician uplift and erosion of a terrane to the northwest is recorded in the Exploits Zone by a subsequent upward-coarsening flysh-type sedimentary

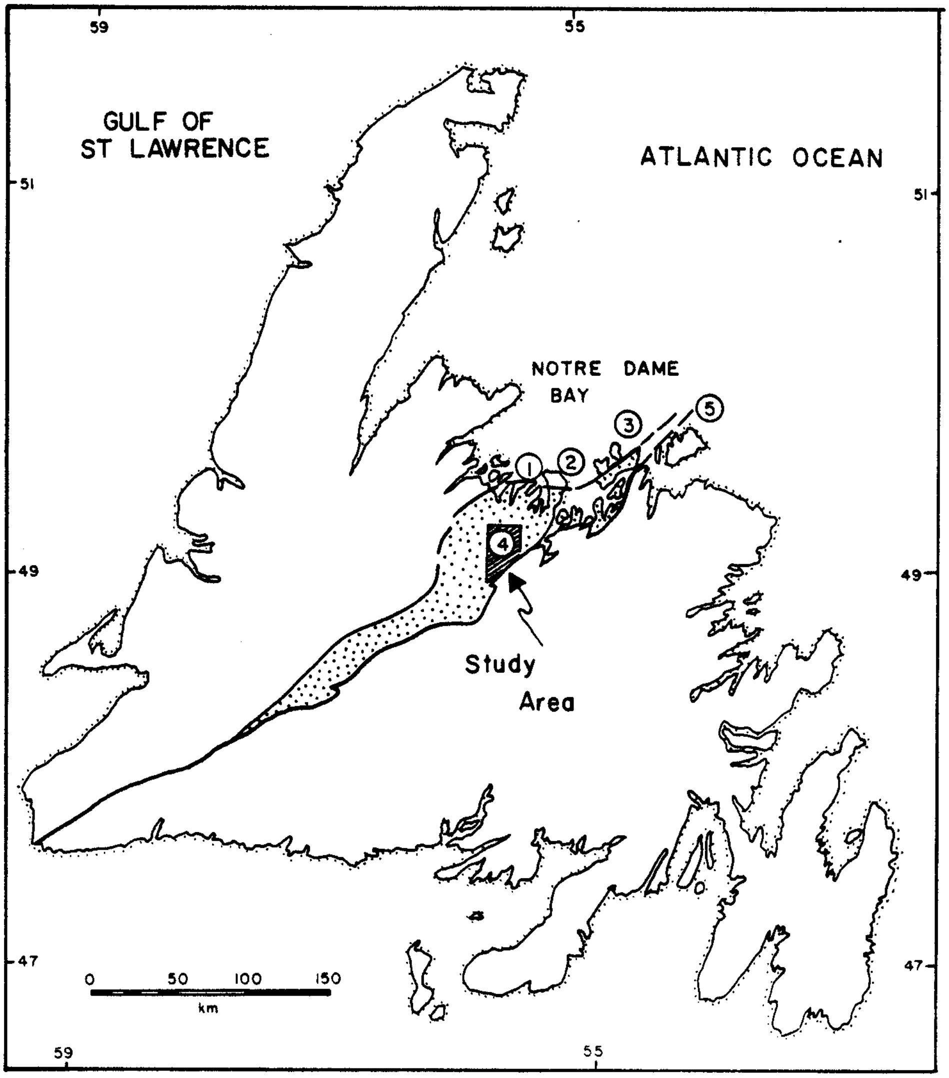


Figure 1.1. Location of the Frozen Ocean Group within the Exploits Tectonostratigraphic Zone (stippled) of central Newfoundland. Numbers refer to stratigraphic columns in Figure 1.2. The Exploits Terrane is bounded on the north and west by a thrust fault (locally known as the Lukes Arm - Sops Head Fault) and by a dextral strike slip fault system on the south and east (including the Reach, Northern Arm and Noels Pauls Faults).

sequence that is not known to contain volcanic rocks anywhere else than in the F.O.G. area (Dean and Kean, 1980)(Figure 1.2). For this reason a detailed study of the Frozen Ocean Group and its relationships to the surrounding sediments seemed warranted.

Nelson (1979) suggested synchroneity of Fleur de Lys metamorphism and deformation in the region believed to be the general source of the flysh, ophiolite obduction on the western platform, and cessation of arc-type volcanism in the Notre Dame Bay area (i.e. Caradocian times). Therefore, the presence of these supposedly post-Caradocian volcanics within the Exploits Zone implies the existence of either a previously unrecognized tectonic environment or, more likely, unappreciated structural complexities in the Frozen Ocean Lake - New Bay Pond area.

Several possibilities were selected as adequate explanations for the presence of these volcanic rocks in the Exploits Zone. Included were:

(1). The F.O.G. may have formed in a Cordilleran strike-slip regime, the volcanics and volcaniclastics forming in and filling a small pull-apart basin (This may imply an oblique Taconic collision(s))

(2). Their presence may imply post-Caradocian subduction, although this is unlikely, considering the regional evidence (summarized in Dewey, Kennedy and Kidd, 1983)

(3). The shales and graywackes "mapped" by

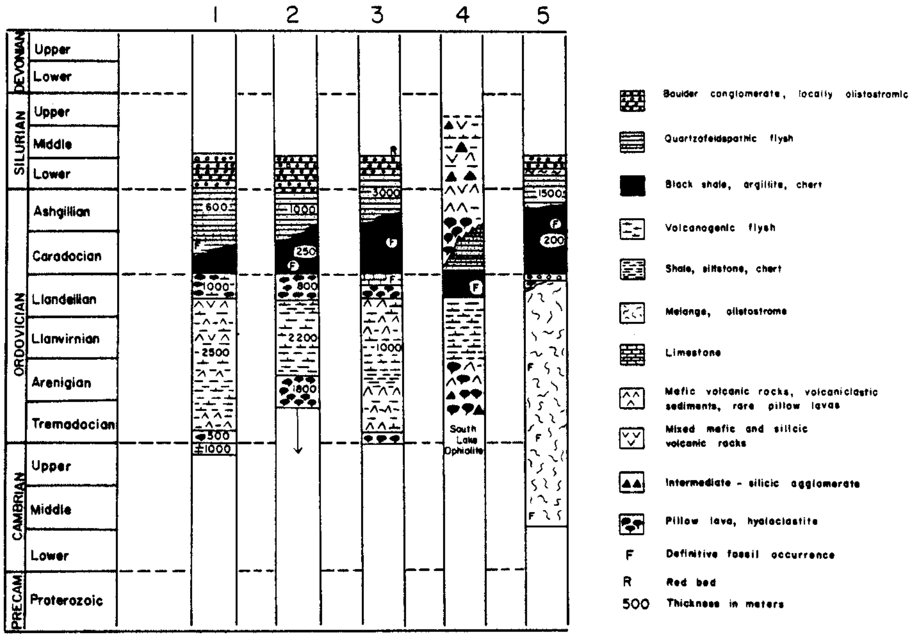


Figure 1.2. Stratigraphic columns from the Exploits Terrane (locations on Figure 1.1) as they existed prior to this study, indicating the apparently anomalous position occupied by the Frozen Ocean Group as reported by Dean (1977, 1978). This is because the New Bay Pond area was suggested to be the only place in the Exploits Terrane where Ordovician volcanism could demonstrably be shown to post-date the deposition of the ubiquitous Caradocian black shales (Dean and Kean, 1980). For this reason, a detailed investigation of the Frozen Ocean Group and its relationships to underlying sediments was needed. Columns 1, 2, 3 and 5 from Dewey et al., 1983; column 4 redrawn graphically after Dean (1978).

Dean (1977) may not be equivalent to those of Caradocian age, leaving the true age of the F.O.G. open for speculation

(4). The F.O.G. volcanics may be faulted against the Caradocian(?) sediments, and the F.O.G. may actually be equivalent to other Exploits Terrane strata including some parts of the (early Ordovician) Wild Bight Group, New Bay Group, the Tea Arm Volcanics or the Lawrence Head Volcanics (see below).

In order to differentiate between these possibilities and any others that might have arisen during the fieldwork the following objectives were set out:

(1). To produce a detailed outcrop map (1:16,000 and locally larger-scale) of the Frozen Ocean Lake - New Bay Pond area, north central Newfoundland

(2). To define as precisely as possible the contact relationships and structural attitudes of the F.O.G. relative to surrounding units

(3). To define and relate the stratigraphy of the F.O.G. to other Exploits Terrane strata

(4). To collect a suite of samples of the Frozen Ocean Group and surrounding sediments for subsequent petrographic analysis, leading to comparison and possible correlation with other similar well studied sequences from north-central Newfoundland.

Using the information gathered in this study it was hoped to be able to test the hypotheses for the age of the Frozen Ocean Group set out above and to modify the existing, or formulate a new tectonic model for central (and western) Newfoundland that is consistent with all the observed field relations.

Field Methods and Nature of Terrane

Rocks of the Frozen Ocean Group (Dean, 1977) outcrop in an approximately 100 square km area in north-central Newfoundland, about half way between Grand Falls and the open waters of Notre Dame Bay to the north (figure 1.1). The terrane generally consists of gently rolling hills that reach altitudes of 300 meters, and these are commonly dissected by northeast-trending, narrow linear valleys with steep, vegetation-covered sides. The lower elevations are usually occupied by fog-encircled swamps and lakes, which are prone, at least during the field season of 1983, to fluctuations in water level with drastic consequences for the lakeshore outcrop. The area was lumbered in the early 1970's by Abitibi-Price-Newfoundland, and since that company's land managment policies did not, at that time, require the removal of the portions of trees not used, nor the replanting of the forest, traverses across this area are often exceedingly difficult and time-consuming. However, Abitibi-Price-Newfoundland plans to bulldoze and replant the area within the next few years making future access easier (Dex Hoffe, Personal communication). Also, in 1983 Crown-Lands began accepting bids for cabin sites along the southern portion of New Bay Pond and the new landusers will undoubtedly keep the old roads into the area at least passable (Russell Bursey, personal communication).

Mapping was performed on 1:15,860 nominal scale aerial photographs (photos A18843-183 to 189, A18844-16 to 18, A18882-134, A18902-243 to 244, A18956-110, A18982-207 to 211, A18616-158 to 162, A18947-81 to 85) and enlarged 1:50,000 standard topographic maps for 10 days in August 1982 and for 2 months in the summer of 1983. The numerous logging roads in the area provided adequate access; however, most of these trails are very disgraded, and key bridges have been washed out by floods, and are now only traversable on foot or motorcycle. The author found a canoe to be the most useful means of transportation through the Frozen Ocean Lake - New Bay Pond area, although All Terrain Motor Cycles would also be useful.

CHAPTER II

STRATIGRAPHY OF THE FROZEN OCEAN LAKE - NEW BAY POND AREA, NEWFOUNDLAND

General Introduction

Plate 1 and Figure 2.1 show the distribution of, and relationships between, the wide variety of Ordovician, Silurian, and Devonian rocks preserved in the Frozen Ocean Lake - New Bay Pond area. From north to south these strata include the Wild Bight Group, Shoal Arm Group, Point Leamington Formation, Frozen Ocean Group and the Botwood Group. All of these, except for the Botwood Group, have been intruded by the Twin Lakes/Hodges Hill Intrusive Suite in this area, although it should be noted that the Botwood Group is intruded by a similar batholithic complex (Mount Peyton Pluton) elsewhere in central Newfoundland.

Rocks of the Frozen Ocean Group are discussd first, from base to top, because they are everywhere separated from the structurally underlying sediments by a fault and are believed to represent the oldest rocks preserved in the area. Next, rocks from the northern part of the area, including the Wild Bight Group, Shoal Arm Group, and Point Leamington Formation are described and their relationship to the Frozen Ocean Group is considered. Discussion of rocks composing the Botwood Group is reserved until Chapter

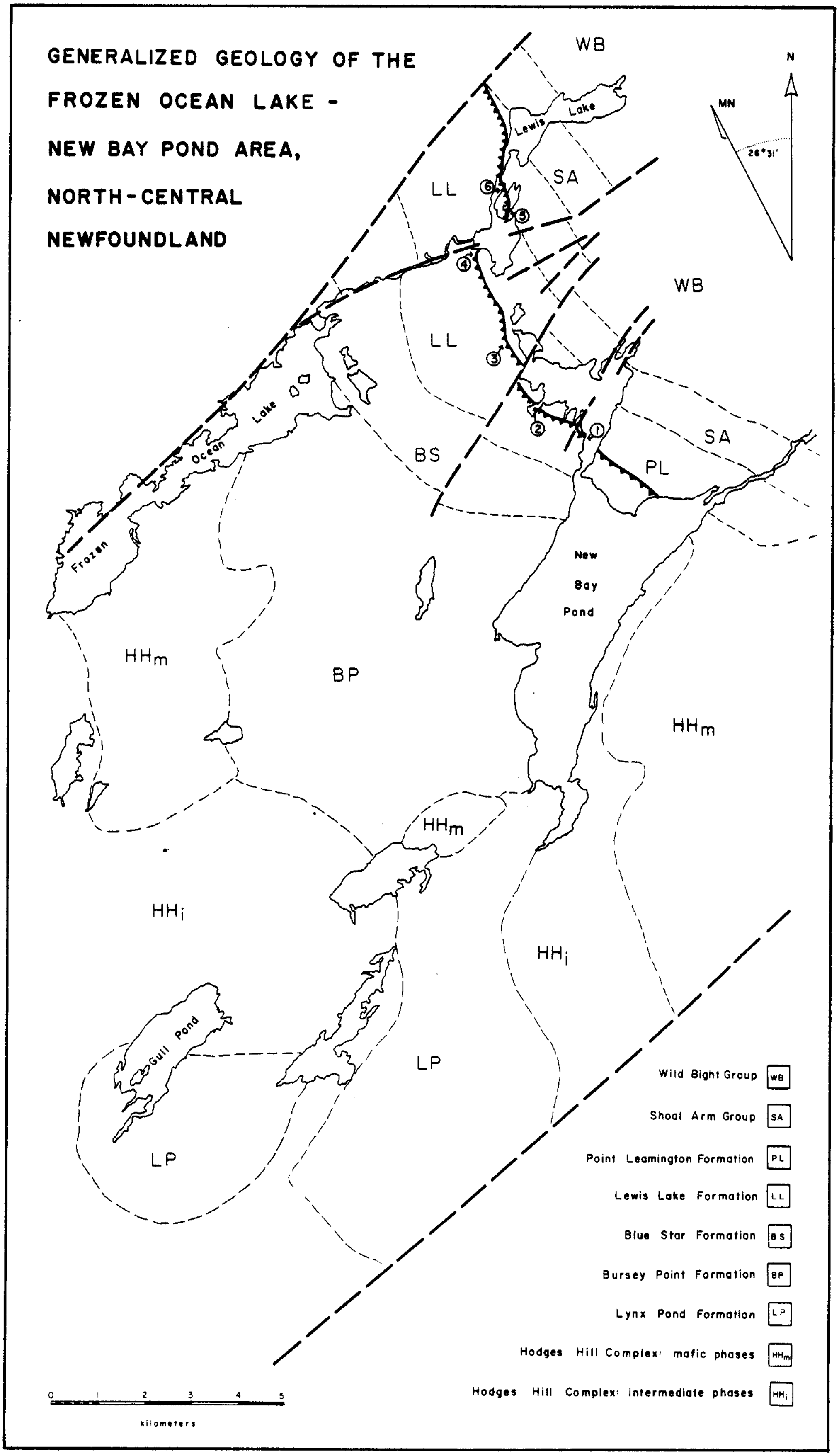


Figure 2.1. Generalized geologic map of the Frozen Ocean Lake - New Bay Pond area.

7. Because outcrops in the Frozen Ocean Lake/New Bay Pond area are extremely sparse, detailed lithological mapping was only locally possible. However, rocks of the area have been divided into several Formations, each possessing distinctive suites of lithologies and a tendency to outcrop in northwest trending belts (Plate 1). The paucity of outcrop makes it difficult to assign a "type section" (in the restricted sense) for every formation, although a type area or "representative section" (or better) has been defined for each.

Frozen Ocean Group

Introduction

Rocks of the Frozen Ocean Group include volcaniclastic sediments, mafic, intermediate and silicic volcanics, as well as local cherts. Sediments greatly predominate in abundance over volcanics, which is common for most pre-Caradocian sequences east of the Roberts Arm Belt. The entire thickness of the Frozen Ocean Group has been intruded by numerous mafic dikes and sills, locally forming more than 50% of the outcrop. Volcanic and volcaniclastic rocks in the New Bay Pond - Frozen Ocean Lake area were originally regarded as equivalents to the Wild Bight Group by the few early mineral exploration workers in the area (Bud James, Noranda Exploration Company, personal communication), but Dean (1977, 1978) chose to rename these strata the Frozen Ocean Group and, for reasons which seem somewhat foggy to this investigator, to correlate them with the Roberts Arm Group which lies farther to the west and north than the Wild Bight Group. The Roberts Arm belt consists predominantly of volcanic rocks (Bostock, 1978), and is strikingly different from the Frozen Ocean Group in many aspects, although it could have been the source for most Exploits Terrane volcaniclastic detritus (Helwig, 1967; Helwig and Sarpi, 1969; Bird and Dewey, 1970; Nelson, 1979).

The division of Frozen Ocean Group strata into several northwest trending belts that were originally mapped by NORANDA (unpublished maps, 1972), and subsequently published in maps compiled by Dean (1977, 1978), was found to be fairly accurate; therefore, this basic stratigraphic subdivision of the Frozen Ocean Group is followed here, although some minor changes have been made (Figure 2.2). However, the structure of the area, and relationships between various lithologies on the Noranda maps and, hence, on Dean's compilation, was largely ignored because the aim of the Noranda surveys was only to determine the approximate distribution of lithologies in an attempt to identify areas with a high potential for economic-grade mineral deposits (Wayne Reid, Noranda Exploration Company, personal communication).

Rocks of the Frozen Ocean Group are here divided into four formations; the Lewis Lake Formation, the Blue Star Formation, the Bursey Point Formation and the Lynx Pond Formation (Figure 2.2). The Lewis Lake Formation forms the structural base of the Frozen Ocean Group and is

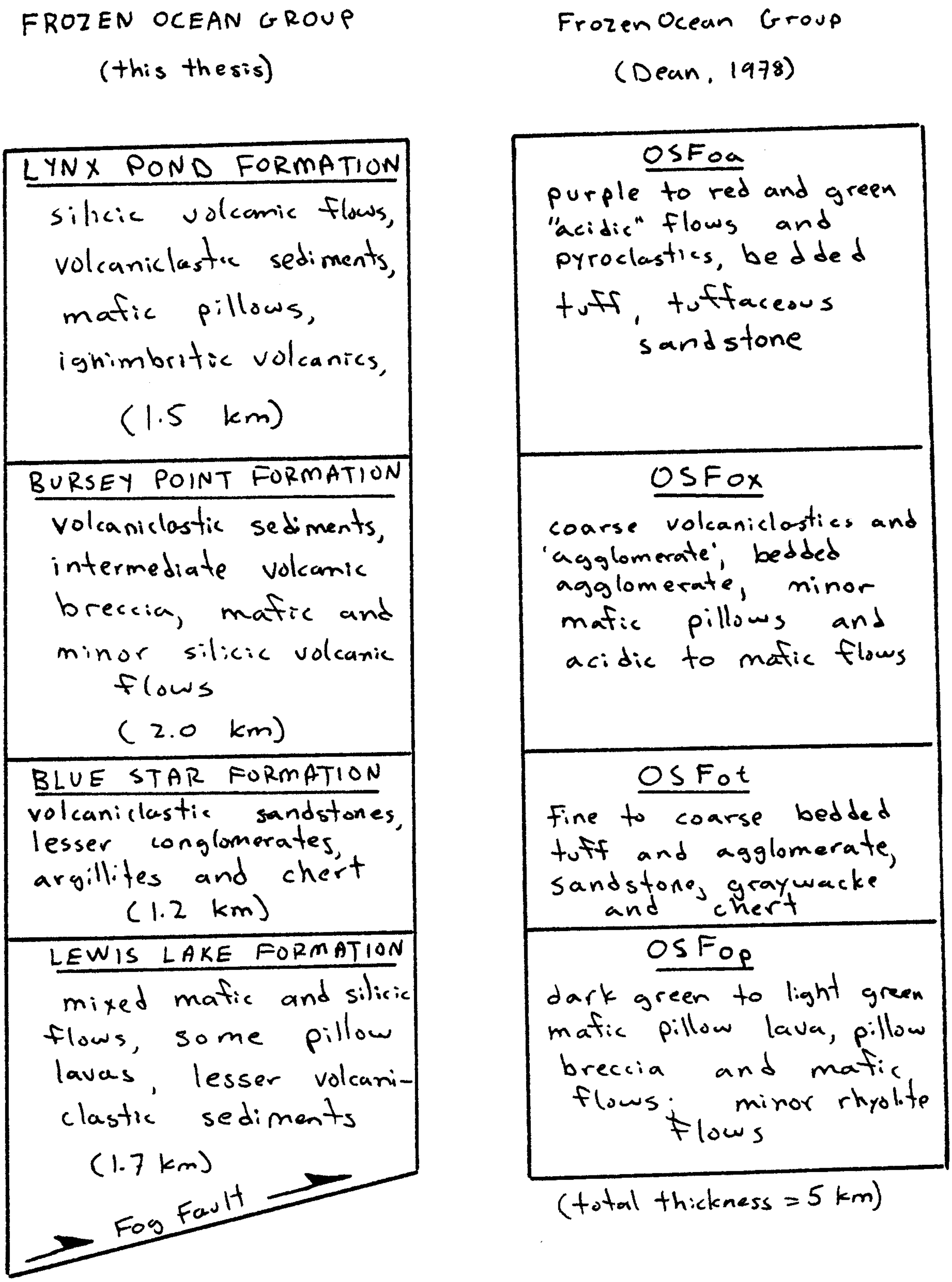


Figure 2.2. Comparison of the stratigraphy of the Frozen Ocean Group as described by Dean (1977, 1978) and from this study.

characterized by abundant mafic lava flows. The entirely sedimentary Blue Star Formation conformably overlies the Lewis Lake Formation, and is in turn conformably overlain by a mixed volcanic/sedimentary unit named the Bursey Point Formation. The top of the Frozen Ocean Group is marked by a mixed mafic- and subaerially erupted silicic-volcanic unit (Lynx Pond Formation) that has an unknown relationship with the rest of the Frozen Ocean Group.

Lewis Lake Formation

The Lewis Lake Formation forms a semi-circular belt around the western part of the Lewis Lakes and south of the northern part of New Bay Pond (Plate 1, Figure 2.1). Outcrop is fairly good, at least when compared to the rest of the Frozen Ocean Group. The dominant lithologies of the Lewis Lake Formation include mafic volcanic flows which typically exhibit a "smeared" appearance, although pillows are locally clearly recognizable (Figure 2.4). Other lithologies include hyaloclastite (*sensu* Rittmann, 1958), mafic volcaniclastic sandstones, intermediate and silicic volcanic flows including rhyolite, and various types of volcanic breccia.

Large cliffs located on the southeastern side of West Arm Brook have been selected as the type section for the Lewis Lake Formation (Figure 2.3) because they are accessible, offer good outcrop and display a representative selection of most lithologies encountered throughout the formation. Also, this choice presents a thicker section

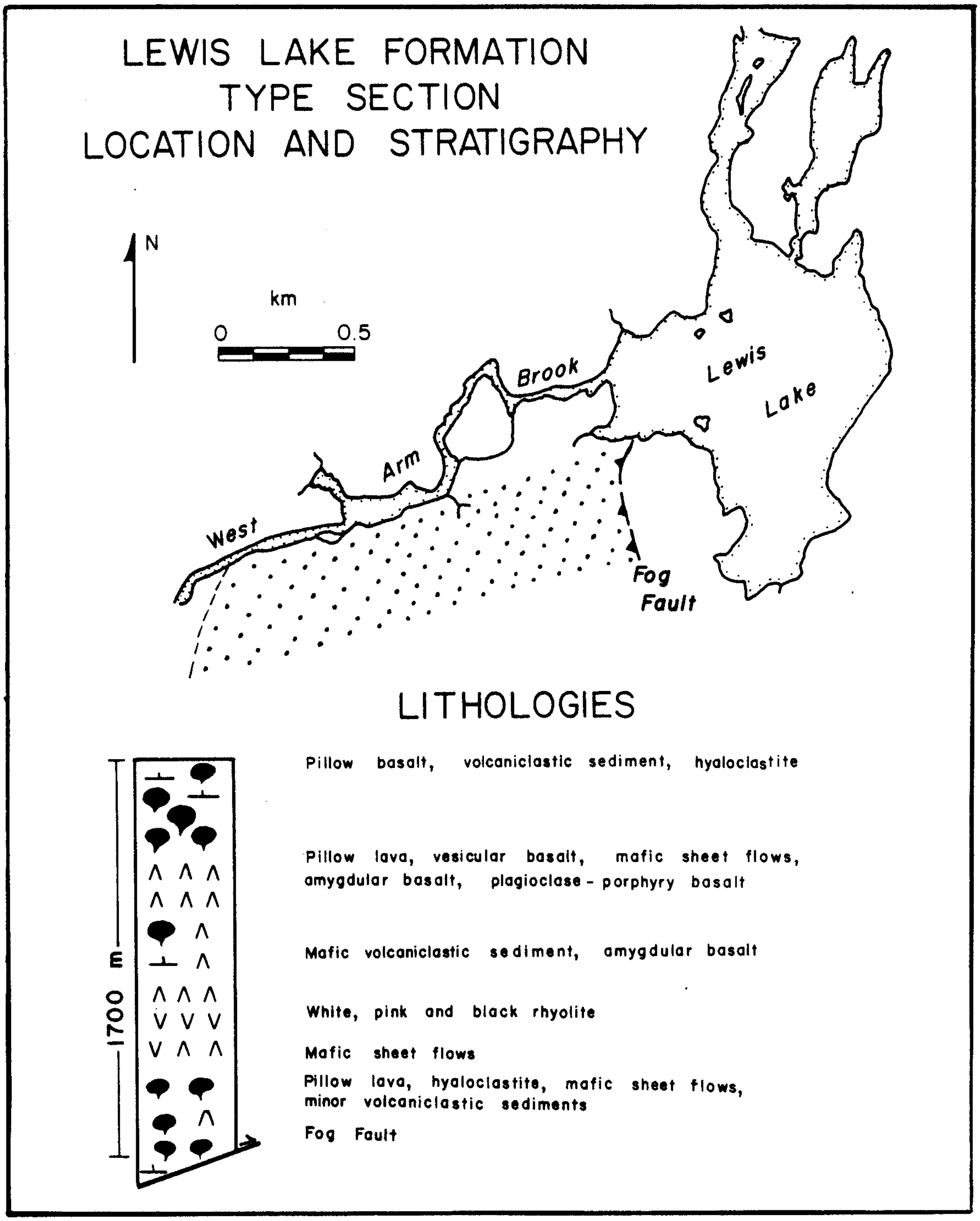


Figure 2.3. Type section location and detailed stratigraphy of the Lewis Lake Formation.

than areas farther east. Dean (1977) described a unit (his OSFOp) here designated the Lewis Lake Formation as a unit consisting "dominantly of mafic pillow lavas and pillow breccia", although he did not assign a type or representative section. The stratigraphic base of the Lewis Lake Formation is everywhere cut out by a fault that separates it from the Point Leamington Formation; the top of the formation is regarded as the base of the well bedded cherts which overlie these volcanics.

Where observable, a lithologically diverse and heterogeneously deformed unit marks the exposed base of the Lewis Lake Formation. This unit is best characterized as a silty appearing mafic lava, locally containing large equiaxed and randomly oriented xenoliths of more altered lava, which weather white (Figure 2.6). In some places, such as in Third Cove at the north end of New Bay Pond (Plate 1), this xenolith-bearing mafic lava is quite deformed and thinned because of its involvement in the Fog Fault (see Figure 3. 6).

Mafic volcanic flows, breccias, and pillow lavas constitute the lithologically most-abundant rock types in the Lewis Lake Formation. The flows are typically massive in appearance and exhibit a brown weathering color. Pillows are less abundant than the massive flows, although an anastamosing cleavage which is locally developed in the massive flows may mimick pillow shapes in outcrop. The mafic volcanic breccias generally contain angular fragments and are probably flow breccias, although rare fragments

Figure 2.4. Pillow lavas of the Lewis Lake Formation. Most mafic lavas from this formation are considerably more deformed and exhibit a "sheared" appearance, especially along the margins of individual pillows.

Figure 2.5. Hyaloclastite of the Lewis Lake Formation believed to have formed by the collapse (implosion) of pillow lava tubes during submarine extrusion of the basalt.

that are clearly identifiable as pillow fragments (Figure 2.5) suggests that some are hyaloclastites (cf. Parsons, 1968).

Overlying and interdigitated with these mafic lavas are some silicic volcanic deposits. A white-weathering rhyolitic flow occurs on the west shore of New Bay Pond approximately 400 meters north of the causeway (Plate 1), while its lateral equivalents are black to dark green rhyolites containing common doubly terminated quartz crystals. A white-weathering silicic volcanic rock also occurs at the same stratigraphic horizon in the type section of the Lewis Lake Formation (Plate 1). The flow on the west shore of New Bay Pond is nearly 100% exposed and its base is marked by a 25 meter thick monolithologic silicic volcanic flow breccia containing angular fragments of the rhyolite, as well as some large (> 1 m) oblate spheroidal shapes reminiscent of pillow lavas, suggesting subaqueous extrusion. The alignment of numerous phenocrysts in stratigraphically higher parts of the flow presumably represent flow banding formed during the movement of the lava, while the presence of numerous devitrification rinds around some areas are attributed to later alteration of originally glassy areas. The top of this member is marked by a "flow" breccia containing irregularly shaped blocks of silicic lava in a petrographically identical matrix (Figure 2.7).

Some similarity is seen between this flow and other silicic submarine flows from the Rouyn-Noranda area, Quebec

Figure 2.6. "Silty" appearing mafic volcanic flow of the Lewis Lake Formation containing large areas of more altered lava.

Figure 2.7. Monolithologic silicic volcanic breccia of the Lewis Lake Formation which is suggested to represent the top of a submarine flow.

(De Rosen-Spence et al., 1980). Fisher and Schmincke (1984) have suggested that silicic submarine volcanic flows should differ from their mafic counterparts "by being (1) thicker and less extensive, (2) lava pods, lobes and tongues are larger than typical basalt pillows, (3) the flow-laminated skin on pods, lobes and tongues is much thicker than on basalt and (4) vesicles are larger (Dimroth et al., 1979)". Most of these characteristics were observed from the silicic flows within the Lewis Lake Formation, supporting my suggestion that they are subaqueous in origin.

Mafic volcaniclastic and pyroclastic rocks interbedded with homogenous appearing mafic flows and pillow lavas compose the rest of the Lewis Lake Formation. A distinctive green-blue mafic pyroclastic (?) unit may be observed interbedded with mafic lava flows at Sunset Point on the northeastern side of New Bay Pond (Plate 1). It is a framework-supported sandstone containing abundant mafic volcanic clasts and fragmental plagioclase grains. The presence of a few scattered vesicular basalt lapilli, euhedral plagioclase crystals, and the apparent welding of some clasts to each other suggests a pyroclastic rather than a sedimentary origin for this deposit.

The entire thickness of the Lewis Lake Formation has been intruded by numerous mafic dikes and sills which may be divided into two groups on the basis of their field relations and petrography. The older group locally exhibit ameboid shapes and strangely terminating ends suggesting that they may have been intruded while the sediments were still unconsolidated. A similar situation was reported by Nelson (1979) from the Seal Bay - Badger Bay area, suggesting penecontemporaneous intrusion, volcanic eruption and deposition of sediments throughout the area. The second, younger group of intrusives are related to the Hodges Hill Pluton (see below).

Blue Star Formation

The Blue Star Formation is a relatively thin unit and, as far as was discernable, entirely lacks volcanic flows. The dominant lithology is blue-green volcaniclastic sandstone (Figure 2.9) which in some places contains large, well-rounded, blue chert fragments. The bottom of the formation is here designated as the base of the first chert bed overlying mafic volcanic rocks of the Lewis Lake Formation, while the top is here defined as the base of the first volcanic flow of the Bursey Point Formation. The Blue Star Formation becomes coarser grained upwards and towards the northwest, suggesting that during deposition of the Blue Star sediments there was increased erosion of the source terrane, which lay in that direction. A representative section is selected as the outcrops from New Bay Pond to the stream approximately 1 km west of causeway (Figure 2.8).

The basal member of the Blue Star Formation consists of well bedded blue, green, red and maroon cherts that were deposited on top of basalts of the Lewis Lake Formation,

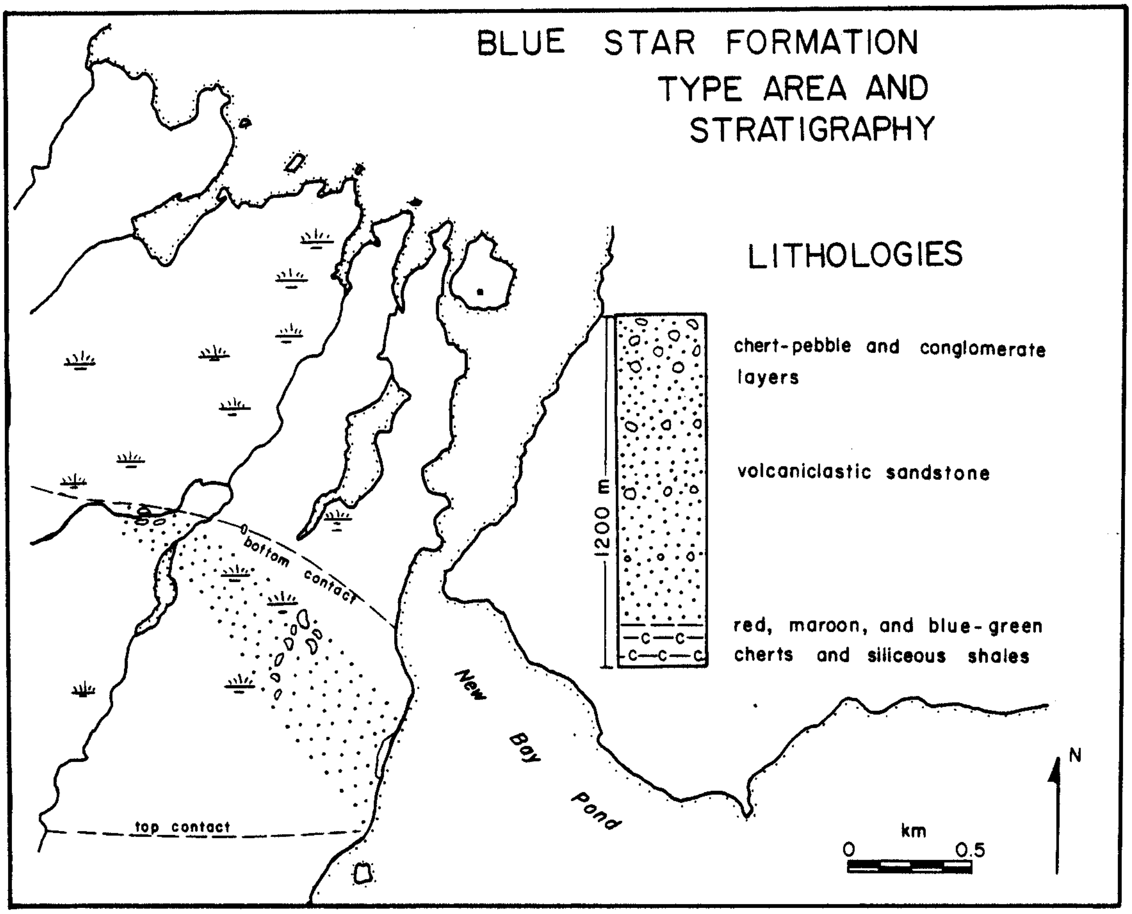


Figure 2.8. Representative section location and detailed stratigraphy of the Blue Star Formation.

presumably reflecting a deep marine origin. These are overlain by fine to coarse grained mafic volcaniclastic rocks which are rich in chert pebbles. These pebbles are locally greater than 10 cm long near the top and western parts of the formation. Penecontemporaneous deformation structures induced by the transportation and deposition of these chert fragments over finer grained sands are common; for instance, the truncation and faulting of cross-stratification observed north of the Frozen Ocean Lake (Figure 3.4).

A lesser proportion of the Blue Star Formation consists of tuffaceous rocks. For instance, northeast of the Frozen Ocean Lake, outcrops of grey-green silty rocks contain flattened black clasts that resemble collapsed pumice shards or fiamme. However, the flattening of the clasts is parallel to the local cleavage direction, and is not evidence for subaerial welding of the deposit. These presumed tuffs are interbedded with parallel-laminated purple and green cherty rocks, which may also represent fine grained silicic tuffs or bentonites. The deposit is dissected by several channels containing coarser-grained volcaniclastic deposits.

Paleocurrent indicators from the Blue Star Formation indicate a source that lay to the northwest (except for one cross bed suggesting northwest flowing currents), and this is consistent with the general coarsening and thickening of the formation in that direction (Plate 1).

Volcaniclastic sediments of the Blue Star Formation

Figure 2.9. Blue volcaniclastic sandstone of the Blue Star Formation, containing large clasts of blue chert (outlined area is that of Figure 3.4). The white bed is a fine grained silicic deposit, possibly representing a metabentonite.

which overlie mafic and silicic volcanic rocks of the Lewis Lake Formation are locally extremely rich in sulfide minerals, including pyrite, pyrrhotite, Manganese oxides, copper sulfides and possibly silver. The geometry of a particularly rich area (in an undisclosed location) shows some resemblance to the Noranda-type massive sulfide deposits that are common in Canada (Jensen and Bateman, 1981). No evaluation or attempt to estimate the grade or extent of mineralization has been performed by this author.

The entire thickness of the Blue Star Formation has been intruded by mafic dikes and sills, which locally display spectacular flow segregation and glomerocrystic aggregates of feldspar phenocrysts visible in outcrop.

Bursey Point Formation

The Bursey Point Formation is a relatively thick unit that is characterized by extremely poor outcrop, rendering further stratigraphic subdivision impossible. Several traverses were made in the area between Gull Pond, the Frozen Ocean Lake and New Bay Pond (Plate 1), and these yielded NO outcrops, although approximately 20 km were walked. Considering this poor percentage of outcrop, the Bursey Point Formation is best characterized from the outcrops that do exist as a mixed sedimentary and volcanic unit. It was found to contain volcaniclastic rocks, some of which may be crystal and lithic tuffs, silicic and minor mafic volcanic flows, and some volcanic breccias (which become finer grained upwards). Dean (1977, 1978) described

Figure 2.10. Volcanic breccia of the Bursey Point Formation containing angular to well rounded bombs of intermediate composition. This represents an unusually good outcrop for this formation!

Figure 2.11. Lithic tuff of the Bursey Point Formation.

a similar stratigraphic section in the Frozen Ocean Group (his OSFOx) as a "mixed volcanic unit". On the basis of the outcrops observed, this author estimates that sedimentary rocks compose at least 60% of this formation. Scattered outcrops along the old lumber road parallel to New Bay Pond contain most of the lithologies encountered throughout the Formation and, thus, are here designated as a representative section of the Bursey Point Formation (Plate 1).

The base of the Bursey Point Formation is here defined as the base of the first volcanic flow overlying volcaniclastic sediments belonging to the Blue Star Formation. East of the Frozen Ocean Lake this contact is marked by a massive silicic volcanic flow that shows numerous 'gas escape tube' structures oriented perpendicular to bedding. Features of this sort typically form shortly after eruption and subaerial deposition of pyroclastic flows, during the vapor-phase mineralization (Steve Self, personal communication), and a well-known example is the Valley of Ten Thousand Smokes associated with the eruption of Mount Katmai in Alaska. However, it is perhaps possible that this structure could alternatively form in a submarine environment and its presence alone is not thought to be conclusive enough to demonstrate subaerial deposition of this flow. The top of the Bursey Point Formation is covered by vast expanses of muskeg (Plate 1), rendering its definition obscure. This contact may be an intrusive contact against rocks of the Hodges

Figure 2.12. Mafic dike (dark) cutting volcanic breccia of Bursey Point Formation.
[Tim Kusky on the outcrop]

Hill/Twin Lakes Complex or, alternatively, it may pass conformably into the Lynx Pond Formation. The Bursey Point Formation differs from the underlying Blue Star Formation in that it contains local volcanic flows while the Blue Star Formation does not. Also, none of the blue chert fragments which are common in the Blue Star Formation were noted in this formation.

An unusual and distinctive "isolated-pillow breccia" (sensu Carlisle, 1963) occurs near the base of the Bursey Point Formation, and is characterized by small (1 mm - 5 cm) lava stringers and isolated pillow fragments enclosed within a chaotic matrix. The formation of pillow breccias of this sort has been attributed to leakage from larger pillows (Moore, 1975) and submarine lava fountaining (Carlisle, 1963; Schmincke et al., 1983; Fisher and Schmincke, 1984)

The entire thickness of the Bursey Point Formation has been intruded by mafic dikes and sills, which locally display spectacular flow segregation and glomerocrystic clots of plagioclase laths visible in outcrop. A minor amount of silicic intrusive rocks were noted as well.

Lynx Pond Formation

Rocks referred to as the Lynx Pond Formation include rhyolites, agglomerates, and ignimbrites, although some mafic massive and pillow lavas occur as well. In fact, Noranda (unpublished, 1972) reported that this horizon is composed of approximately 50% pillow lavas. Because these rocks appear vastly different from those that comprise the

Figure 2.13. Silicic volcanic flow front (or side) from the Lynx Pond Formation, containing intermediate lithic volcanic clast.

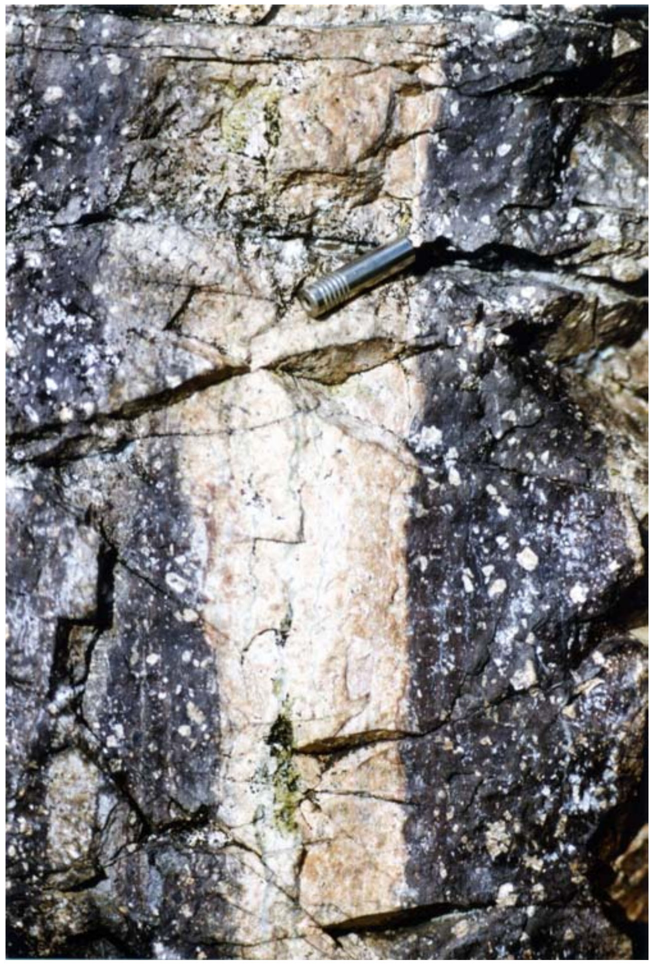


Figure 2.14. Silicic volcanic rock from the Lynx Pond Formation displaying ignimbritic textures, demonstrating subaerial extrusion.

Wild Bight Group

The northeastern-most rocks observed in the area are equivalent to the Seal Bay Head Formation (cf. Nelson, 1979) of the Wild Bight Group. Included in the type section of this formation at Seal Bay Head on the mouth of Seal Bay are mafic pillow lavas, volcanic breccias, green volcaniclastic sandstones, and argillites (Nelson, 1979). Lithologies observed by this author in the Frozen Ocean Lake - New Bay Pond area include green and brown volcaniclastic sandstones (Figure 2.15) which may include some tuffs (suggested by the presence of flattened pumiceous fragments), manganiferous siltstone, conglomerate, basalt, mafic volcanic breccia and, tan, blue and white weathering cherts and dark blue-black argillites.

The top of the Wild Bight Group was observed to pass conformably up into red cherts of the Shoal Arm Group on an island in Moose Cove at the north end of New Bay Pond. Within 5 meters of this contact the Shoal Arm Group is openly folded about northeast trending axes and if this outcrop were not observed this contact would probably have been interpreted as disconformable. The geometry of the folds on the islands in Moose Cove suggests that this relationship developed as a result of differening competency between the Wild Bight and Shoal Arm Group rocks and, hence, different processes operated to accomodate the shortening in each lithology.

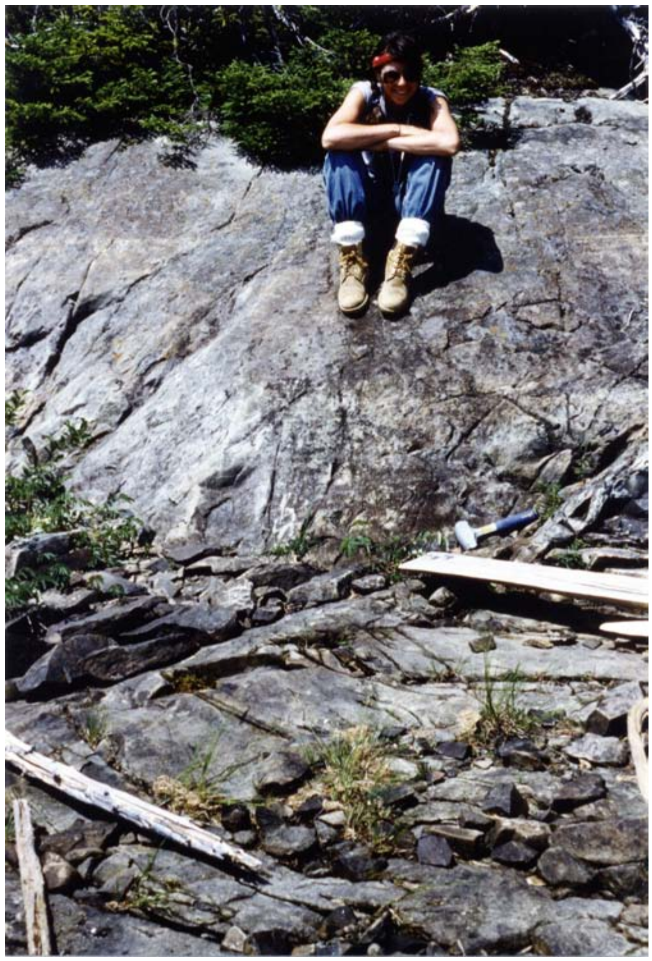


Figure 2.15. Grey-green volcaniclastic sediments of the Wild Bight Group.
[Sharon Poissant on the outcrop]

Shoal Arm Group

Introduction

Rocks of the Shoal Arm Group occur throughout the Notre Dame Bay area and because of their distinctive character and abundance of graptolites in one unit they provide an extremely useful stratigraphic marker horizon for the region. Equivalents to these and stratigraphically overlying rocks, were first defined as the Shoal Arm Formation by Espenshade (1937). Most workers have retained Espenshade's terminology for the lower part of his Shoal Arm Formation, although the upper part is now generally known as the Sansom Graywacke (and equivalents). The thickest section of the Shoal Arm Group occurs in the New Bay Pond Area (Dean, 1978) and examination of the outcrop from this, and surrounding areas, has enabled a more detailed subdivision of the Shoal Arm Group to be obtained. It is clearly possible to divide these rocks into three formations (Plate 1), and to rename the whole sequence the 'Shoal Arm Group' (Kusky and Kidd, in preparation). From base to top, these formations are informally named in this thesis, the Moose Cove Formation, White Point Formation, and the Drowning Point Formation. However, other formal names for type sections elsewhere will be chosen. These separate formations are recognizable throughout the Notre Dame Bay region, and this subdivision is extremely useful as a way up indicator and as a marker of tectonic repitition.

The Shoal Arm Group is conformably underlain by volcanic and volcaniclastic rocks of the Wild Bight Group and, although its upper contact appears to be tectonic in the New Bay Pond area (see below), workers elsewhere in the region have reported a gradational change into the overlying Point Leamington Formation (Sansom equivalent). Thus, the regional stratigraphy appears to have been preserved across this upper contact, interpreted in the New Bay Pond area as an olistostromic melange (see below), even though it may have been the site of considerable bedding-plane parallel slip. Soft-sediment deformation is a nearly ubiquitous feature of rocks of the Shoal Arm Group. Dean (1978) and Nelson (1979) have suggested that the top of the Shoal Arm Group should be defined as the base of the first graywacke bed overlying the black shales, and this usage is continued here.

Moose Cove Formation

The Moose Cove Formation is the most distinctive part of the Shoal Arm Group. It is composed of bright red cherts that commonly contain small round or elliptical quartz replacement features (Figure 2.17) that were probably originally radiolaria (Sampson, 1923). Few axial ratios of greater than 3:1 were observed; this flattening was observed to be parallel to the local bedding orientation and not the regional cleavage surfaces, suggesting that these rocks have only suffered nominal strain.

These cherts locally display a steely blue manganese

Figure 2.16. Maroon and white banded cherts of the Moose Cove Formation, Shoal Arm Group, exhibiting steely blue-black manganese weathering stains.

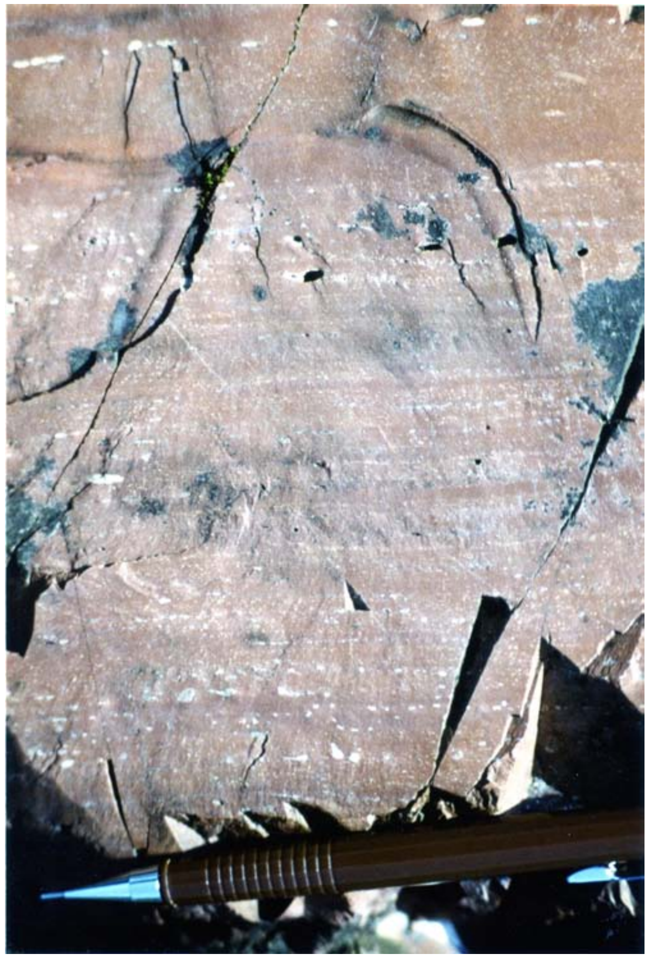


Figure 2.17. Red chert of the Moose Cove Formation displaying numerous elliptical recrystallized quartz nucleii, which were most likely originally radiolaria.

oxide weathering stain (Figure 2.16), and this was found to be especially concentrated in a few individual beds. Also present are preferentially weathered carbonate and manganese stained nodules.

Bed thicknesses range from less than 1 cm to greater than 10 cm, and parallel laminations are ubiquitous. Some thin (< 5 cm.) iron oxide stained clastic horizons were noted, and these contain small (< 3 mm) fragments of variously altered basalt and volcanic glass, broken and altered feldspar grains, some of which display albite twinning, quartz, and finally, numerous opaque grains with rare cubic habit. These clastic beds are poorly-sorted and grain-supported, with grains ranging from angular to well-rounded. The matrix is composed of microcrystalline quartz grains identical to the surrounding chert beds. The sequence of sedimentary structures in these beds was found to be consistent with a "Bouma-turbidite" interpretation (Bouma, 1962). The top of the Moose Cove Formation grades over a distance of 5 - 10 meters into the White Point Formation, with lithologies of both units being interbedded over this interval. Some lenticular chert layers exhibiting a red tinge were noted in this transition zone, suggesting that the overlying cherts of the White Point Formation may represent the altered product of the Moose Cove Formation.

White Point Formation

The White Point Formation contains white weathering blue-grey bioturbated cherts which are interbedded with argillite horizons, especially near the top of the formation. Steely-blue manganese weathering horizons are often found, and rusty orange weathering rinds are common as well. Two scales and types of sedimentary lamination are noted from within the White Point Formation (Figure 2.18):

(1) the alternation between chert and argillite, and

(2) the banding within the chert. Numerous mechanisms have been proposed over the years to explain the banding commonly observed in chert sequences (e.g., Davis, 1918; Grunau, 1965; McBride and Thompson, 1970; Garrison, 1974; Iwao, 1976; Fischer, 1977; Steinberg et al., 1977; Barrett, 1982). These mechanisms include (after Iijima et al., 1985):

I. Diagenetic alteration

(1). Segregation of silica (chert) and clay (shale parting) from a silica gel/clay-water mixture during early diagenesis

(2). Selective dissolution of siliceous tests in shale partings, the dissolved silica precipitating as the cement in nearby chert beds

II. Fluctuating productivity of siliceous tests

III. Sedimentary differentiation by turbidity currents

(1). Continuous settling of siliceous tests and clay from periodical turbidity currrents

IV. Double accumulation

(1). Chert beds are siliceous turbidites, while shale partings are pelagic or hemipelagic clay

(2). Siliceous tests (chert) accumulated at a rather constant and slow rate, whereas terrigenous mud (shale partings) settled rapidly from distal turbidity currents which occurred periodically

Since sedimentary structures indicative of turbidite origin (Bouma sequences) were noted in a few of the chert beds, and the argillites were found to be essentially structureless, a combination of III (sedimentary differentiation) and IV (double deposition) is selected as the mode of deposition for the White Point Formation. Differentiation by separate turbidity currents is suggested to be responsible for the banding within the cherts, and the argillites are suggested to represent hemipelagic oozes. The regular spacing of the chert beds suggests a cyclical nature of turbidite deposition: it is possible that they represent storm-induced turbidity flows, perhaps on a 50,000 year interval (Ed Landing, personal communication).

The top of the White Point Formation grades over approximately 2 meters into the overlying Drowning Point Formation.

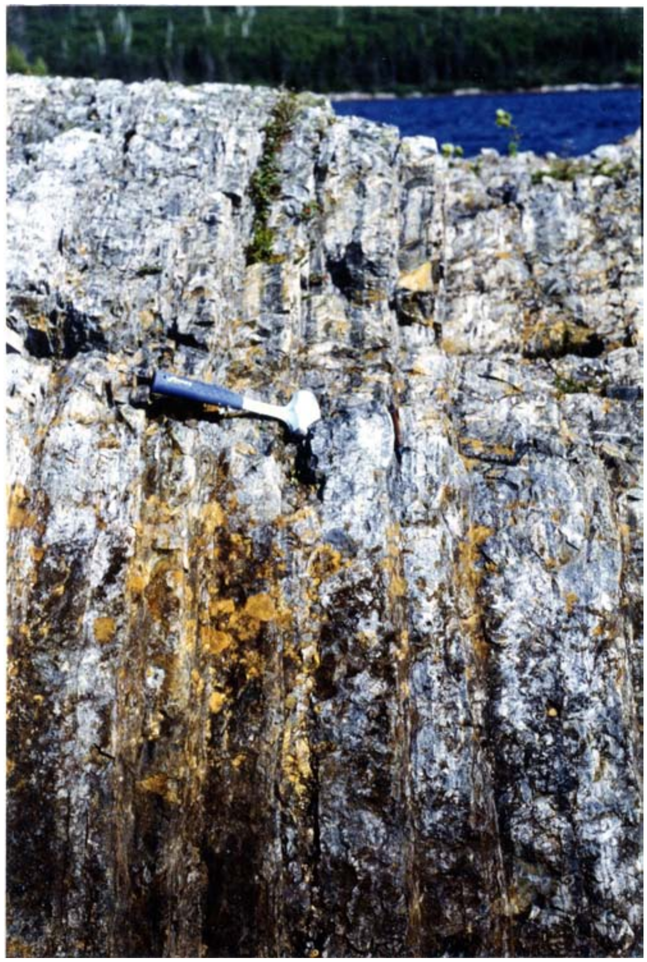


Figure 2.18. Interbedded white weathering blue-grey chert and black iron-rich argillite of the White Point Formation, Shoal Arm Group. Note the two scales of lamination; (1) the alternation between chert and argillite and (2) the variations within the chert.

Drowning Point Formation

The Drowning Point Formation contains interbedded black shales, argillites and very rare, thin graywacke beds. The argillites range from dark black and sooty to light gray and silica-rich in nature, and contain abundant pyrite. Weathered outcrops typically exhibit a yellow to orange color weathering stain (Figure 2.19), reflecting a high content of iron sulfides. This feature was found to be extremely useful for mapping the distribution of the Shoal Arm Group because the Drowning Point Formation (and the Moose Cove Formation) have a very distinctive signature on aeromagnetic surveys of the area (confidential data of Noranda Exploration Company). Using the distribution of these magnetic horizons it was possible to "map" in considerable detail regions where the outcrop is very sparse (see Plate 1).

This part of the Shoal Arm Group was found to be the richest in graptolites, and has yielded the following specimens (collected by Kusky, Kidd, and Poissant; identified by John Riva, personal communication, 1983):

Orthograptus quadrimucronatus (Hall)
Leptograptus cf. flaccidus (Hall)
Dicellograptus flexuosus Lapworth or D. gravis
Plegmatograptus sp.
Orthograptus sp.

This assemblage, according to Riva, is typical of upper Caradoc - Lower Ashgill (Dicranograptus clingani -

Figure 2.19. "Stinky black shales" of the Drowning Point Formation (Shoal Arm Group) with iron weathering stains. This formation has yielded a graptolite fauna representing a Pleurograptus linearis zone age (upper Caradoc/lower Ashgill), or younger (identified by J. Riva).

Pleurograptus linearis zones, or younger) faunas from Newfoundland, and is identical to faunas taken from the Moffat area, Scotland (John Riva, personal communication). These faunas indicate an age for the upper Shoal Arm Group in this area that is significantly younger than that suggested by Dean (1978), on the basis of the following graptolites extracted from the same outcrop which our samples came from (collected by H. Williams and identified by L.M. Cumming: Dean, 1978).:

Leptograptus flaccidus (Hall)

Climacograptus sp., either bicornis (Hall) or diplacanthus (Bulman)

Orthograptus sp.

Point Leamington Formation

The Point Leamington Formation is an upward coarsening flysch-type sedimentary sequence that has correlatives throughout the entire Exploits Terrane; these are generally known as Sansom-equivalent strata (Nelson, 1979). In the New Bay Pond area the Point Leamington Formation occurs as a northwesterly tapering wedge that is bounded below by the Shoal Arm Group and locally? by the Killer Terr Complex. The Point Leamington Formation is here informally divided into two members; a basal unit composed of alternating shale and graywacke beds, and an upper member containing massively bedded, quartz rich volcanic-lithic wackes, and only minor shale beds. These are termed the Killer Terr Member and the Wacky Island Member, respectively. The upper contact of the Point Leamington Formation with the Frozen Ocean Group is everywhere marked by a fault which is usually parallel to bedding, but has numerous ramps that cut up through the formation towards the southest, sing the apparent thickening of the Point Leamington Graywacke in this direction (Plate 1).

Killer Terr Member

Rocks composing the Killer Terr Member include buff-weathering graywackes interbedded with more abundant black shales. Where measurable, the ratio of sand:shale was found to range from 1:10 to 3:1. Higher ratios were found near the top of the member, suggesting an increasing supply of clastic detritus during deposition of the lower Point Leamington Formation. Because this "stratigraphic" horizon has suffered a unique and complex deformation history, stratigraphic continuity cannot be demonstrated within the Killer Terr Member, although the regionally recognized stratigraphy has been preserved across this zone. Detailed discussion of the constituents of the Killer Terr Member is reserved until Chapter 3, under the heading "Deformation of the Contact between the Shoal Arm Group and the Point Leamington Formation".

Wacke Island Member

Sediments of the Wacky Island Member generally appear as massive light brown to buff weathering sandstones (Figure 2.20), although these may appear blue to grey on glacially polished outcrops. Sediments of the Point Leamington Formation are distinctive from other graywackes that occur, for instance, in the Wild Bight Group because of the abundance of detrital quartz grains and silicic volcanic pebbles which are rare or absent in pre-Caradocian sediments (Helwig, 1967; Nelson, 1979). The graywackes are usually massively bedded with individual bed thicknesses ranging from <1 cm to 3 meters. Paleocurrent indicators including cross-laminations, flame structures, and flute marks are fairly abundant and generally suggest transport from a source terrane that lay to the north or northwest (present coordinates). However, their orientation relative to the generally low glacially-scoured outcrops in the New Bay Pond area does not usually allow accurate orientation measurements of these features to made and, therefore, precludes any detailed paleocurrent analysis. Structures indicative of paleoslope (slumps and other soft sediment deformation) are also quite abundant, and they suggest that the basin which these rocks were deposited in sloped generally towards the southeast.

The graywackes include both matrix- and grain-supported varieties, with a large variation in the amount of matrix material present. Detrital grains observed

Figure 2.20. Weathered "graywacke" of the Point Leamington Formation (Wacke Island Member), intruded by mafic dike from the Hodges Hill Pluton. Note the feldspar, quartz and volcanic-lithic fragments which stand out on the weathered surface.

Figure 2.21. Transition from the top of one upward-fining sequence to the base of another in the Point Leamington Graywacke, marked by flame structures and a proto rip-up clast. The coarse sands display low-angle cross-stratification.

include abundant quartz, some of which show hexagonal prismatic morphology, demonstrating a volcanic origin. Silicic volcanic lithic fragments are fairly abundant and the large grain size of some of these suggests that they may have been eroded from a shallow plutonic source. Rare mafic volcanic clasts were noted, as were some coarse-grained polycrystalline quartz aggregates which may be vein quartz. Opaque grains are fairly abundant and usually offer a golden yellow color in reflected light. One opaque grain exhibited a reddish-brown color in plane light and is probably chromite, suggesting (cf. Nelson and Casey, 1979) that an ophiolitic terrane was being eroded in the source terrane during deposition of these sediments.

CHAPTER III

STRUCTURE OF THE FROZEN OCEAN LAKE - NEW BAY POND AREA, NORTH-CENTRAL NEWFOUNDLAND

GENERAL INTRODUCTION

Rocks of the Frozen Ocean Group comprise a generally homoclinal sequence exposed on the southwest limb of the Seal Bay Fold, a northwest trending anticline that is offset by numerous, dominantly right-lateral, strike slip faults (Plate 3). These strata strike west to northwest and are vertical to steeply southwestward dipping (Figure 3.1). Except locally, rocks of the Frozen Ocean Lake - New Bay Pond region are only mildly cleaved, if at all. This suggests that they have only experienced modest amounts of flattening.

Rocks of the Frozen Ocean Group (Figure 3.1b) exhibit a considerably greater scatter of bedding orientations than do sediments of the Point Leamington Formation and Shoal Arm Group (Figure 3.1a). This may be attributable, at least in part, to the nature of the respective depositional environments. While rocks of the Frozen Ocean Group were deposited in an area of considerable relief, sediments of the Shoal Arm Group and Point Leamington Formation were probably deposited in a basin characterized by relatively subdued topography, leading to more homogenous bedding orientations. Alternatively, some of the scatter of the

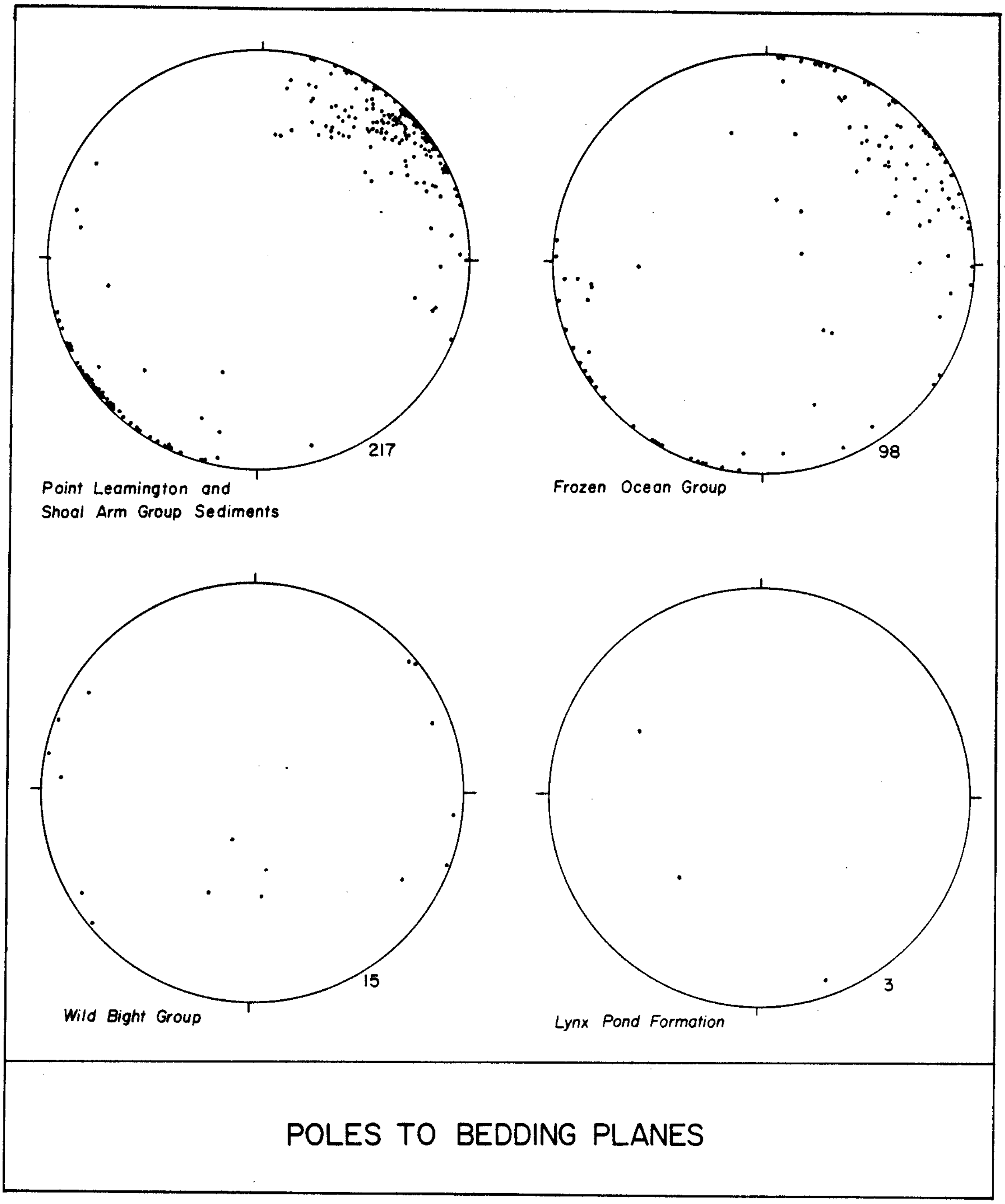


Figure 3.1. Lower hemisphere Equal area projection of all bedding orientations from the Point Leamington and Shoal Arm Group sediments, the Frozen Ocean Group, the Wild Bight Group, and the Lynx Pond Formation. Note the general northwest strike of all strata except those of the Lynx Pond Formation.

Frozen Ocean group bedding orientations may be attributed to the more varied competency of these rocks as compared to the younger sediments, leading to a greater amount of differential deformation.

Foliation orientations within the Frozen Ocean Group and the structurally underlying sedimentary rocks are highly variable, although the most abundant surfaces are subvertical and strike to the northeast (Plate 1). However, a closer inspection of foliation orientations plotted on a Schmidt net reveals the presence of four point maxima, particularly in the Frozen Ocean Group (Figure 3.2b). These maxima correspond to (1) the regional northeast trending cleavage and (2) a generally northwest trending foliation which appears to be spatially restricted to areas near the Fog Fault. The character of the northeast striking cleavage is best described as spaced, although these surfaces may also be considered transitional between joints and spaced cleavage (cf. Borradaile et al., 1982; Powell, 1979). The northwest striking foliation ranges from anastamosing to sinuous, and these surfaces are commonly decorated with slickenside striations. In rare localities (see Plate 1) a northwest striking spaced cleavage is present, and the parallelism between these planes and the axial surface of the Seal Bay and related folds suggests some causal relationship between the two.

The rocks of the Frozen Ocean Lake-New Bay Pond area are only mildly metamorphosed (see below) and primary structures are readily discernable. Analysis of

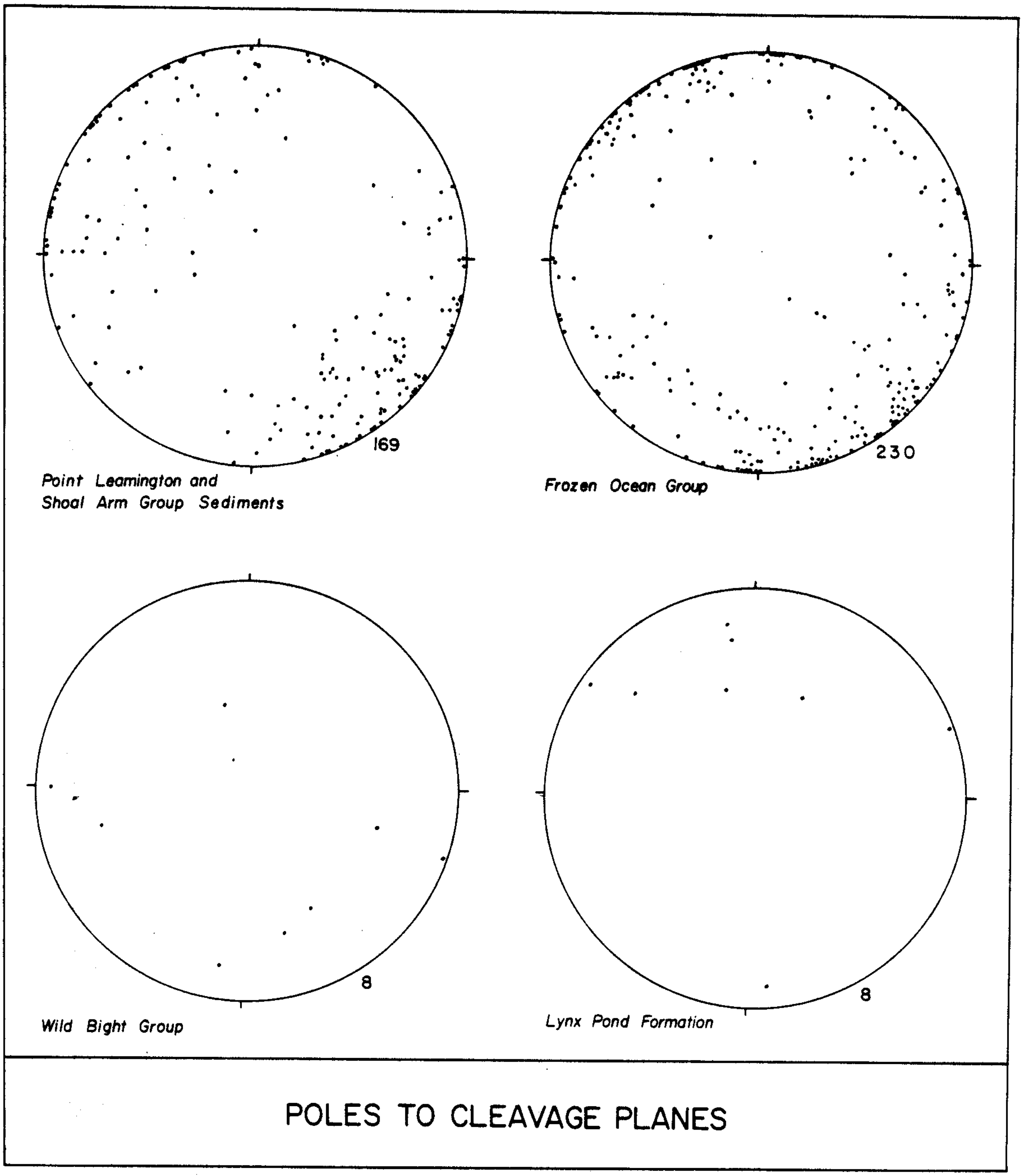


Figure 3.2. Poles to cleavage planes in the Point Leamington Formation, Shoal Arm Group, Frozen Ocean Group, and the Lynx Pond Formation. Note the two (widely scattered) different orientations of cleavage in the Frozen Ocean Group.

overprinting relationships reveals that structures within this area can be divided into six "generations"; D0, D1, D2, D3, D4 and D5. These are not all thought to represent different tectonic events, but merely the progression of deformation. Structures assigned to each generation from throughout the area are next discussed.

D_0: Soft Sediment Deformation

Structures which disrupted the rocks they are preserved in prior to lithification are here assigned to D_0. These include rip-up clasts, slump folds, flame structures and load casts (Figure 3.3) and, locally, soft sediment faults (Figure 3.4). The nearly ubiquitous presence of these structures in rocks of the Frozen Ocean Lake - New Bay Pond area suggests that they were deposited in a very unstable tectonic environment. Slump folds are distinguished from tectonic folds using the following critereon (after Helwig, 1967):

I Within slump-folded horizons

(1). decollement

(2). detached fold blobs

(3). disruption of beds

(4). isolated stratigraphic horizon of folds

(5). curved hinges

(6). variable and/or irregular fold style

(7). "welded" contacts between contrasting lithologies through the folds

(8). piled up, imbricated, or nappe-like folds

(9). cleavage across folds refracted arround folds

II Within folded or associated unfolded beds

(1). ductile faulting

(2). sandstone dikes

(3). sedimentary breccia

(4). chaotic structure not cut by open fractures or vein fillings

(5). folded clasts

Paleoslope indicators such as slump folds are especially abundant in the Shoal Arm Group and the Point Leamington Formation; however, the low and glacially worn nature of the outcrop in the New Bay Pond area does not allow accurate spatial orientations of these features to be measured and, furthermore, many of these features were apparently rotated significantly by later tectonic deformation (see below). Despite this, the overturning directions and asymmetry of all slump folds observed are consistent with the supposition that they formed in a basin whose floor sloped towards the southeast (Figure 3.3).

Cross-laminae indicative of current directions occur locally in rocks of the Frozen Ocean Group and are also abundant in the Point Leamington Formation although, again, the poor control on the spatial orientation of these structures obviates any detailed paleocurrent analysis of the area. In general, the two dimensional orientation of these features (not being able to define the spatial

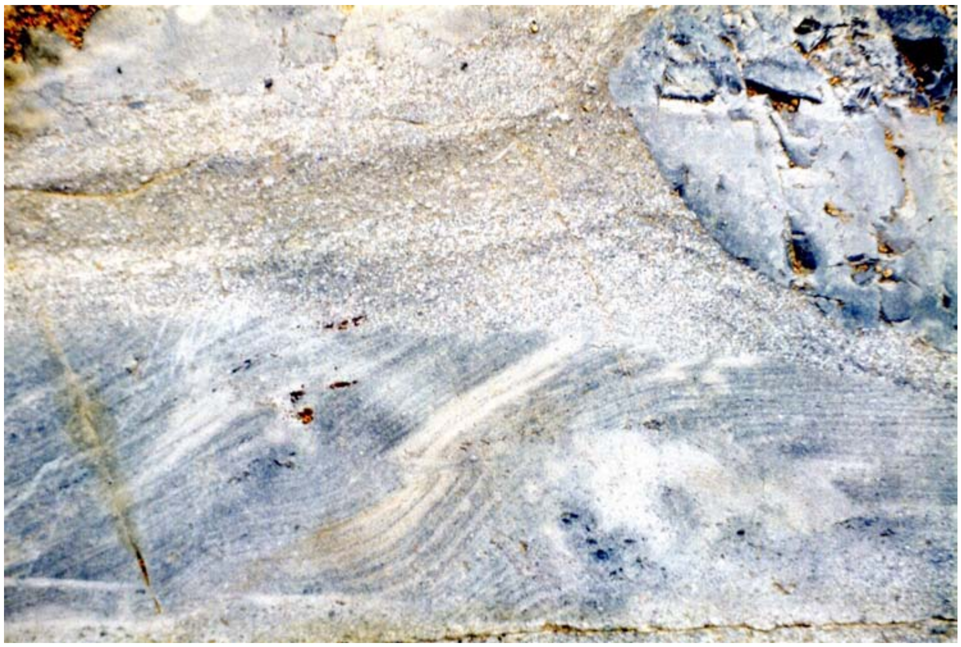


Figure 3.3. Truncation and soft-sediment faulting of sandstone from the Blue Star Formation (see Figure 2.9) caused by the transportation and re-deposition of large chert clast over these sands.

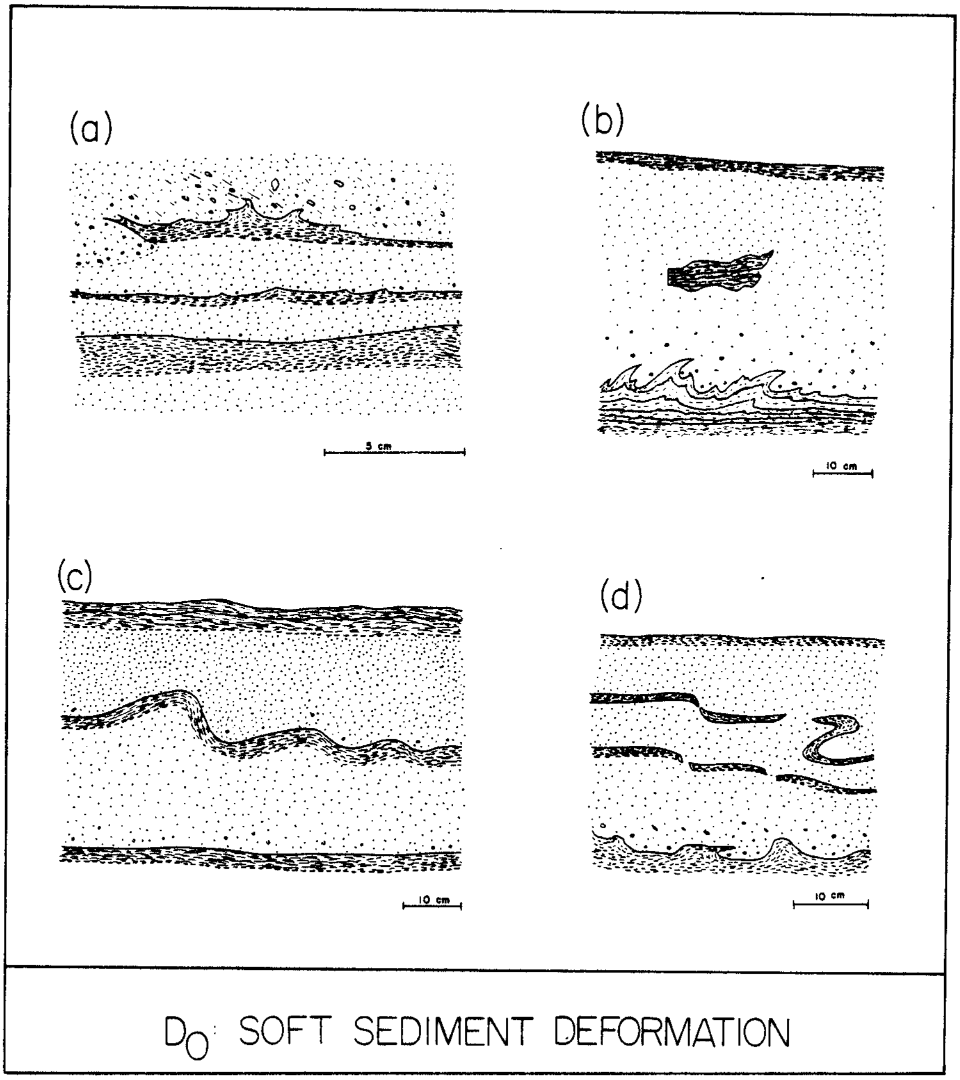


Figure 3.4. Soft-sediment deformation features from the Point Leamington graywacke including (A) proto rip-up clast, (B) rip-up clast and, (C and D) slump folds.

orientation precisely) suggests that the depositional currents flowed from somewhere between the southwest and northwest (assuming a strike rotation to horizontal).

D_1: Early Silurian Back-Thrusting

Introduction

Recognition of structures that formed during this deformation episode, and their implications, are the major concern of this thesis. D_1 structures include southward directed thrust faults, regional folds about an approximately east - west axis (present direction), and numerous other associated small-scale structures. The results of this deformation episode are here suggested to be responsible for the general distribution of rock units throughout the Exploits Terrane. Identification and interpretation of these structures is hampered by several episodes of later deformation, although once the effects of these are removed, a good understanding of the tectonics of this region during the late Ordovician - early Silurian can be obtained.

Helwig (1967) recognized a pre-Acadian generation of folds about north to northwest trending axes from the New Bay area, and also suggested that several of the important faults in that area formed during this (his F_2) deformation episode. Nelson (1979, 1981) described a post-Taconic and pre-Acadian back-thrusting event from the Notre Dame Bay area, although he only recognized one generation of regional folding. He states that "the regional plunge of these [Acadian] folds is not interpreted here as evidence for a second generation of folding, because nowhere in the map area were any mesoscopic structures observed which crosscut the regional slaty cleavage and which might reasonably be associated with a second folding event" (Nelson, 1979, pp. 88). However, this evidence does not preclude an earlier, pre-Acadian folding event. Dean (1978) did not recognize any pre-Acadian structures from east of the Hall's Bay Fault. Some other workers (e.g. Dean and Strong, 1977) have suggested that the Lobster Cove and Chanceport Faults from the Notre Dame Bay region may have formed during the deformation event named D_1 here. These authors attributed the formation of these faults to isostatic rebound of the Burlington Peninsula following continental collision, which they suggested as a mechanism to initiate "gravity sliding" (sic) of large 'slices' into the Notre Dame Bay Basin during Silurian times.

<u>The Fog Fault</u>

As previously stated, the contact between rocks of the Frozen Ocean Group and the structurally underlying sediments is everywhere marked by a fault, in contradiction to the conformable contact assumed by Dean (1977, 1978), Dean and Kean (1980), Strong (1977), and others. The failure to recognize this fault by these previous workers has resulted in the publication of several overly-complex tectonic models for the Newfoundland Appalachians (eg.

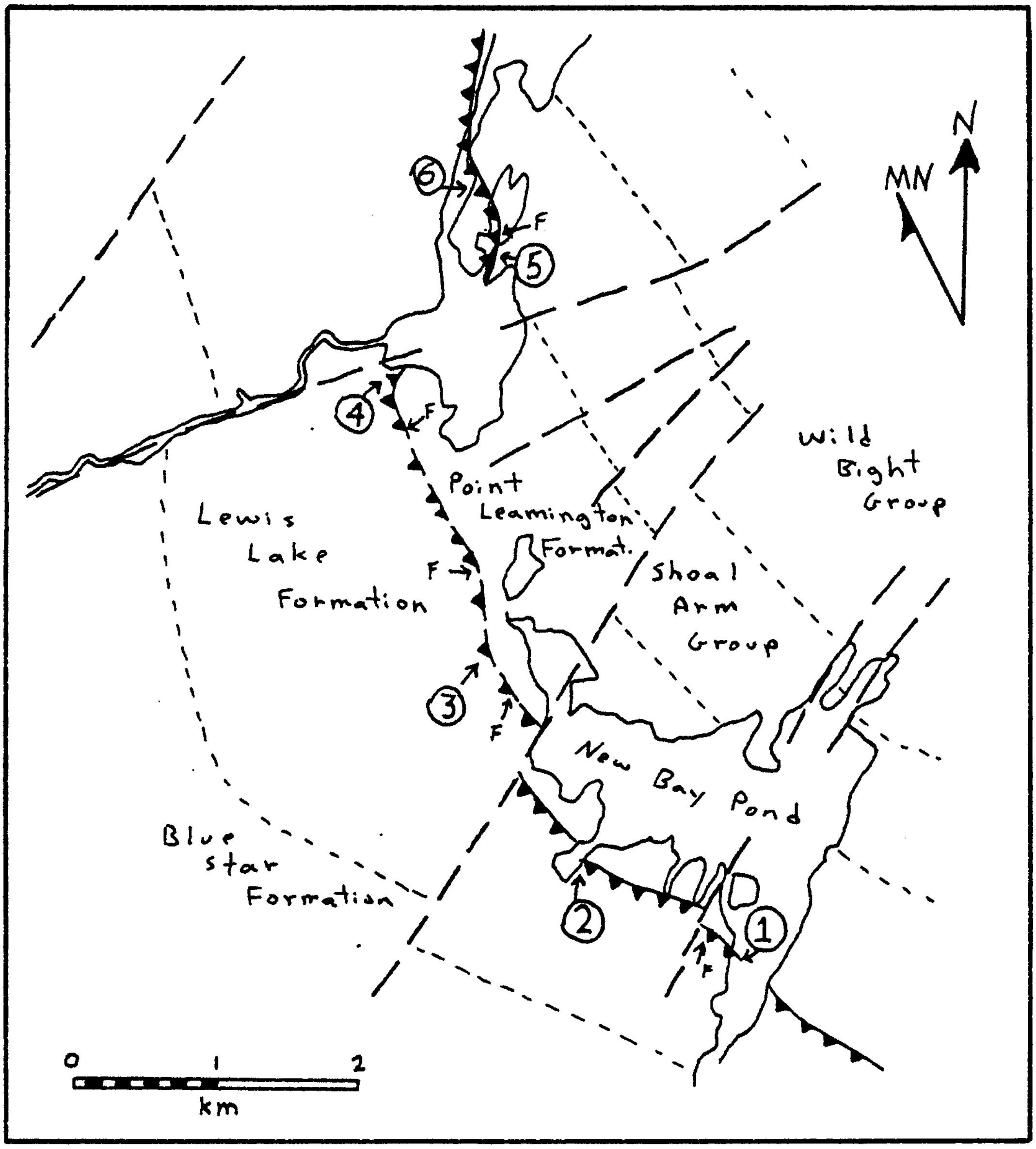


Figure 3.5. Schematic map showing locations of the Fog Fault which are discussed in the text, as well as other locations where the fault zone was observed (these are not discussed in the text). This fault is a late Ordovician (?) - early Silurian thrust that emplaced the Frozen Ocean Group over flysh-type sediments of the Point Leamington Formation, and is only one of a series of back-thrusts in central Newfoundland. See Plate 1 for details of structure.

Coleman-Saad, 1982). However, the Lewis Lake - New Bay Pond area offers at least six locations where the faulted contact between the Frozen Ocean Group and structurally underlying strata is well exposed (Figure 3.5). In no place within the map area was I able to demonstrate a conformable relationship between these two units; however, in several other localities from the area, which I will not describe here, these two formations display a less spectacular faulted contact relationship. Several of these better-exposed locations are described below in order to remove any reasonable doubt that the contact is indeed faulted, and to constrain the sense of movement along this important fault zone.

Locality 1

The most easily accessible section across the Fog Fault occurs on the west shore of the north end of New Bay Pond, just north of the causeway (locality 1, figure 3.5). Here, the Fog Fault is not itself exposed, although the contact between silicic volcanic breccia and mafic "siltstone" of the Lewis Lake Formation on the south, with the Point Leamington Formation on the north, is marked by a subdued topographic lineament containing many boulders of mafic-derived fault breccia. Immediately adjacent to the contact, graywacke beds of the Point Leamington Formation are isoclinally folded with the fold's axial trace parallel to the air-photo lineament marking the contact (Plate 1). A parasitic synform on the northern limb of this fold plunge 25 degrees northwest; because of the common rotation of linear and planar structural elements into the movement direction of shear zones (cf. Skjerna, 1979), this orientation is not assumed to be even roughly perpendicular to the direction of movement on the Fog Fault.

Locality 2

Excellent exposures along one of the small coves south of the northernmost portion of New Bay Pond have been selected as the "type locality" of the Fog Fault (locality 2, figure 3.5). Here, there is continuous exposure from the Point Leamington Formation through the Fog Fault and the associated fold, into mafic volcanics of the Frozen Ocean Group (Plate 1). The fault zone itself is about 5 meters wide and composed of strongly foliated blue-grey "mylonite" (Figure 3.6). Foliation intensity decreases gradually away from the fault although, in general, it is more intense on the southern than on the northern side of the fault. Rocks of the Lewis Lake Formation on the southern side of the fault are brecciated and cut by thin disrete shear zones for a distance of a few meters away from the fault (Figure 3.8), where they take on a "normal" appearance once again.

Field-scale rotated porphyroclasts and the orientation of fault zone parallel- and oblique-foliations (Figure 3.9), interpreted as S-C banding (cf. Berthe et al., 1979; Lister and Snoke, 1984), indicate a relative 'northern side down' and 'southern side up' sense of shear (Figure 3.9).

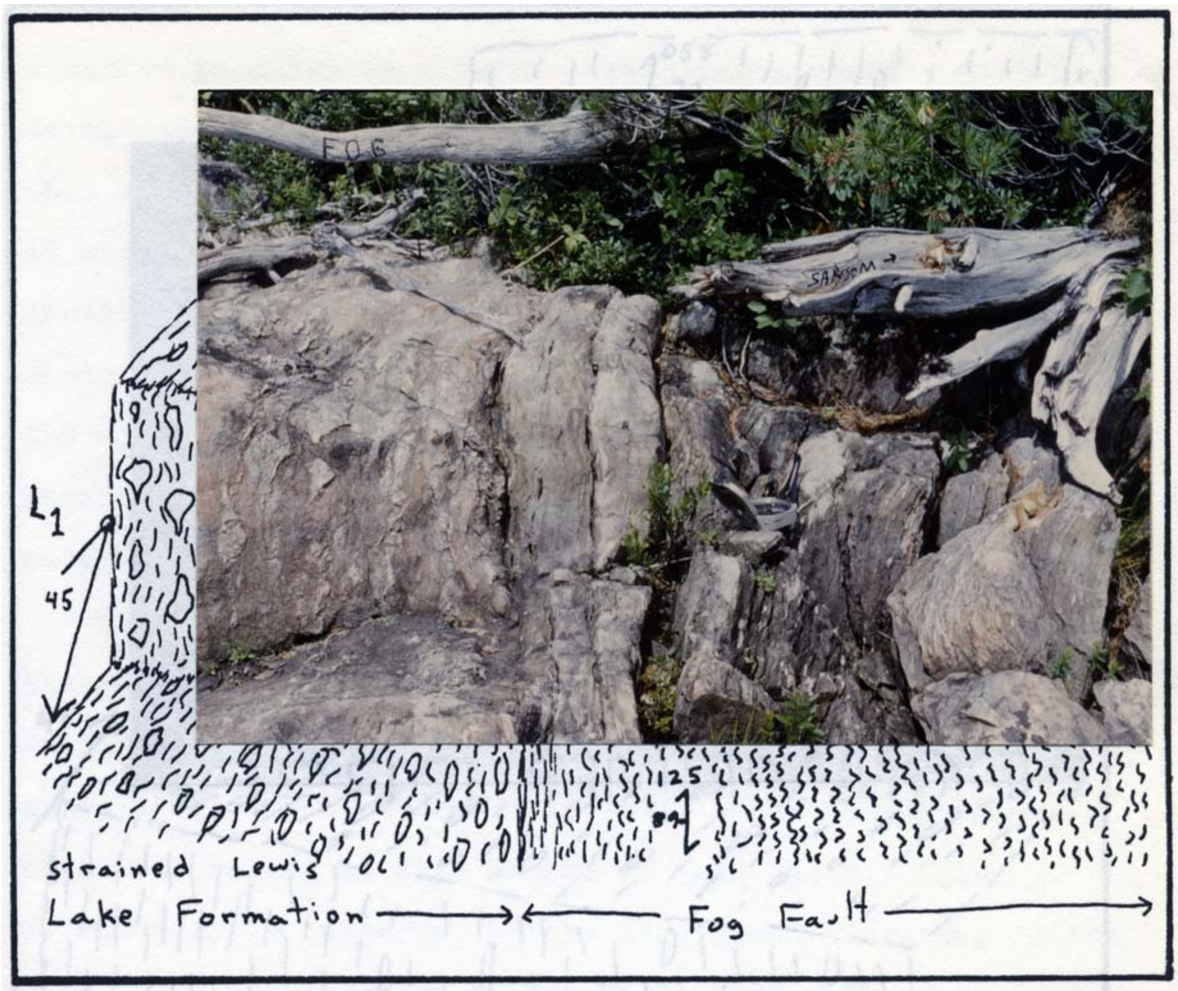


Figure 3.6. The Fog Fault from locality (2) in Third Cove. The elongated white objects enclosed in a dark matrix are altered areas which were originally randomly oriented and generally equiaxed (Figure 2.6 shows an undeformed equivalent).

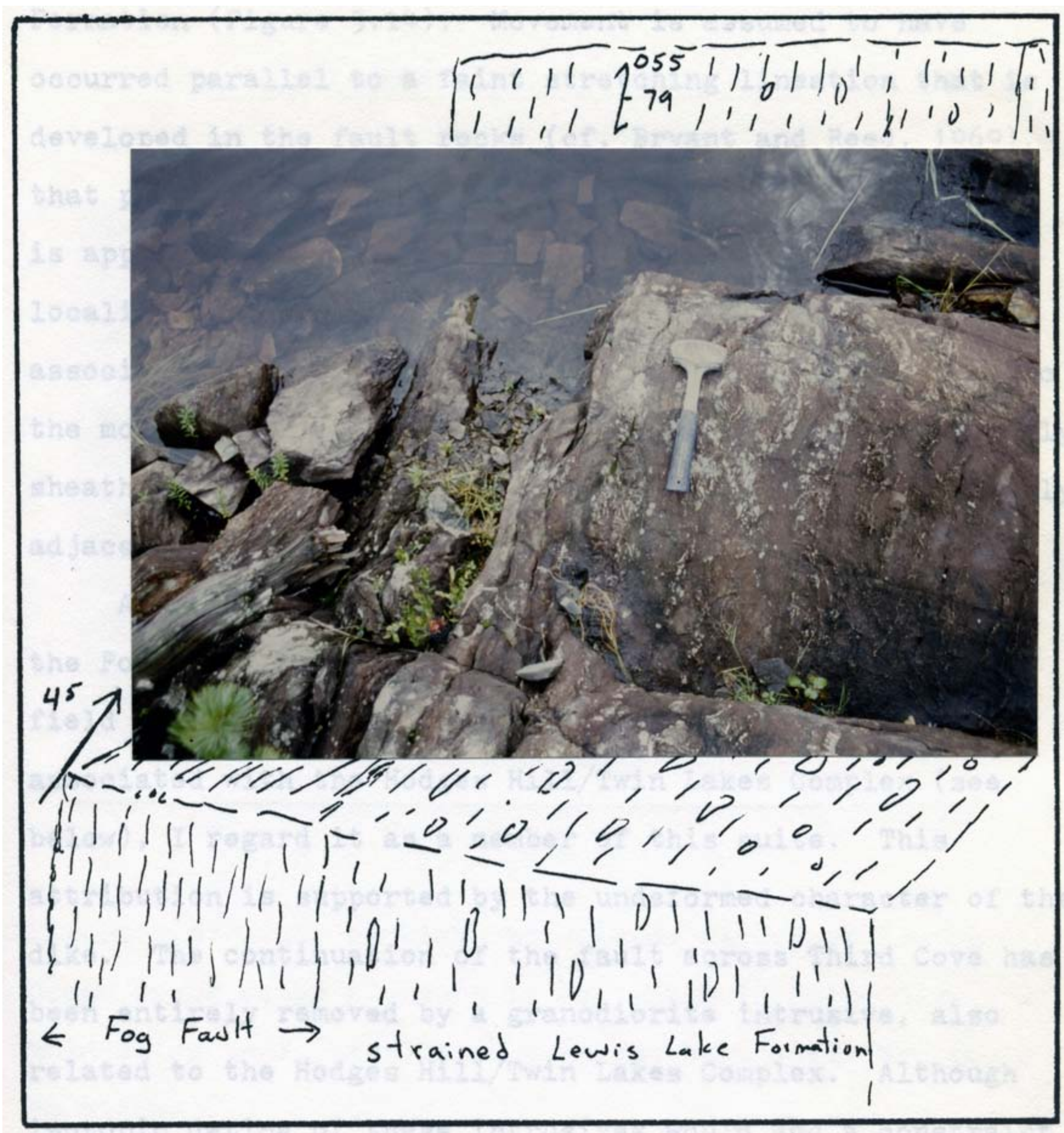


Figure 3.7. Frozen Ocean Group rocks immediately adjacent to the Fog Fault in Third Cove. Photograph is taken looking "down lineation".

When the effects of later folding are removed these indicate that rocks of the Frozen Ocean Group were thrust towards the south and over the underlying Point Leamington Formation (Figure 3.14). Movement is assumed to have occurred parallel to a faint stretching lineation that is developed in the fault rocks (cf. Bryant and Reed, 1969), that plunges 45 degrees to the southeast. This lineation is approximately parallel to fold hinge lines observed at locality 1 (Figure 3.13), suggesting that the folds associated with this fault have been severely rotated into the movement direction of the Fog Fault and are most likely sheath folds. This in turn suggests that rocks immediately adjacent to the Fog Fault have suffered large strains.

A small 10 cm wide mafic dike intrudes a portion of the Fog Fault zone at this locality and because of its field and petrographic similarity to the mafic intrusives associated with the Hodges Hill/Twin Lakes Complex (see below), I regard it as a member of this suite. This attribution is supported by the undeformed character of the dike. The continuation of the fault across Third Cove has been entirely removed by a granodiorite intrusive, also related to the Hodges Hill/Twin Lakes Complex. Although isotopic dating of these intrusives would add a constraint to the timing of movement along the Fog Fault, it is likely that the intrusives are much younger (Devonian) than the well constrained (early Silurian) age of the Point Leamington Formation, and would not contribute significantly to the problem.

Figure 3.8. Slab showing brecciated nature of Frozen Ocean Group rocks adjacent to Fog Fault in Third Cove. A thin shear zone (dark) also cuts the slab (Specimen is 10 cm across).

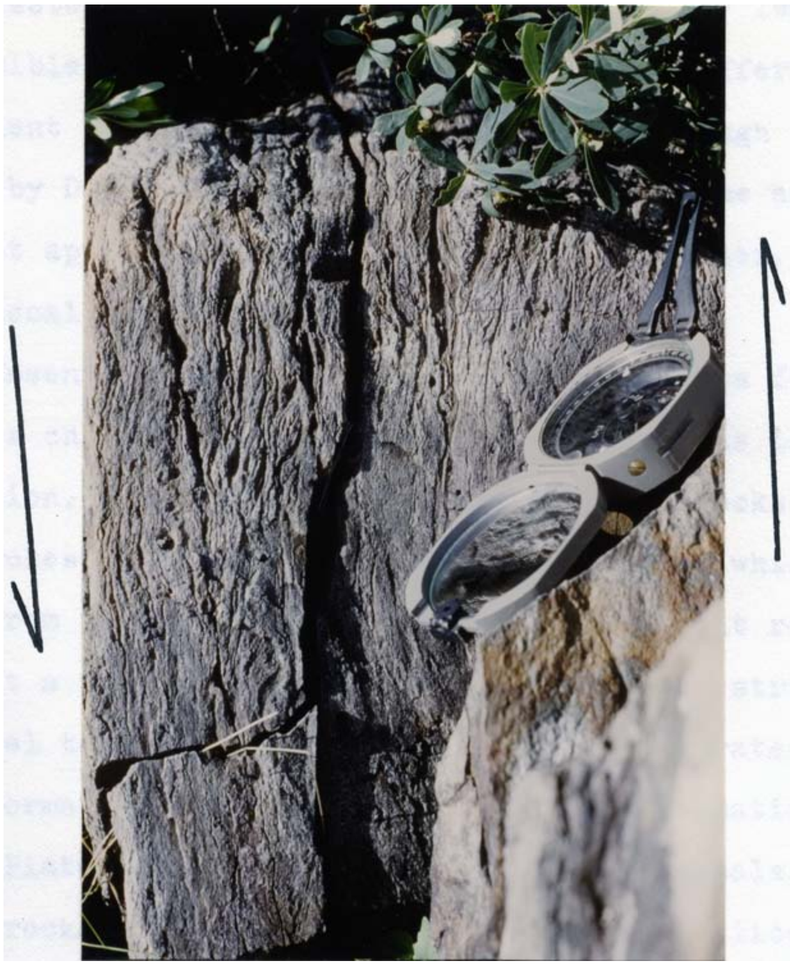


Figure 3.9. Close-up of the Fog Fault from Third Cove, showing rotated porphyroclasts and oblique foliation, both suggesting sense of motion indicated by arrows. Photo taken looking west.

Locality 3

Locality 3 along the abandoned lumber road at the northwestern end of New Bay Pond (Figure 3.5) is easily accessible by motorcycle or boat, and also offers an excellent view of the Fog Fault Zone. Although a fault was noted by Dean (1977, 1978) in this location he apparently did not appreciate its significance but, rather, attributed only local importance to it.

Essentially continuous outcrop across the fault exposes chloritic mafic volcanics of the Lewis Lake Formation, altered, rusty-weathering fault rocks, and graywackes of the Point Leamington Formation which face away from the fault zone (Plate 1). The fault rocks exhibit a pervasive vertical foliation which strikes parallel to a pronounced lineament that separates the Lewis Lake Formation from the Point Leamington Formation in this area (Plate 2). Microscopic examination reveals that the fault rocks are composed of recrystallized siliceous material containing abundant iron oxides and carbonate veins. The fault material may originally have been rhyolite. No macroscopic sense of shear indicators were obtainable from this locality; however, two foliation orientations defined by iron oxide rich zones were observeed in thin section. If these can be interpreted as S and C surfaces (cf. Berthe et al., 1979; Lister and Snoke, 1984)) then they suggest a relative 'northeast side up' and 'southwest side down' sense of displacement on the fault at this locality.

Locality 4

Locality 4 on the southwestern side of the lower Lewis Lake (Figure 3.5) exhibits a well-defined topographic lineament separating Frozen Ocean Group rocks from the Point Leamington Formation. Although outcrop in this valley is very sparse, abundant fault breccia boulders may be found as bedload in streams, and rocks on either side of the lineament are more strongly foliated than is typical of either rock unit. On a path cut by Abitibi-Price Co., the Fog Fault is exposed (locality 4, Fig. 3.5). Here, the fault dips at 55 degrees to the west and is composed of orange weathering siliceous material similiar to that at locality 3 (Figure 3.10). Microscopic observation of these fault rocks has revealed some sense of shear indicators, including asymmetric foliations around porphyroclasts and S-C banding, suggesting a 'west side down' and 'east side up' displacement sense across the Fog Fault. The movement is again assumed to be parallel to a stretching lineation developed on these fault rocks (Figures 3.13 and 3.14).

Locality 5

The outcrops on the jetty at the northern part of the southern Lewis Lake compose locality 5 of the Fog Fault (Figure 3.5). As the fault is approached from the east at this locality, both the spacing and intensity of a

Figure 3.10. The Fog Fault as it outcrops at locality 4 south of Lewis Lake.

Figure 3.11. Folded Point Leamington Graywacke adjacent to the Fog Fault at locality 5 on the Lewis Lake. Photograph taken looking south.

northeast striking, vertically dipping cleavage become more intense: these planes are locally coated with southwestward plunging slickenlines. Immediately adjacent to the trace of the fault the Point Leamington strata can be shown, by the use of graded bedding, to face away from the contact with the Lewis Lake Formation. In fact, these beds can be shown to be folded in a sheath-like manner, with the limbs plunging approximately 30° to the southwest (Figure 3.11). This indicates high shear strains at this locality (Cobbold and Quinquis, 1980).

The Fog Fault is observable in outcrops located a short distance (50 meters) from the shore, where it exhibits a northeast striking, steeply westward dipping foliation. The map pattern from this location (Plate 1) shows that the fault cuts stratigraphically down into the Point Leamington Formation towards the north, while beds within the Lewis Lake Formation remain parallel to the curved trace of the fault. This is interpreted as a ramp structure which was subsequently rotated, during later folding, to expose a cross-sectional view. This ramping-down to the northwest explains the apparent thinning (cf. Dean, 1978) of the Point Leamington Formation in this direction (Plate 1).

Locality 6

Fault locality 6, on northern Lewis Lake (Figure 3.5) offers very good outcrop of deformed mafic volcanic rocks

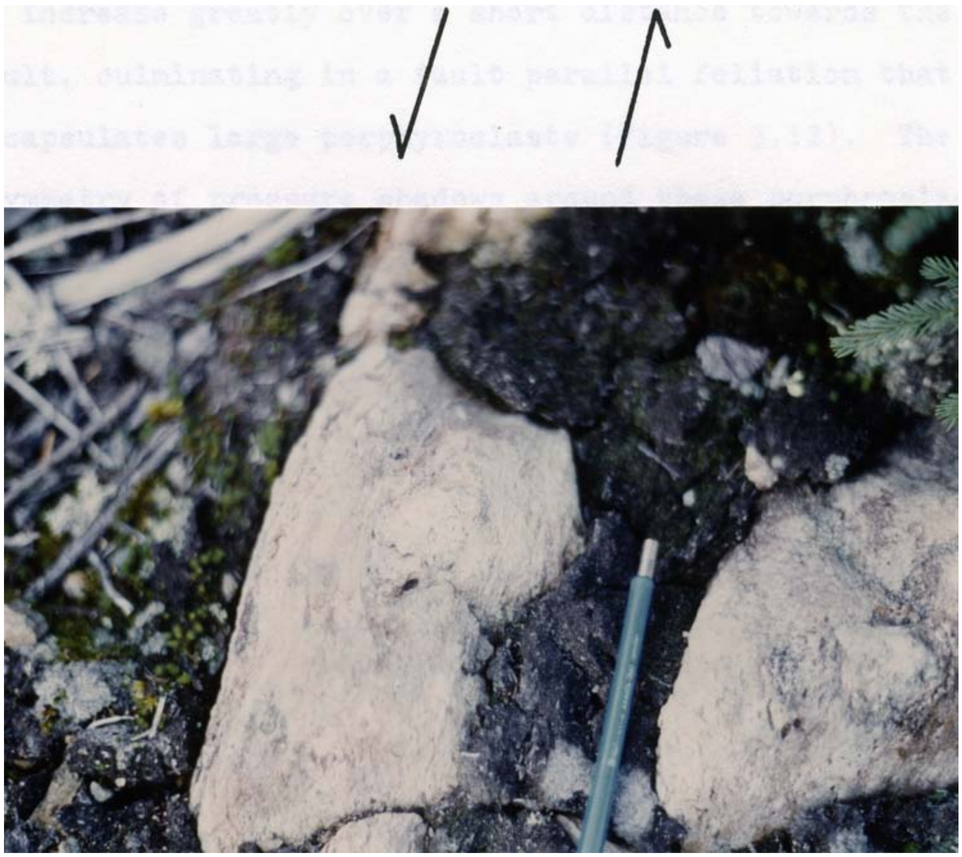


Figure 3.12. Porphyroclasts in mafic volcanic rock near Fog Fault on West Arm Brook (locality 6). Fabric asymmetry suggests sense of shear indicated by arrows. (Photo taken looking northwest).

of the Lewis Lake Formation adjacent to the Fog Fault zone. The rocks become intensely foliated and strain is presumed to increase greatly over a short distance towards the fault, culminating in a fault parallel foliation that encapsulates large porphyroclasts (Figure 3.12). The asymmetry of pressure shadows around these porphroclasts again suggests a sense of movement whereby rocks of the Frozen Ocean Group moved down and towards the southeast with respect to the Point Leaminton Formation (Figure 3.12). When the beds are restored to their presumed pre-Acadian folding orientation (Figure 3.14), it becomes apparent that they were thrust towards the south over the Point Leamington graywackes. The central portions of the fault zone occur as very small, low outcrops in a swampy area between the higher outcrops of the Frozen Ocean Group to the west, and the Point Leamington Formation to the east. The Point Leamington Formation can be shown, again, to face away from the fault contact for a distance of approximately 10 meters. At this distance an isoclinal fold closure is exposed: it strikes parallel to the fault trace although some late kink folding is evident as well.

Regional Extension of the Fog Fault Beyond the Study Area

All lineations observed to be associated with the Fog Fault have been plotted on an equal area stereonet (Figure 3.13), and restored to their presumed post-D1 orientation

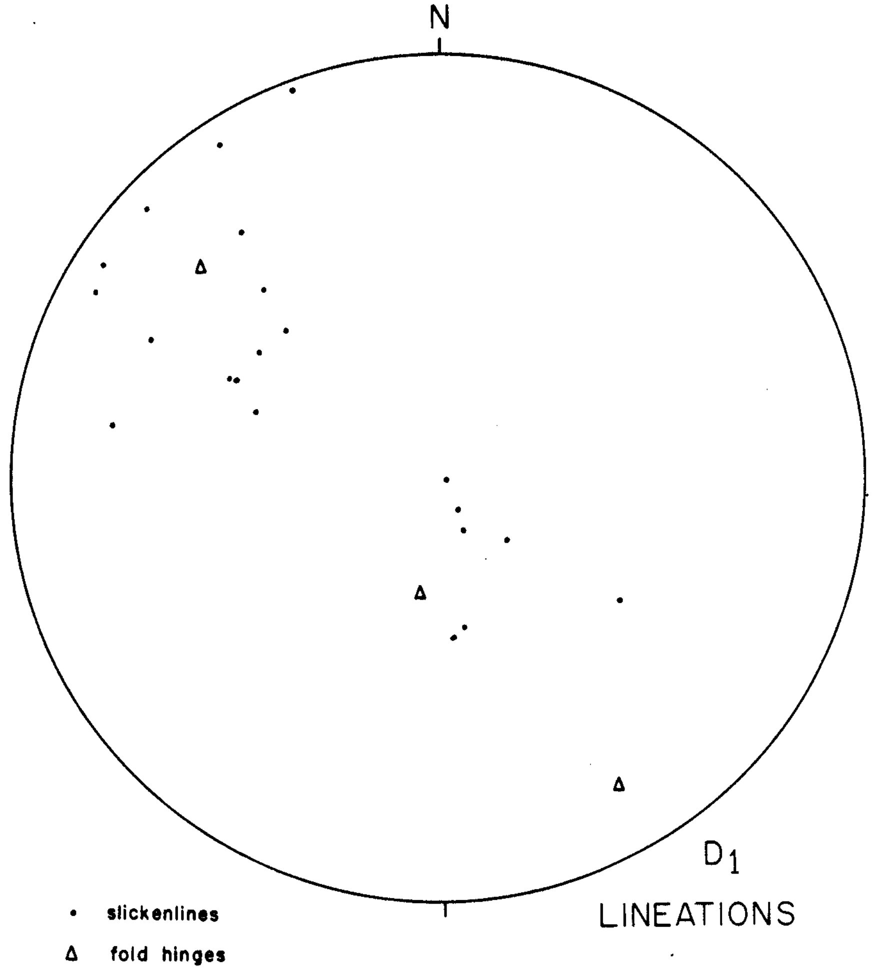


Figure 3.13. Lower hemisphere Equal area net showing the orientation of linear elements associated with D_1 Fog Fault zone.

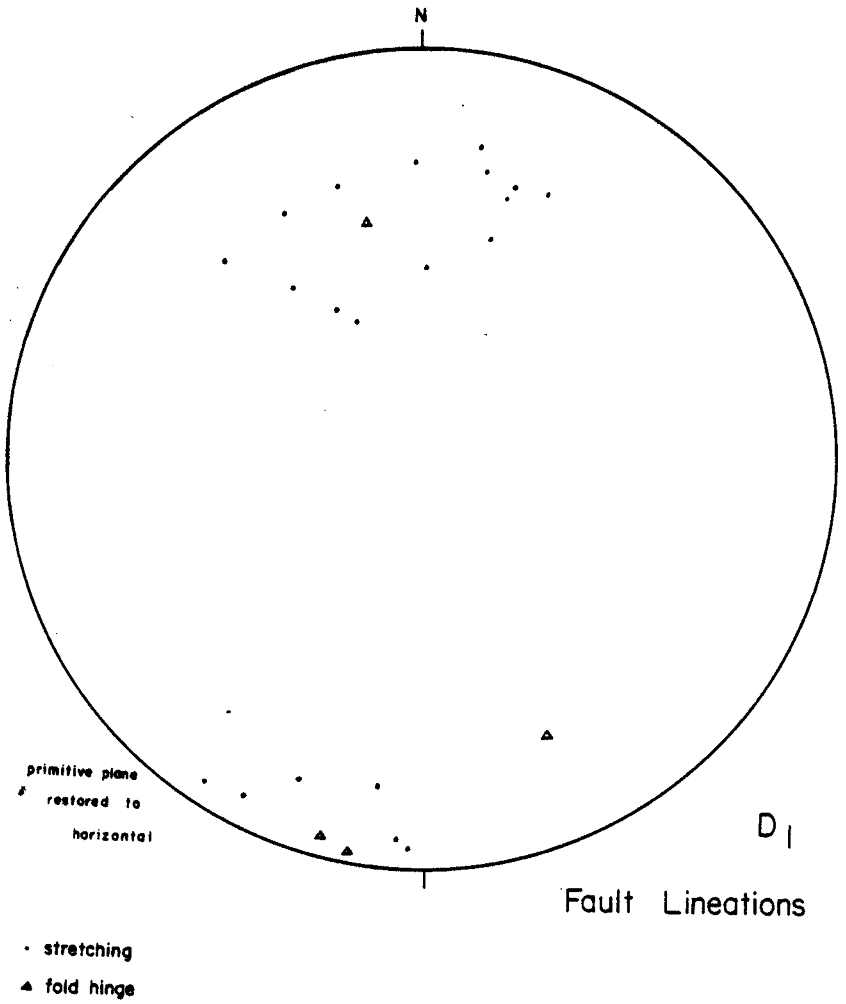


Figure 3.14. Lower hemisphere Equal area net showing D_1 lineations with the effects of later deformations removed by rotating bedding back to the primitive plane.

by simply rotating bedding orientations back to the horizontal plane (Figure 3.14). This effectively removes the tilting imposed by Acadian folding, although it does not take into account any deviation of bedding planes from the horizontal incurred during D_1. The result (Figure 3.14) shows two point maxima indicating nearly horizontal north-south oriented lineations. The group that plunge shallowly to the north have a slightly steeper plunge than those that plunge to the south; when considered with the map pattern (Plate 1), which shows several small footwall ramps which cut stratigraphically up towards the south, it can be reasonably assumed that (1) the Frozen Ocean Group was thrust over the Point Leamington Formation and, (2) the rocks were thrust from the north towards the south. This interpretation is supported by the sense of shear indicators obtained from the outcrops described above.

In order to better-understand the regional tectonic significance of the Fog Fault it was first necessary to trace its northwestward extensions beyond the study area. On an air-photo mosaic of the area at a scale of 1:35,000 (approximate) the Fog Fault forms a distinctive lineament marked by higher, rougher terrain on the southwest, and flatter, generally low-lying terrain on the northeast. Comparison of the trace of this lineament (Plate 2) with confidential geologic maps of the area (Noranda Exploration Company, 1972) suggests that the Fog Fault has been folded, and can be traced generally down-section to the vicinity of South Lake (Plate 2), where oceanic/island arc-type basement of the South Lake Ophiolite is exposed (Lorenz and Fontain, 1982; Dean, 1977, 1978). Examination in the field of the Cramp Crazy Fault, the probable extension of the Fog Fault near South Lake (Plates 2 and 3), revealed only a linear till-filled depression. A detailed geometric analysis of the probable northern extension of the Fog Fault is not possible with the amount of existing information. However, a liberal interpretation of regional-scale lineaments (Plate 2) shows numerous fold packets bound by faults; this bears a remarkable resemblance to an antiformal stack of thrust sheets developed over a footwall ramp in a thrust system (cf. Boyer and Elliott, 1982). Most of these suggested thrust faults are parallel to bedding planes, although numerous ramps up to higher stratigraphic horizons are recognized.

Deformation of the Contact Between the Shoal Arm Group and the Point Leamington Formation

Because the contact between the Point Leaminton Formation and the Shoal Arm Group was observed to be structurally complex across a distance approximately equal to the combined thicknesses of the Killer Terr Member and the Drowning Point Formation a detailed discussion of the style and cause of this disruption seems warranted. The area best-exhibiting this deformation is exposed at the northeastern end of New Bay Pond (Plate 1 and Figure 3.15). From the Shoal Arm Group below, deformation is observed to gradually increase into and through the Killer Terr Member, becoming quite complex in appearance near the base of the Wacke Island Member. A fault contact is recognized between the Killer Terr and the Wacky Island Members of the Point Leamington Formation and, where the outcrop is abundant enough to permit detailed mapping, this contact is marked by a duplex structure (Figure 3.15). Even though the Killer Terr Member exhibits complex internal deformation the regionally recognized stratigraphy is preserved across this zone. However, distal shales and occasional sandstone beds below and within the Killer Terr Member are juxtaposed with more proximal massive sandstones of the Wacke Island Member above, suggesting that considerable amounts of displacement may have been accomodated along this zone.

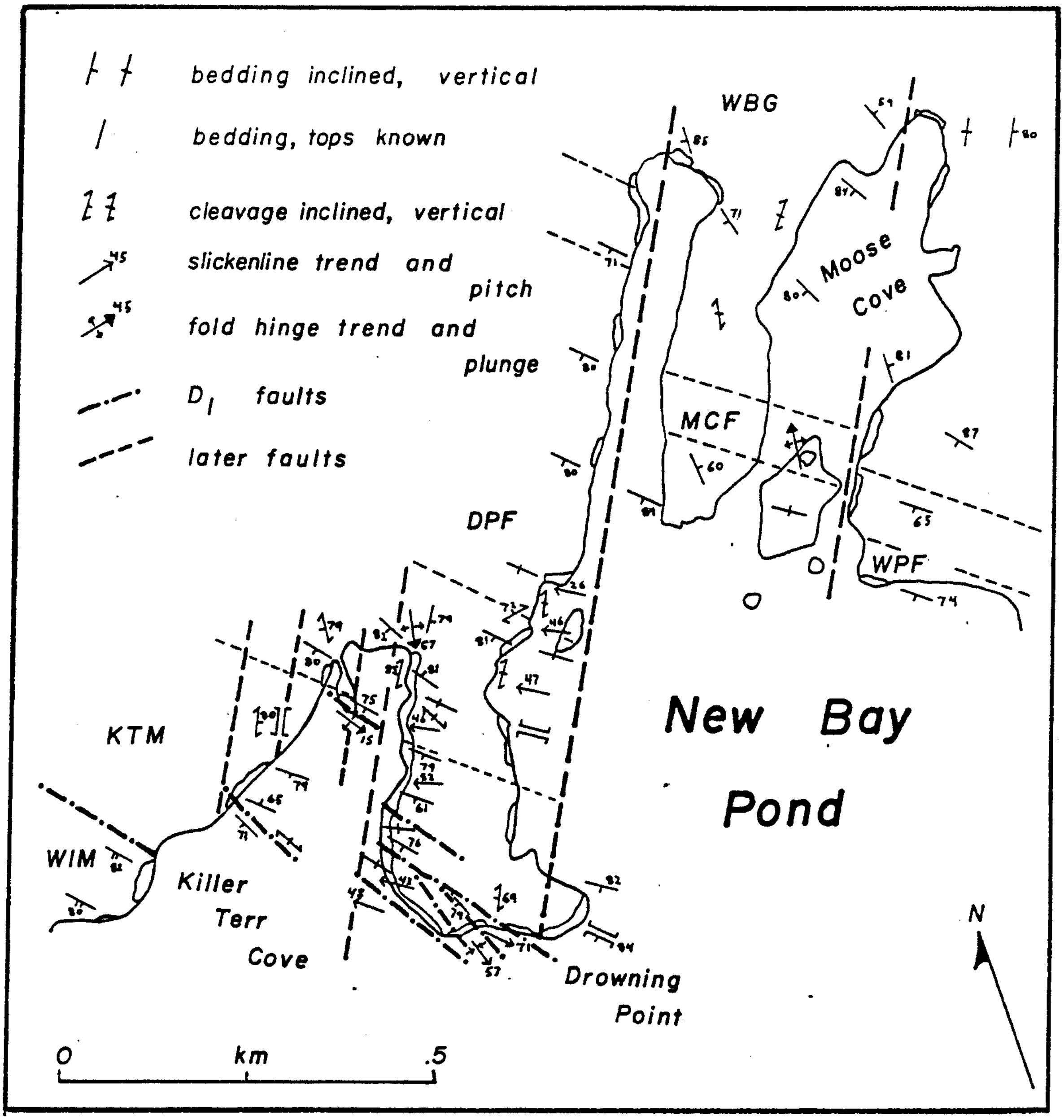


Figure 3.15. Map of the northeastern-most portion of New Bay Pond. Note especially the northwest trending faults that are both oblique and parallel to bedding planes: these define a duplex structure at the base of the Point Leamington Formation.

Figure 3.16. Folds above a decollement in the Killer Terr Member at Drowning Point.

Figure 3.17. Intrafolial rootless isoclinal fold of graywacke and a kink band in the Killer Terr Member at Drowning Point.

Many styles of deformation are recognized from within the Killer Terr Member. Some obvious slump folds occur, although the origin of numerous other folds is somewhat enigmatic. At Drowning Point on New Bay Pond numerous folds with wild variations in hinge line orientations may be observed (Figure 3.16). They typically occur over a basal detachment or décöllement zone and, despite the radical changes in hinge line orientations over very short distances, the axial planes have a fairly constant orientation. Their orientation suggests that these fold packets moved towards the south, whether they had a slump, tectonic, or combination origin. In numerous places detached blocks of "graywacke" may be found in an argillaceous matrix and these are locally in the form of rootless intrafolial folds (Figure 3.17). It is also common for these wacke "beds" to be boudinaged (Figure 3.18), and the occurence of a few boudenaged mafic dikes of the Hodges Hill Batholith (Figure 3.19) demonstrates that some of the structures in the region are of post-Devonian age (see below).

The orientations of fold hinge lines, slickenline fibers and fault planes are all somewhat variable (Figure 3.20), even when they are "restored" by graphically rotating the bedding planes back to the horizontal (Figure 3.21). However, when structures that are clearly associated with late, cross-cutting faults are removed from consideration (Figure 3.21b), a much clearer picture of the earlier deformation emerges (Figure 3.21a). Numerous

Figure 3.18. End of a long boudin of graywacke in the Killer Terr Member; it indicates at least 50% layerparallel extension because the other end was not observed within a distance equal to its length.

Figure 3.19. Boudinaged mafic dike (Hodges Hill/Twin Lakes Type) in the Killer Terr Member, documenting some post-Devonian deformation.

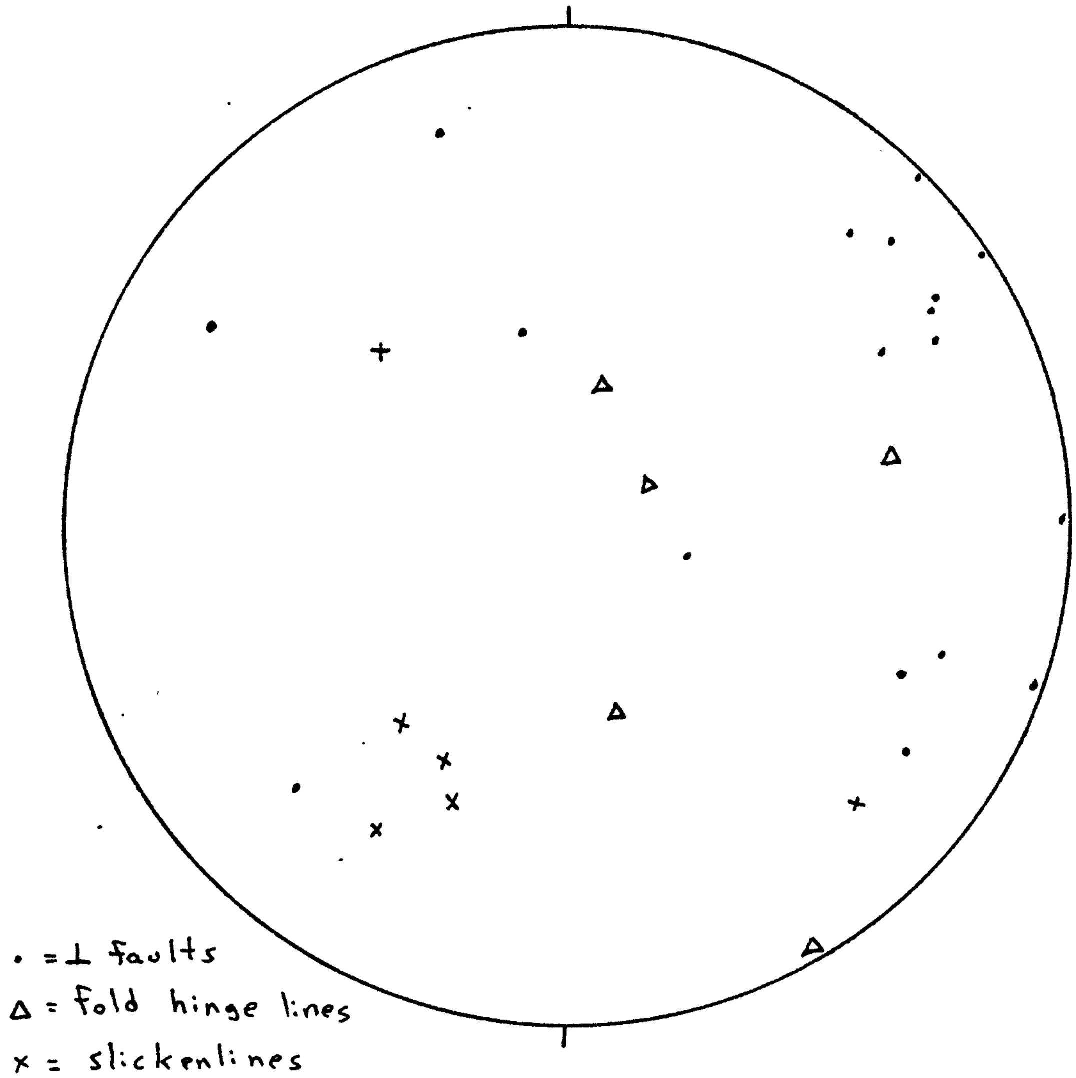
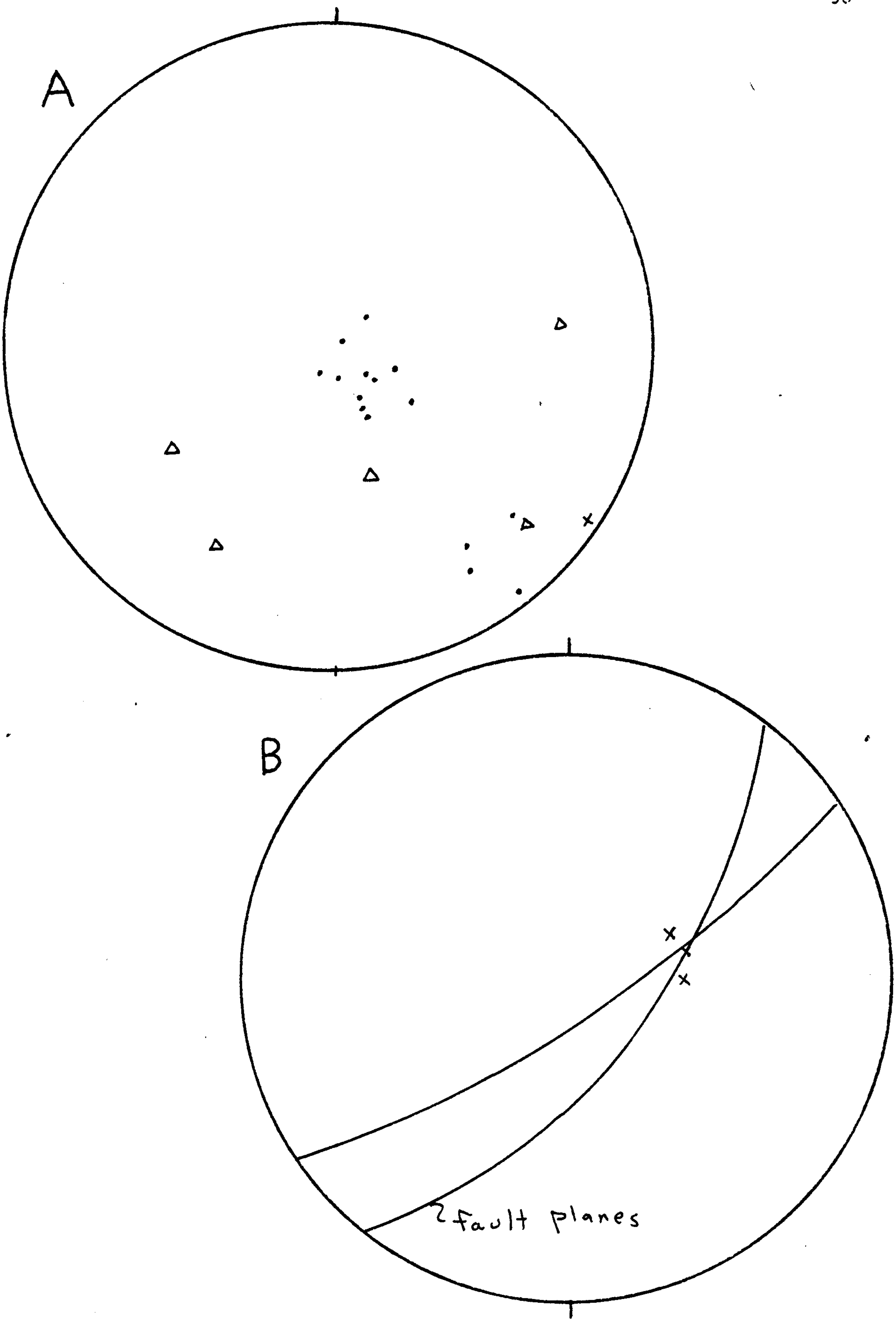


Figure 3.20. Lower hemisphere equal area net showing the orientation of faults, slickenlines and fold hinge lines in the Killer Terr Member.

Figure 3.21. (A) shows the orientation of D_1 structures with the primitive plane rotated back to the horizontal. Two sets of faults are associated with the duplex structure at the base of the Point Leamington Formation; the first was subhorizontal and parallel to bedding planes, while the second dipped shallowly towards the northwest, consistent with a south-southeastward direction of thrusting. Fold hinge lines show some degree of rotation into the movement direction. (B) shows the orientation of younger structures which cross-cut the duplex.


A
B
2 fault planes

faults are seen as originally being bedding plane parallel, in association with a northwesterly dipping set in the duplex structure. Slickenlines indicate a south-southeast sense of movement on essentially horizontal planes and fold hinge lines, whether they had a slump or tectonic origin, show some rotation into the movement direction along the faults. Most of the structures at the base of the Point Leamington Formation are thus clearly related to an early deformation episode involving north-northwest to south-southeast relative movement of the Wacke Island Member over the Shoal Arm Group. The parallelism between the sense of movement which produced these structures, and the movement direction on the Fog Fault, suggests a common origin. It is suggested here that the fault system at the base of the Point Leamington Formation represents a "propigating" or blind thrust (cf. Boyer and Elliott, 1982) developed under the possibly emergent Fog Fault (Figure 3.22). Had deformation progressed beyond its present state, this fault system might have incorporated another slice or "basement horse" consisting of the Wacke Island Member into the allochthon containing the Frozen Ocean Group.

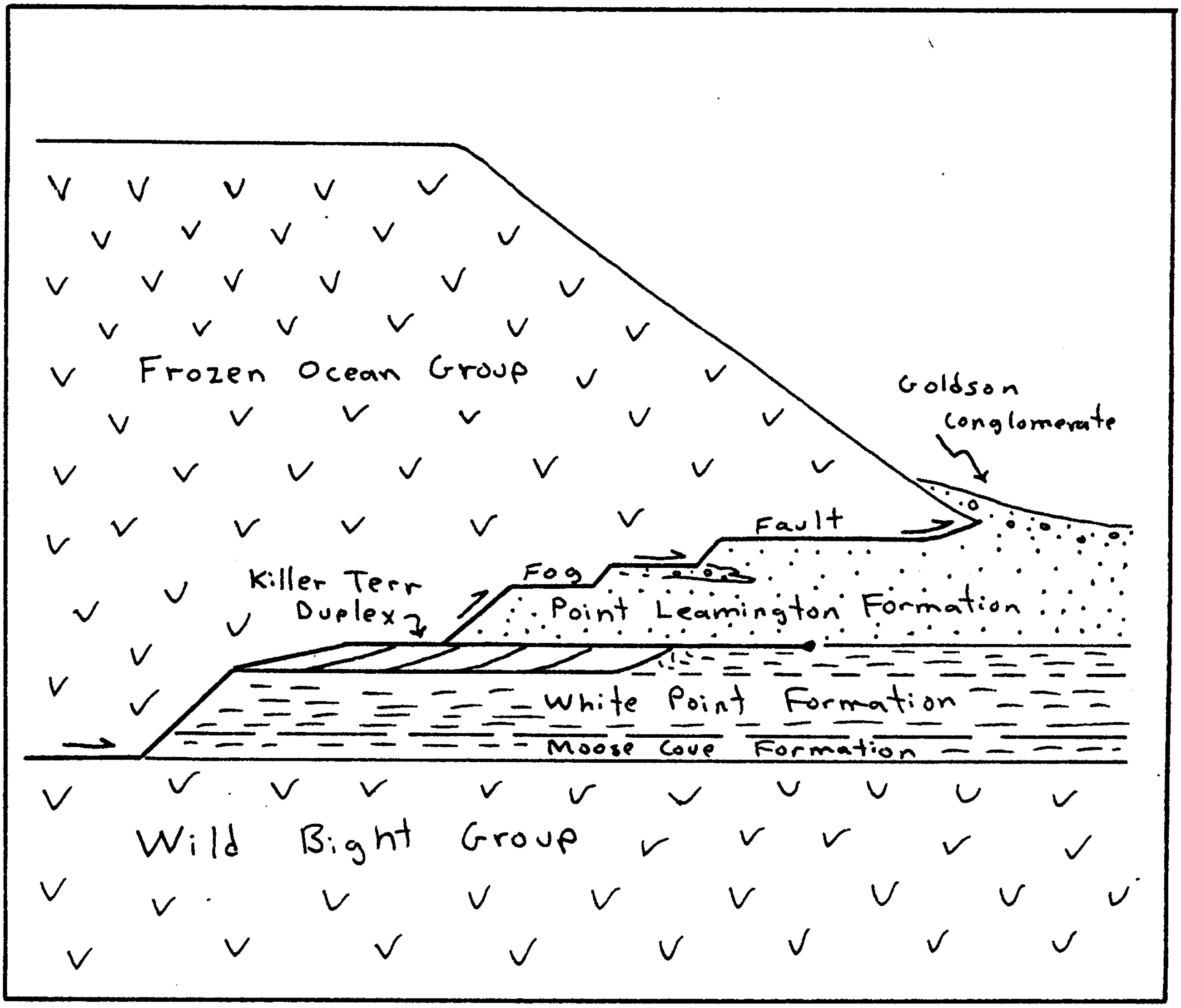


Figure 3.22. Schematic restored cross-section showing the proposed relationship of the duplex structure at the base of the Point Leamington Formation to the Fog Fault.

Folds of the First Generation (F_1)

The general distribution of lithologies within the northwestern portion of the Exploits Terrane (Plate 3), coupled with the doubly plunging folds evident on the air photo lineament map of the same region (Plate 2), suggests to me that these rocks may have experienced two generations of folding. The first generation is suggested to have been contemporaneous with the late Ordovician - early Silurian back-thrusting event described in the previous section, while the second generation is of Acadian age and is described in a later section. Folds of this generation include those of local importance, such as that exhibited by the Point Leamington Formation immediately below the Fog Fault, and also, generally east-west trending regional-scale structures (Plate 3) which are probably antiformal stacks developed over footwall ramps (cf. Figure 3.22). Although the amount of reliable regional-scale structural data supporting the existence of these folds is still sparse, it is suggested that the rare, northwest striking spaced cleavage observed in the Frozen Ocean Group may be related to this folding generation.

D_2: Pre-Batholith Right Lateral Strike Slip Faulting

Faults that are assigned a D_2 age are those that are demonstrably pre-Twin Lakes/Hodges Hill Batholith in age, are cut by the regional cleavage and, are generally north-northeast trending. They are slightly more northerly trending than those assigned a D_5 age. Locally good exposure of these faults coupled with offsets of distinctive marker horizons around the northern portion of New Bay Pond demonstrates their dextral offsets, with displacements ranging from a few cm to approximately .5 km on individual faults (Plate 1). This sense of offset is also supported by the stepping directions of numerous fibrous slickenlines that trend parallel to these faults and plunge gently to the southwest and northeast (Figure 3.25), suggesting some kind of oblique strike slip - thrust system origin with relative uplift of the terrane to the west. This is consistent with the generally steeply westward dip of these faults. A total dextral displacement of about 3 km is estimated for these faults across the width of the map area (Plate 1), although some subordinate sinistral offsets (Total = .5 meter) are recognized as well.

Figure 3.23. Boulder containing chloritized slickenside surfaces in Point Leamington Graywacke. This is representative of a suite of shallowly southwest plunging slickenlines which are parallel to faults of D2 age, and indicate dextral motion on these faults (from south of Lewis Lake, Plate 1).

Figure 3.24. Boulder of mineralized fault breccia from fault zone on New Bay Pond. These faults are predominantly strike slip faults, although some thrusting may have occurred on them as well. Photo taken looking south.

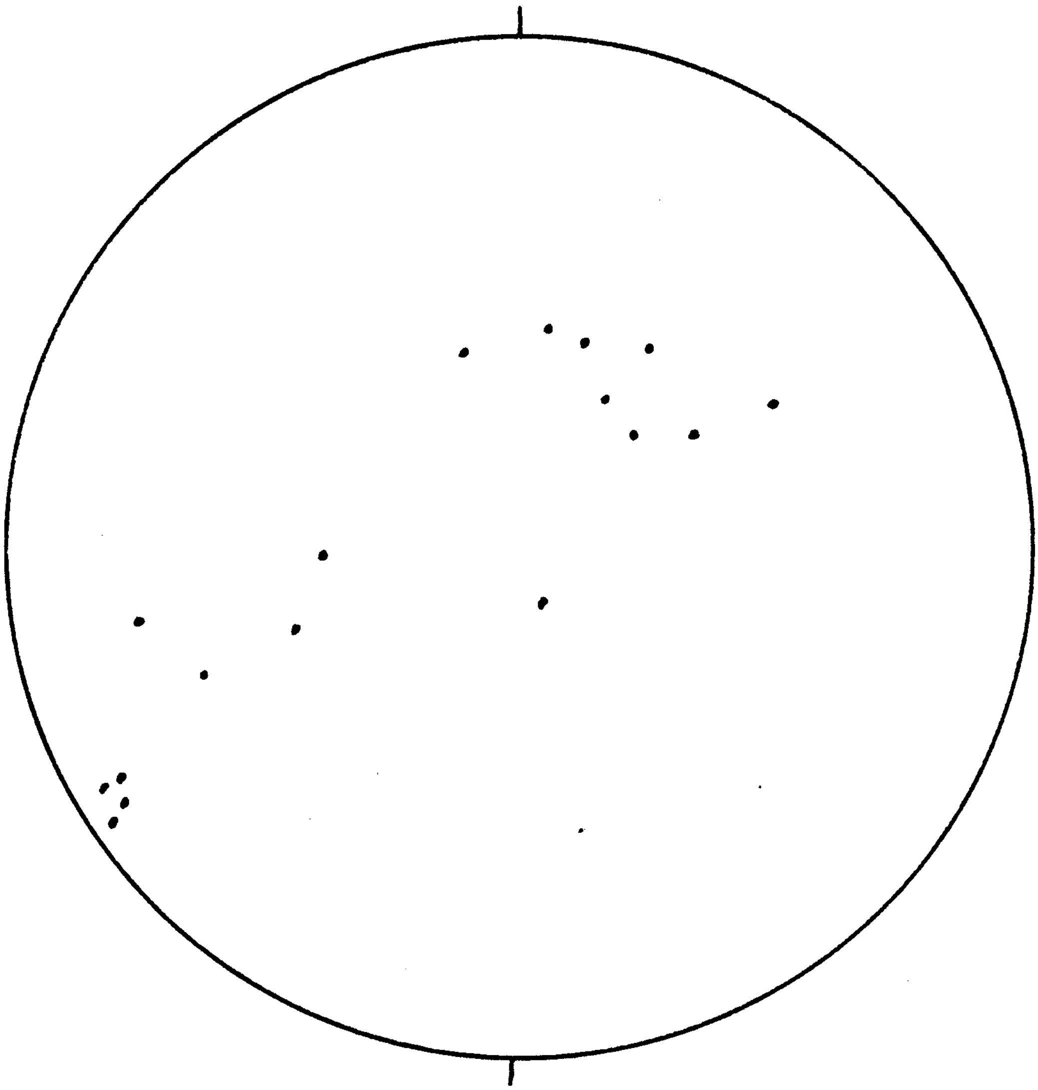


Figure 3.25. Lower hemisphere Equal area net showing orientations of slickenlines associated with D_2 fault zones. (primitive plane restored to horizontal).

D_3: Acadian Regional Folding and Cleavage Development

The Acadian Orogeny has traditionally been regarded as "the main" deformation episode to affect rocks of central Newfoundland (Dewey et al., 1983, and references therein). Structures typically attributed to this "event" include northeast trending folds along with an associated axial planar cleavage. Although there is a northeast trending cleavage in rocks of the Frozen Ocean Lake area (Plate 1; Figure 3.2), northeast trending folds were found to be extremely scarce. In the rare instances where northeast trending folds were observed they were found to be restricted to layers of low competence, such as the shaly horizons in the Shoal Arm Group (Plate 1). This apparent scarcity of Acadian-related folds in the Frozen Ocean Lake - New Bay Pond area is somewhat puzzling, especially in the light of their abundance elsewhere in central Newfoundland. If, as a result of D_1 deformation, layers in the area were oriented at a high angle to the Acadian shortening direction, then the strain may have been accomodated by homogeneous shortening and thickening of these layers. It is also possible that some Acadian shortening in the area was accomodated within the more competent layers by dissolution and mass transfer along cleavage surfaces. This is supported by the concentration of iron-oxide residue along these surfaces, by their micro-stylolitic nature, and by the common occurrence of offset markers across cleavage planes. It is also noteworthy that the northwest trend of the Seal Bay Fold (Plate 3) could result from the interference of an early (D_1) east-west trending fold and a later (Acadian) north-south trending fold set.

D_4: Batholith Intrusion

Numerous batholiths occur in central Newfoundland and their formation is usually attributed to crustal anatexis related to the Devonian Acadian Orogeny (Dewey et al., 1983). The Hodges Hill/Twin Lakes Pluton intrudes rocks of the Frozen Ocean Group and, although it has not been isotopically dated, cross-cutting relationships suggest that it is probably also of Devonian age. This pluton is surrounded by a small ($<$ 1 km) contact metamorphic aurole which is best exhibited by the Point Leamington Graywacke because of the abundance of carbonate nodules within it. As the pluton is approached these nodules which, in their non-thermally metamorphosed state weather out forming cavities in the rock, begin to stand out as concentrically zoned knobs (Figure 4.1). This is probably a result of the carbonate's metamorphism to a calc-silicate mineral such as wollastonite (cf. Miyashiro, 1973).

Near the margins of the Hodges Hill/Twin Lakes Pluton, dikes and apophyses which are common in the whole area, become particularly abundant. On the northeast shore of New Bay Pond (Plate 1) a spectacular diatremic breccia marks the contact between the pluton and the thermally metamorphosed sediments (Figure 4.2). This breccia contains clasts lithologically similar to the Point Leamington Formation, Shoal Arm Group and the Wild Bight Group.

D_5: Post-Batholith Right Lateral Strike Slip Faulting

Introduction

The most prominent D_5 structure in the area is the Northern Arm Fault which forms the southern border to the Frozen Ocean Group. This fault zone and its correlatives define the southern boundary to the Exploits Terrane as a whole (Dewey et al., 1983). The Northern Arm Fault cuts the Hodges Hill Pluton, which is assumed to be Devonian in age. Therefore, the latest phase of movement along the Northern Arm Fault is post-Acadian in age, although it may have had a complex history involving several phases of deformation.

New Bay Pond Area

In the New Bay Pond area the terrain near the Northern Arm Fault is characterized by a lack of outcrop, severely limiting any detailed structural study. However, analysis of lineaments observed on aerial photographs of the area at a scale of 1:15,860 reveals a complex pattern (Figure 3.26), with three trends apart from the various bedding

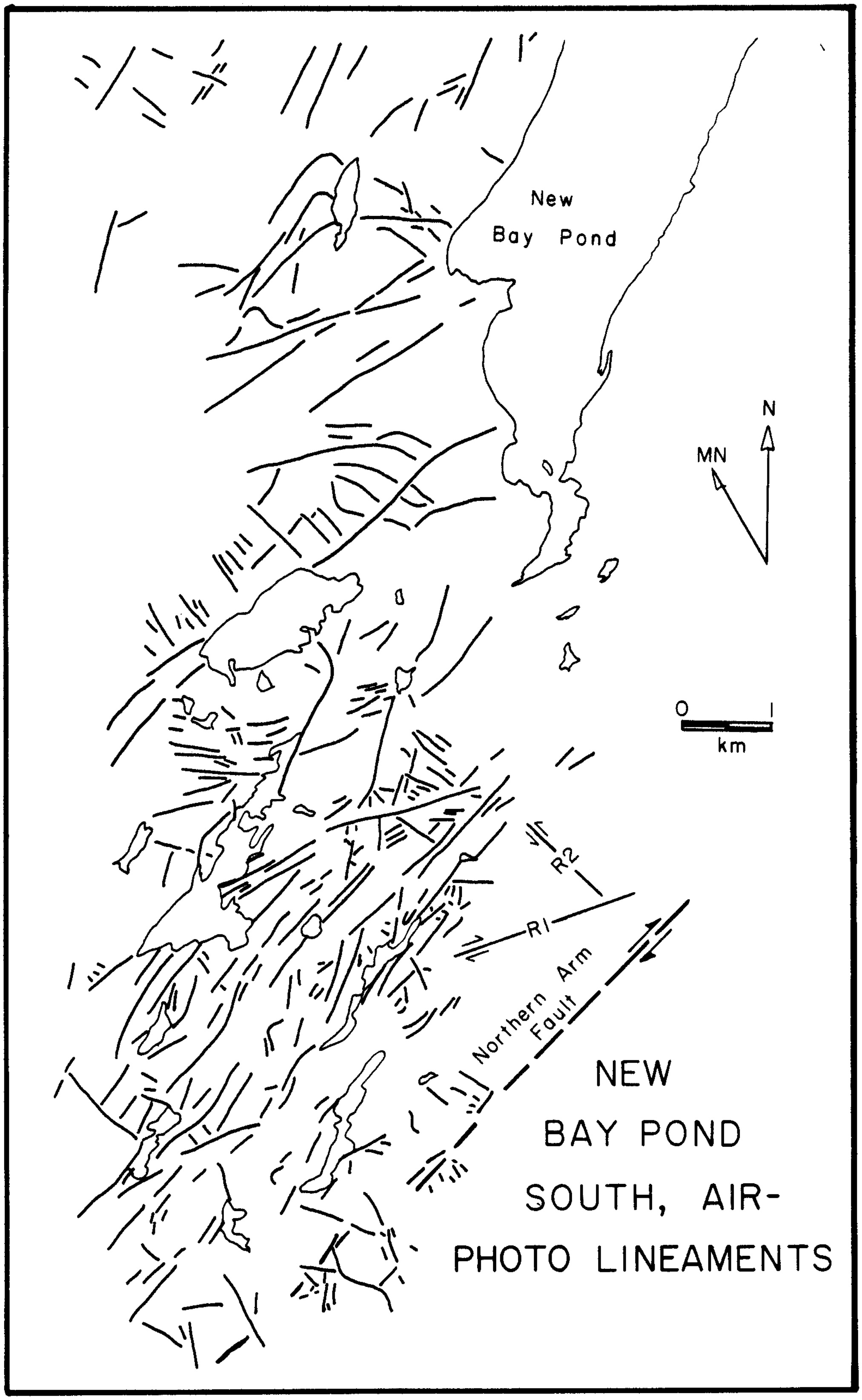


Figure 3.26. Aerial photograph lineament map of the southern portion of the map area.

orientations being discernable. The first and most prominent is parallel to the trace of the Northern Arm Fault, the second makes an acute angle of 25 - 35° with the first and, the third is at an angle of nearly 90° with the Northern Arm Fault (Figure 3.26). The orientation of the second and third sets of fractures, along a fault zone whose orientation is that of the first, is consistent with an R1 - R2 Riedel shear interpretation for their origin (cf. Logan et al., 1979), with right-lateral motion along the fault zone-parallel lineaments.

Northern Arm Area

In order to better-understand the structural history of the Northern Arm Fault, outcrops were sought in other areas along its trace. At Northern Arm, Bay of Exploits (Figures 3.27 and Plate 3), the Northern Arm Fault separates lower Ordovician rocks of the Wild Bight Group and overlying sediments on the north, from the Silurian Botwood Group (Wig Wam Formation) on the south. Rocks of the Wild Bight Group in this area consist of mafic volcanic breccias, hyaloclastites, rare pillow lavas and volcaniclastic sediments, while the Wig Wam Formation (Botwood Sandstone) is composed of orange weathering micaceous sandstones that sometimes display cross-laminations and graded beds. Outcrops from the Northern Arm, Bay of Exploits area were selected for structural analysis because numerous road and quarry cuts in this area offer an excellent cross-section of the fault zone, as well

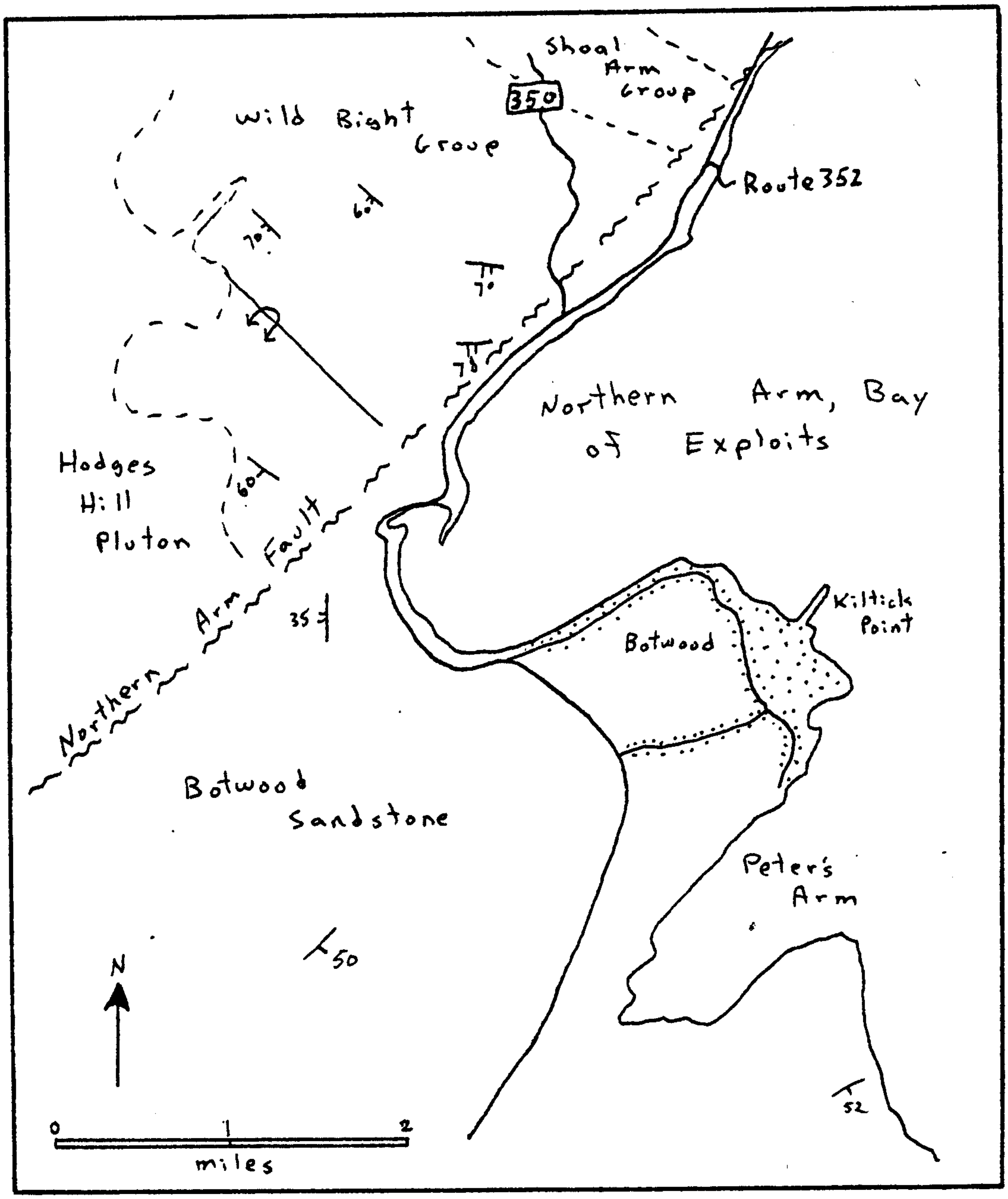


Figure 3.27. Geologic map of the Northern Arm, Bay of Exploits area showing the relationship of the Ordovician Wild Bight Group and the Silurian Botwood Sandstone to the Northern Arm Fault. Excellent outcrops that were selected for study are located where the Northern Arm Fault crosses Route 342, north of the village of Northern Arm. (map modified after Kean et al, (1980), and Dean (1978)).

as rocks on either side of it. Furthermore, many differently oriented surfaces are available for observation, precluding a statistical bias in the measurements.

The fault zone is associated with a pronounced topographic lineament that forms the hills on the northwestern side of the Bay of Exploits in this area, and can be traced approximately 40 km southwest to the vicinity of Grand Falls, passing south of the New Bay Pond area. As the fault zone is approached from the north or the south many subvertical slickensided fault surfaces are encountered, the most prominent of which strike northeast (Figures 3.30). Green chlorite commonly coats these surfaces and in places comprises the material of which the slickenline fibers are composed (Figures 3.28 and 3.29).

Many of the slickensides possess 'steps'; these were used as kinematic indicators, with the general interpretation being that the steps face in the direction of movement of the opposite block (Durney and Ramsay, 1973; Hobbs et al. 1976). Most of the slickenlines are sub-horizontal and appear on sub-vertical planes, indicating that the most recent phase of movement on the Northern Arm Fault was strike-slip in nature. However, a few slickenlines plunge steeply (45 - 90°; Figure 4.30c and 4.30d) and are usually overprinted by the sub-horizontal slickenlines, forming palimpsest slickensided surfaces. These slickenlines may suggest a more complex history of movement along the Northern Arm Fault, possibly including

Figure 3.28. Photograph of slickenside surface with subhorizontal slickenline fibers and grooves.

Figure 3.29. Slickenlines on chloritic mafic volcanics of the Wild Bight Group.

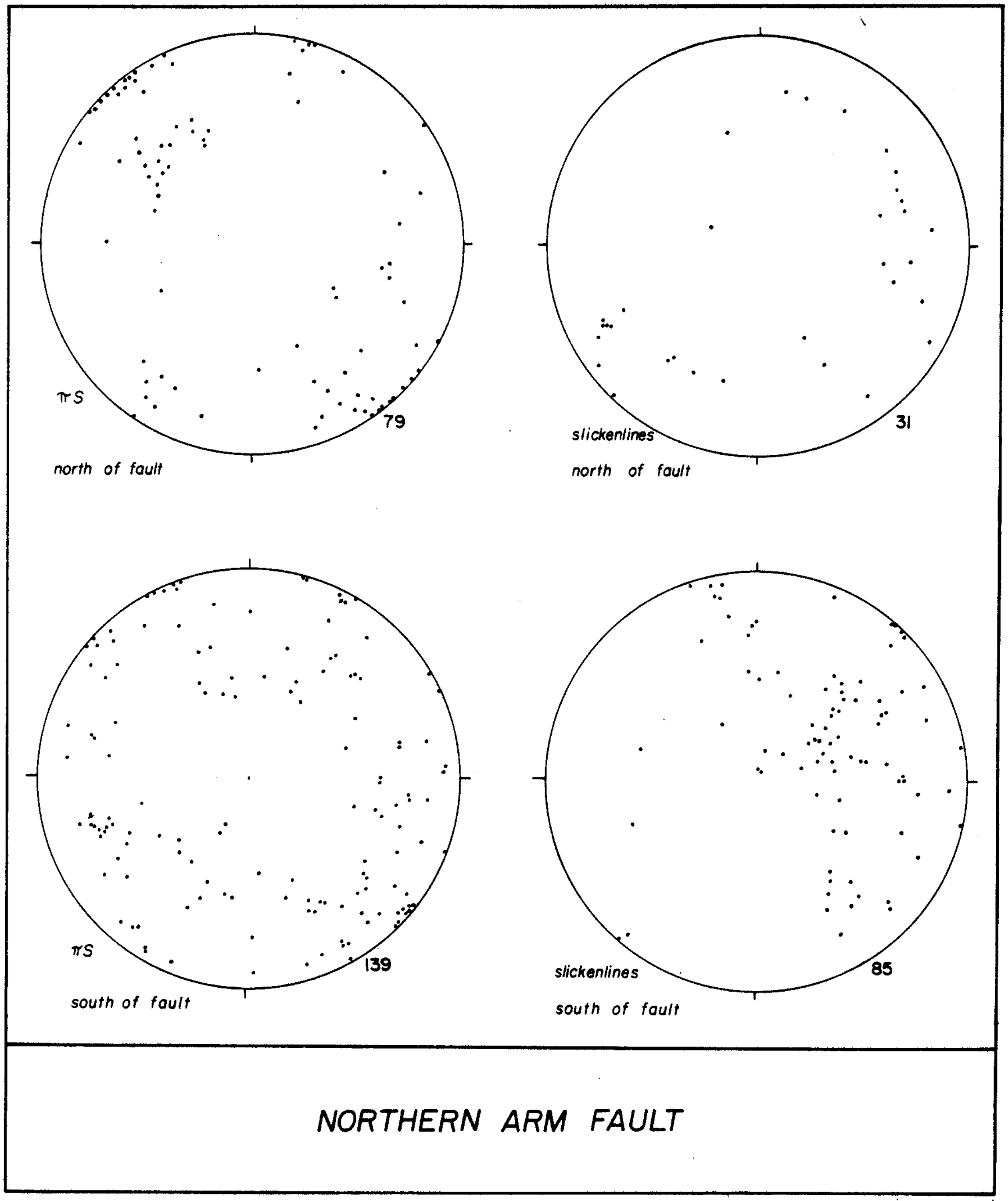


Figure 3.30. Lower hemisphere equal area projections showing the orientation of fracture surfaces (A) north of, and (B) south of the Northern Arm Fault. (C) displays the orientations of slickenline fibers north of the fault, while (D) shows the same south of the fault.

early thrusting. However, because strike slip faults commonly have thrust, normal and/or rotational components of movement associated with them all of these slickenlines are here attributed to the same progressive deformation episode.

Figure 3.31 is a map showing the orientations and locations of all fault surfaces with slickenlines from which the sense of shear could be deduced utilizing their stepping directions. It is readily apparent that there are two sets of faults with opposing senses of shear on them, a northeast trending set with dextral offsets, and a northwest trending set with sinistral displacements. The northeast trending faults are approximately parallel to the trace of the main fault zone (Figure 3.31) and the northwest trending set strikes at a high angle to the main fault. These surfaces are oriented in the predicted R1 and R2 Riedel shear directions and, therefore, are reasonably interpreted as Riedel and antiriedel shear surfaces. Their orientation alone is highly suggestive of right-lateral movement along the Northern Arm Fault (Figure 3.31). The orientation of some of these fault surfaces deviates considerably from the vertical and this suggests the possibility that the Northern Arm Fault had a thrust component of movement. Numerous thrust faults associated with strike slip fault systems have been described as flower structure (Wilcox et al., 1973), and these are common in strike-slip fault systems possesing a component of compression.

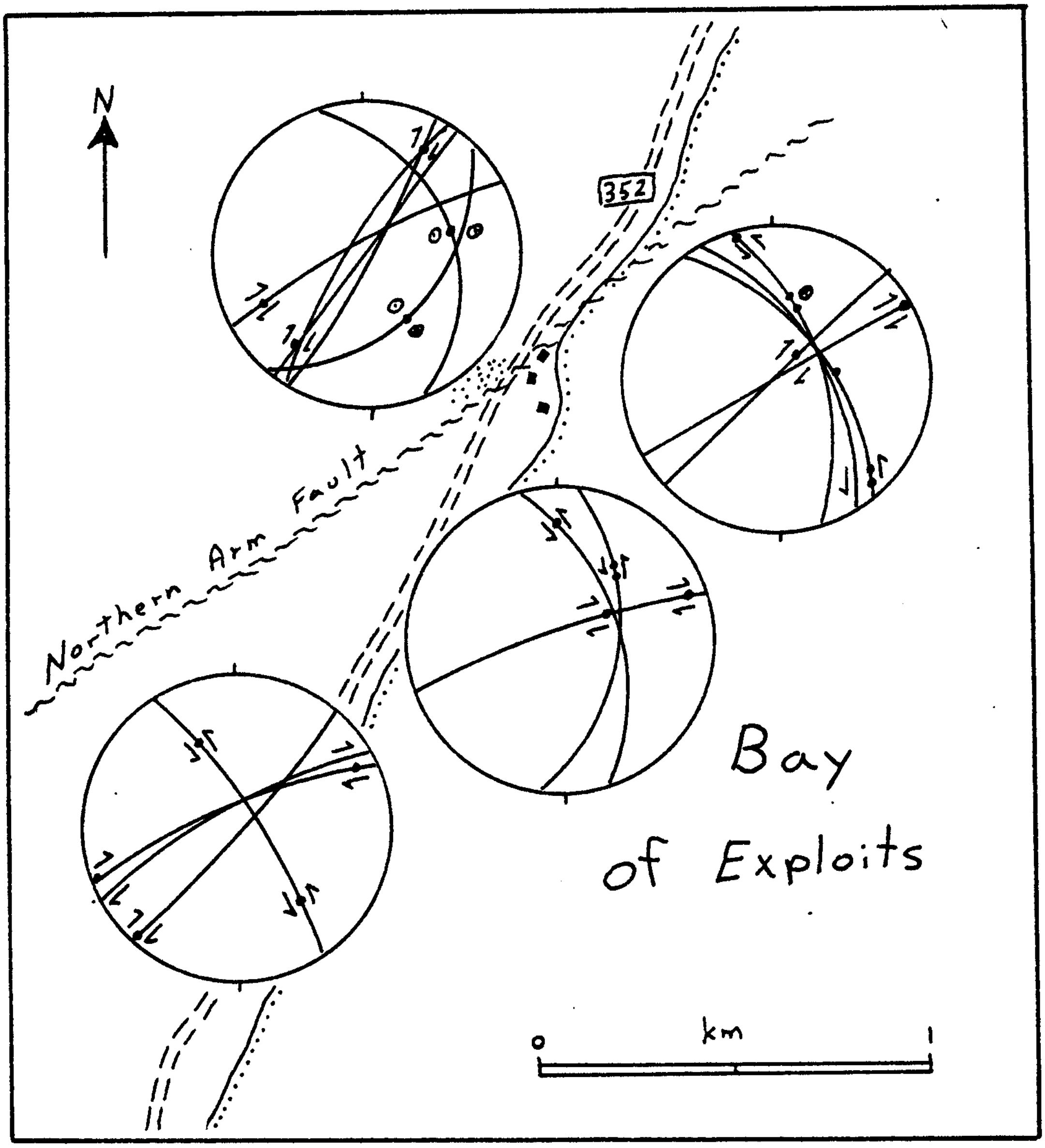


Figure 3.31. Diagramatic map of the Northern Arm Fault Zone showing the orientation of fracture surfaces whoch have slickensides from which the sense of shear can be inferred by stepping direction. Faults with right lateral offsets are subparallel to the main fault trace, while those exhibiting left lateral displacements strike at a high angle into the main fault. These are interpreted as a Reidel/antireidel set, respectively.

The fault zone itself is approximately vertical and displays a zone (approximately 25 meters wide) of complex structure where lozenges of both the Ordovician mafic lavas and the Silurian micaceous sandstones appear intimately sheared together, and are separated by narrow zones of fault gouge, at the rare localities where the contact between the two units is observable (Figures 3.32, 3.33, and 3.34). The character and orientation of several structural features along these faulted contacts (described below) suggests that they originated from right lateral shear along the Northern Arm Fault.

(1) Pinnate Fractures

The most prominent feature of the rocks around these shear zones is the presence of numerous "pinnate" fractures which strike at an oblique angle into the fault gouge zones (Figure 3.33). Comparison of these with other similar features formed near recent faults, with known senses of offset, as well as other experimentally formed pinnate fractures (Cloos, 1932; Hobbs et al., 1977; Quidong and Peizhen, 1984), reveals that the acute angle formed by the intersection of the main fault and the pinnate fracture always points in the direction of relative movement of the block possesing the pinnate fracture (Hobbs et al., 1977). Thus, the orientation of pinnate fractures along this fault zone clearly indicates that it is a right lateral strike slip fault.

Figure 3.32. Photograph of fault gouge zone separating lozenges of Botwood Sandstone and Wild Bight mafic volcanics.

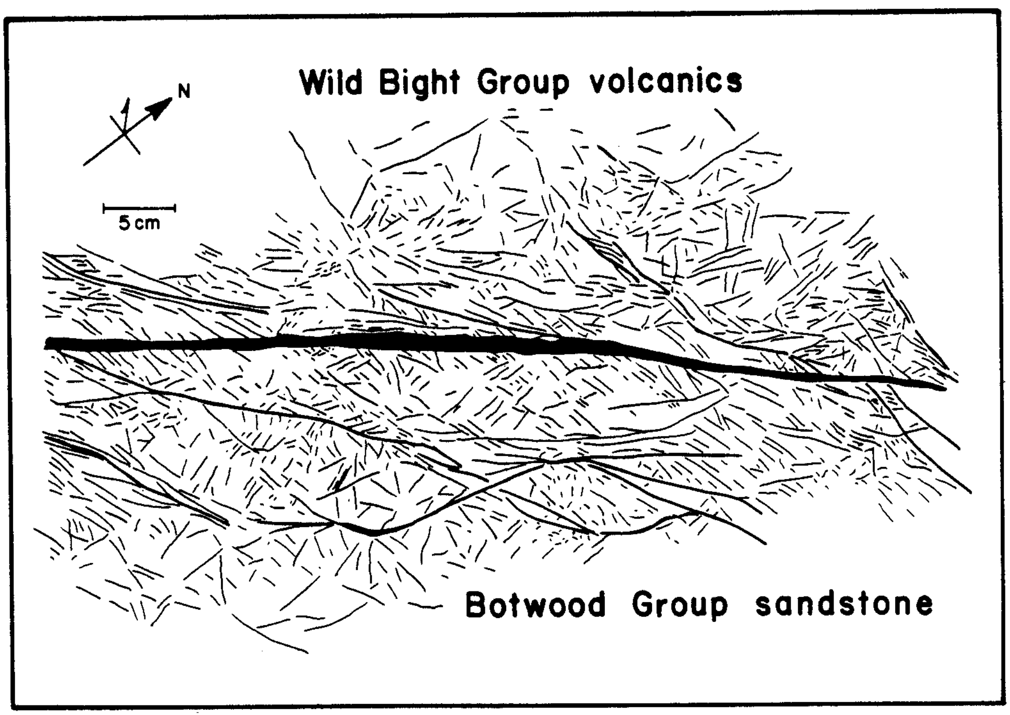


Figure 3.33. Sketch of previous photograph showing orientation of fault zone and numerous fracture surfaces.

(2) Fault Gouge Foliation

Within the Northern Arm Fault Zone the contact between lozenges of Wild Bight Group and Botwood Group lithologies is marked by narrow (<5 cm) zones of fault gouge. Gouge observed from an exceptionally good outcrop exposed by the floods of 1983 (Figure 3.32) possesses three distinct color zones which are separated by thin layers of clay minerals oriented parallel to the shear zone boundaries, presumably reflecting larger amounts of finite strain accumulation along these boundaries (Figure 3.34). The layer closest to the orange Botwood Sandstone closely reflects its color, while the layer closest to the Wild Bight volcanics has a darker red color. The layer in between these two possesses a color transitional between both of these, possibly representing a "mixing zone" between the outer two layers. The predominant costituent of the fault gouge is very small (<2 mm) well-rounded quartz grains. Small clay and mica fragments are present as well, and it is their orientation which defines the fault gouge foliations. Several authors (Engelder, 1974a, Engelder, Logan and Handin, 1975; Paterson, 1978) have suggested that as sliding on fault gouge zones increases, the rounding of the contained quartz grains will also increase, and the mean size of these particles will decrease. These features together with the width of the gouge zone on the Northern Arm Fault suggests that large amounts of displacement were probably accomodated along this zone. However, complications arise in attempting to quantify this value because other facters,

Figure 3.34. Close up of fault zone shown in Figure 3.31, showing oblique fault gouge foliation which is here interpreted as a result of dextral motion along the Northern Arm Fault.

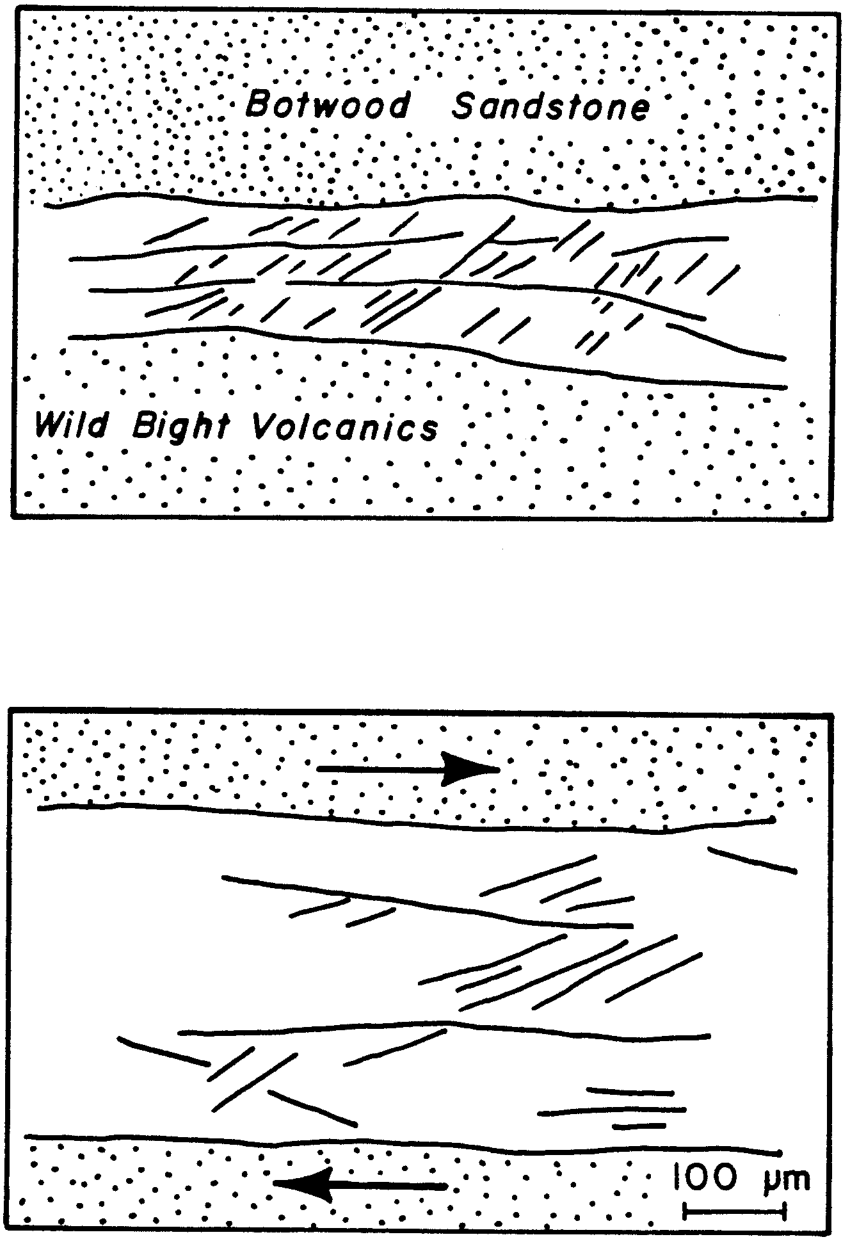


Figure 3.35. Orientation of fault zone-parallel and oblique foliations in gouge from Northern Arm, compared with foliation orientations in experimentally deformed fault gouge of Logan et al., 1981.

including normal load and the amount of water present, also strongly influence these relationships (Paterson, 1978; Okubo and Dieterich, 1984; Stierman, 1984).

Two distinct foliation orientations occur within the fault gouge zone: the first forms an angle of 42 with the shear zone boundary, while the second set is parallel to these boundaries. Several models exist that could adequately explain the presence and orientation of these foliations. Logan et al. (1981) have experimentally deformed gouge from the San Andreas Fault Zone under various applied conditions. Comparison of the orientations of foliations developed in their experiments (right lateral shear) with those observed in the gouge zone along the Northern Arm Fault reveals a striking similarity. The experiment depicted from the San Andreas fault gouge (Figure 3.35) was carried out under 150 MPa confining pressure and at 150° C. Logan et al. (1981) attribute the orientation of these foliations to the alignment of clay particles along R1 and R2 Riedel shears. If, as suggested here, the foliations in the Northern Arm Fault gouge had a similar origin, their orientations indicate that the Northern Arm Fault is a right-lateral strike slip fault. Another possibility is that the orientations of these foliations is analogous to the S-C banding commonly observed in mylonites (Berthe et al., 1979; Bobyarchick, 1983; Ramsay, ; Lister and Snoke, 1984). The foliation orientation with respect to the sense of shear is, in this case, very similar to that just described and would also indicate right lateral strike-slip motion along the Northern Arm Fault.

(3) Extensional Veins

Several arrays of en echelon extensional veins were noted from the vicinity of the Northern Arm Fault. They are calcite-filled and planar in habit: no sigmoidal-type arrays were noted. These veins indicate extension normal to their walls and compression parallel to their traces. Therefore, if the poles to these veins are plotted and the stereonet is divided into quandrants using the orientation of the Northern Arm Fault as one boundary, all of the poles should plot in two opposite quadrants which were in extension during their formation (assuming one generation of vein formation). The result from the Northern Arm Fault extensional veins is compatible with this hypothesis (Figure 3.36) and indicates right lateral motion on the Northern Arm Fault.

Thus, the orientation of all structural features observed to be associated with the Northern Arm Fault, including slickenline fibers, pinnate fractures, fault gouge foliations, and extensional vein arrays indicate that it has experienced right-lateral strike-slip motion.

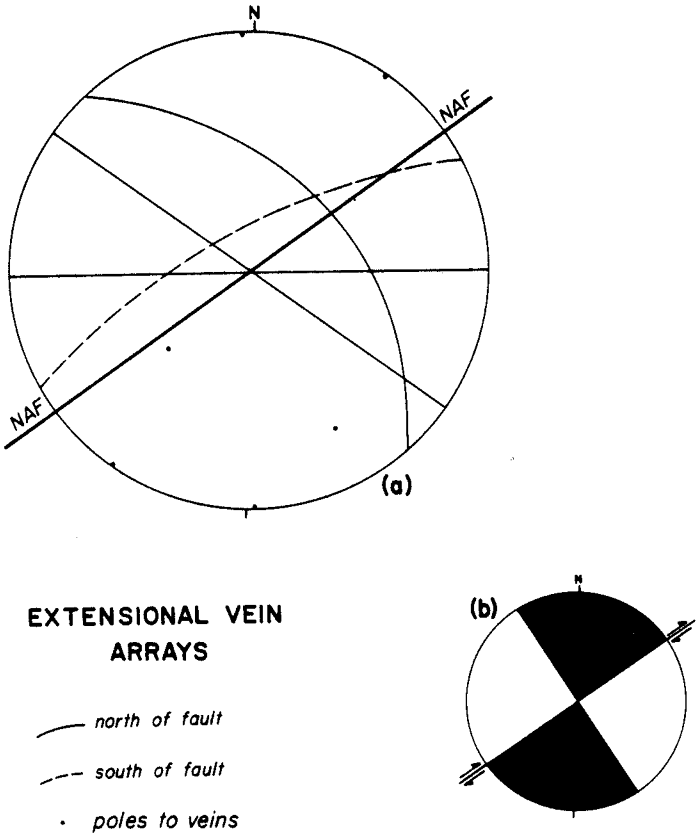


Figure 3.36(a). Orientation of en echelon vein arrays from north of (solid lines) and south of (dashed lines) the Northern Arm Fault. Poles to these planes fall into two opposite quadrants defined by the fault plane: (b) is a "last motion plot" and shows compressional quads (shaded) containing poles to vein arrays, and extensional (unshaded) quadrants.

Regional Extent of D_5 Deformation

There are numerous structures in the Frozen Ocean Lake - New Bay Pond area which are parallel to the Northern Arm Fault (Plates 1 and 3). They are all linear till-filled depressions characterized by a lack of outcrop although it is thought that they are all right-lateral strike slip faults. The northwestern boundary of the Frozen Ocean Group is marked by one of these features, the Long Pond Fault (Plate 1). Offsets of distinctive marker beds across the lineament associated with this fault (Dean, 1977, 1978; Kean et al., 1980) support its suggested right-lateral offset.

The structural data thus supports a late-Acadian or younger episode of right-lateral strike-slip faulting in central-Newfoundland. The tectonic significance of this is discussed below.

Structural Evolution of the Frozen Ocean Lake - New Bay Pond Area: Summary

Rocks of the area have suffered a long and complex history of deformation. Soft sediment structures are common in all rocks of the area and, thus, this "event" was diachronous by definition. The first deformation event (D_1) was related to the emplacement of the Frozen Ocean Group over the Point Leamington Graywacke, the Shoal Arm Group, and the Wild Bight Group. This thrusting event occurred along bedding plane-parallel faults although several small footwall ramp zones are recognized. The second, third, and fourth deformation events are those usually attributed to the Acadian Orogeny. Right-lateral strike slip faulting preceeded regional upright folding on northeasterly trending axis, although the faulting may have continued to occur during folding. These folds are associated with a subvertical, northeast-striking cleavage. The end of the Acadian Orogeny is marked by the intrusion of large batholiths, such as the Hodges Hill Pluton, which locally disrupt the strata. Structures assigned a D_5 age include dextral strike slip faults which cross-cut the Acadian structures, and have a more easterly trend.

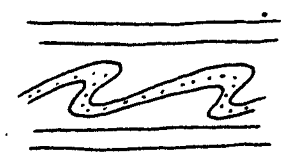
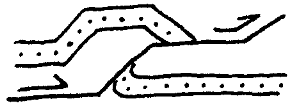
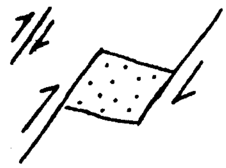
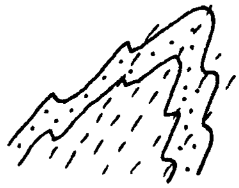
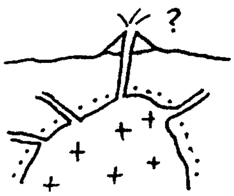
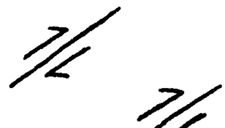
D_0	soft sediment deformation (diachronous)	
D_1	ramp thrusting and folding (Ashgill-Llandoverian)	
D_2	dextral strike-slip faulting (Ludlovian)	
D_3	upright regional folding and cleavage development (Acadian)	
D_4	batholith intrusion (Acadian)	
D_5	dextral strike-slip faulting (?)	

Figure 3.37. Synoptic diagram showing proposed structural evolution of New Bay pond area.

Figure 3.38. The sixth deformation episode is thought to have occurred very recently.

CHAPTER IV

INTRUSIVE ROCKS

Introduction

Two generations of intrusive rocks are recognized from the Frozen Ocean Lake-New Bay Pond area. The earliest was approximately contemporaneous with eruption and deposition of the volcanics and sediments, and these are affected by the regional deformation and metamorphism. The second generation of intrusive rocks is clearly associated with intrusion of the (Devonian?) Hodges Hill/Twin Lakes Batholith Complex. These younger intrusives are easily distinguished from those of the first generation because they generally are not cleaved or deformed, although some cooling joints in these bodies are locally oriented similarly to the regional cleavage. Although some late Jurassic - early Cretaceous lamprophyres have been recognized from central Newfoundland (Nelson, 1979, Helwig, 1967, Helwig, Aronson, and Day, 1974), none of these have been seen in the Frozen Ocean Group area.

Wild Bight - Type Intrusives

Numerous mafic dikes and sills occur intercalated with volcanics and sediments of the Frozen Ocean Group. Some are basaltic and are difficult to distinguish from mafic volcanics of the Frozen Ocean Group, while others are gabbroic and are easily recognized as plutonic rocks. The superficial resemblance of some of these intrusives to mafic rocks of the Frozen Ocean Group is complimented by their petrographic composition. Saussauritized feldspars are abundant as are clinopyroxene, green hornblende, magnetite and occasional altered olivine. Chlorite is abundant as a secondary mineral, and the metamorphic grade of these intrusives appears to be the same as that of the Frozen Ocean Group (lower greenschist facies; see below). The dikes and sills are cleaved and, perhaps more importantly, metamorphosed; therefore, they are regarded as essentially contemporaneous with the extrusion of lavas of the Frozen Ocean Group.

Hodges Hill/Twin Lakes - Type Intrusives

The eastern and western boundaries of the Frozen Ocean Group are intruded by the Hodges Hill/Twin Lakes Complex (Plate 1) and, at least the southern portion of the Frozen Ocean Group area may be regarded as a roof pendant to this batholith. This plutonic complex is associated with a small ($<$ 1 km wide) contact metamorphic aureole, best expressed in the Point Leamington Graywacke, which becomes harder towards the pluton and the carbonate nodules in it stand out as weather resistant calc-silicate nodules (wollastonite?) (Figure 4.1). On the east shore of New Bay Pond near the New Bay River (Plate 1) a spectacular diatremic breccia is associated with this pluton. It

Figure 4.1. Calc-silicate nodules (wollastonite?) in thermally metamorphosed Point Leamington Graywacke which locally constitutes the contact metamorphic aureole surrounding the Hodges Hill/Twin Lakes Intrusive Complex. These are believed to have replaced carbonate nodules which are abundant in the Point Leamington Formation.

Figure 4.2. Diatremic breccia associated with the margin of the Hodges Hill Pluton.

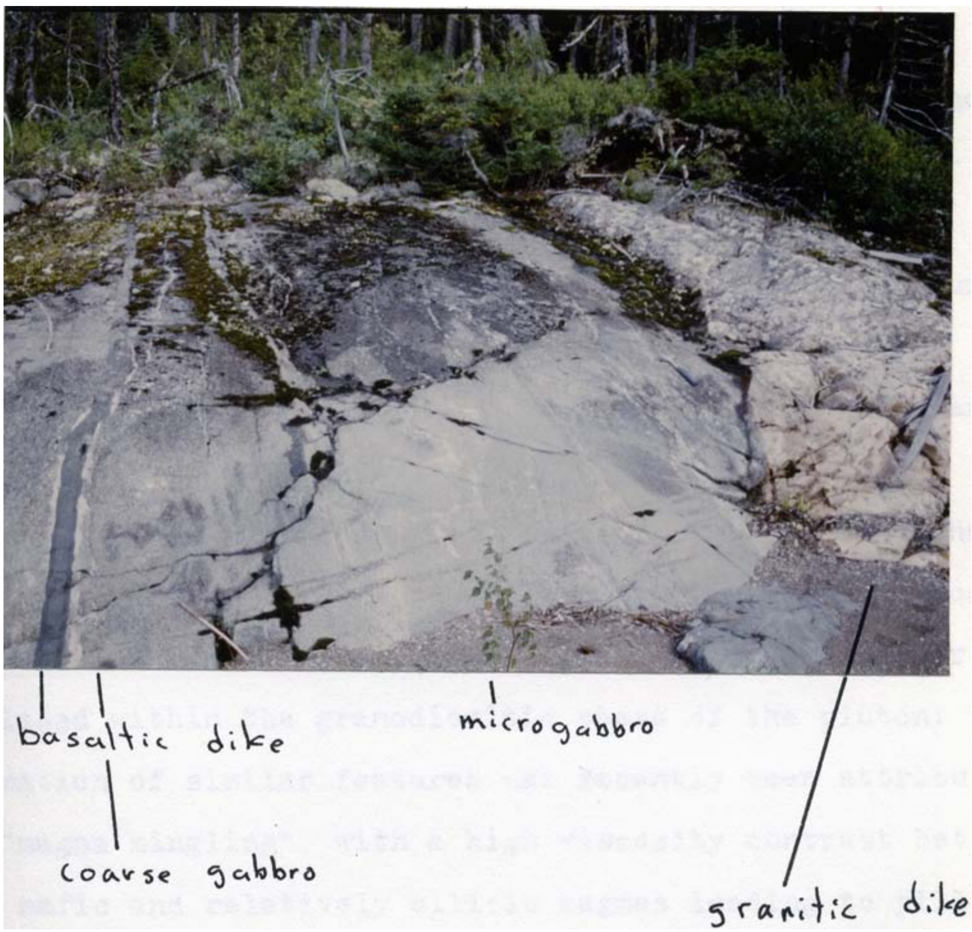


Figure 4.3. Outcrop from the northeast side of New Bay Pond showing coarse gabbro intruded by microgabbro intruded by basalt, the whole of which is intruded by granite, presumably reflecting uplift and differentiation of the pluton during intrusion.

contains clasts lithologicaly identical to the Wild Bight Group, Shoal Arm Group, and Point Leamington Formation (Figure 4.2).

The Hodges Hill/Twin Lakes Intrusive Complex is predominantly granodioritic in composition, although phases ranging from gabbro to granite are recognized. An excellent outcrop along the eastern side of New Bay Pond shows a coarse-grained gabbro phase intruded by a fine-grained gabbro (microgabbro), intruded by a small granodioritic dike; this is in turn intruded by a medium-grained pink granite and a small basaltic dike which intrudes the medium- to coarse-grained layered gabbro and granodioritic phases (Figure 4.3). This sequence is interpreted to reflect differentiation and uplift of the pluton during intrusion into the surrounding country rocks. A few scattered "enclaves" of more mafic lithologies are enclosed within the granodioritic phase of the pluton: the formation of similar features has recently been attributed to "magma mingling", with a high viscosity contrast between the mafic and relatively silicic magmas leading to pillow-lava like blobs flowing through the pluton (Ron Vernon, personal communication).

Numerous dikes and sills associated with the Hodges Hill/Twin Lakes Intrusive Complex intrude the surrounding country rocks, often along previously defined zones of weakness, especially faults (Figures 4.4 and 4.5). However, very crude radial and concentric patterns defined by these dikes around the complex is evident as well (Plate

Figure 4.4. Closely spaced joints in a mafic dike of the Hodges Hill/Twin Lakes Intrusive Suite, intruding the Sansom Graywacke, and enclosing a xenolith of the same. The joints are believed to be related to a nearby fault.

Figure 4.5. Termination of mafic dike intruding thermally metamorphosed Point Leamington Formation from the Hodges Hill/Twin Lakes Intrusive Suite.

1). These dikes are usually dioritic to granodioritic in composition and texture, although several larger gabbroic bodies occur as well. They appear relatively pristine, both in the field and in thin section. These typically contain numerous clusters of plagioclase phenocrysts (some were noted to be radially arranged about a central crystal). Phenocrysts of augite, olivine, orthopyroxene and magnetite are also common, as are zircons. One basaltic dike which intrudes the Point Leamington Formation was found to contain an unusual quantity of chalcopyrite grains. An undeformed rhyolitic dike intrudes the Point Leamington Graywacke south of Lewis Lake (Plate 1), and this probably represents an aphophysis from the Hodges Hill/Twin Lakes Intrusive Complex. If this pluton was associated with any volcanic rocks, such as those composing the Lynx Pond Formation, dikes of this kind would be expected to fairly common in the area.

Figure 4.6. Flow differentiation in a mafic dike from the Hodges Hill Pluton.

CHAPTER V

REGIONAL METAMORPHISM

Despite the wide range of ideas regarding the stratigraphic and structural history of the northern Exploits Terrane, most workers have been able to agree that the regional metamorphism is generally in the prehynite - pumpellyite to lower greenschist facies. Franks (1974) has reported the occurrence of the mineral assemblage albite + calcite + quartz + prehnite + chlorite + epidote from the New Bay Formation, indicative of prehnite - pumpellyite facies metamorphism at temperatures of 300-400° C, and at pressures of less than 1 kb. Franks (1974) and Franks and Helwig (1973) suggested that this metamorphism was a result of the intrusion of numerous mafic dikes and sills into the New Bay sediments and, thus, it was regarded as pre-Caradocian in age.

Nelson (1979) documented metamorphic mineral assemblages in rocks exposed in the Badger Bay - Seal Bay area, to the north of this study area and to the west of Franks and Helwig's study area (Plate 3). In mafic intrusive rocks associated with the Wild Bight Group he found the assemblages:

Carbonate + Chlorite + Epidote + Albite + Quartz + Accesories

Pumpellyite + Chlorite + Epidote + Albite + Quartz + Accessories

Actinolite + Chlorite + Epidote + Albite + Quartz + Accessories

The first assemblage is non-diagnostic, the second is indicative of the Prehynite-Pumpellyite facies, and the third is diagnostic of the Greenschist facies (Nelson, 1979, Miyashiro, 1973). Thus, the metamorphic state of the pre-Caradocian rocks in the Badger Bay - Seal Bay area was concluded to lie transitionally between the prehynite-pumpellyite and the greenschist facies. Nelson found that the metamorphic history experienced by the early Silurian Gull Island Formation (Sansom correlative) was indistinguishable from that of the Wild Bight Group. Because the Gull Island Formation and its correlative strata overlie the ubiquitous Caradocian sediments, the Wild Bight Group,. and the New Bay Group, Nelson suggested that the regional metamorphism was post-Caradocian (and post-lower Silurian) in age. An upper constraint on the age of metamorphism is given by the Early Cretaceous age of unmetamorphosed lamprophyre dikes from the area (Helwig, Aronson and Day, 1974; Nelson, 1979).

Mafic volcanic and intrusive rocks of the Lewis Lake Formation were examined in thin-section in order to determine the metamorphic state of the Frozen Ocean Group. The assemblages Carbonate + Chlorite + Epidote + Albite + Quartz + Accessories and Tremolite-Actinolite + Chlorite + Epidote + Albite + Quartz + Accessories were noted, indicative of Greenschist facies metamorphism (Miyashiro, 1973). Epidote, chlorite, muscovite and rare pumpellyite were observed in the matrix of the Point Leamington Formation, suggesting that it too has been metamorphosed to the lower greenschist facies. These results support the conclusions of Nelson (1979) and not those Franks (1974) and Franks and Helwig (1973); thus, the regional metamorphism appears to be post Lower Silurian and pre-Cretaceous in age, and is most likely a result of the Acadian Orogeny.

CHAPTER VI

REGIONAL STRATIGRAPHIC CORRELATIONS

Introduction

Even a brief glance at a regional geologic map reveals that the Frozen Ocean Group occupies an anomalous position in the Appalachian orogen. The strata's northwest strike in the interior of a northeast striking mountain belt is indeed strange, and some explanation must be sought for this phenomenon. Several hypotheses appear as particularly attractive explanations:

(1). The northwest strike results from a fold interference pattern.

(2). A heterogeneity in the basement induced anomalous surface deformation.

(3a). The northwest strike is a result of rotation during strike-slip faulting.

(3b). The anomalous strike is a result of large-scale late-orogenic kinking.

These possibilities are discussed in more detail below.

Once it was determined that the Frozen Ocean Group is in fault contact with the structurally underlying sediments the task of finding strata within the Exploits Terrane that could possibly be correlative with the Frozen Ocean Group remained to be tackled. A perusal of Exploits Terrane stratigraphy reveals the many striking similarities between

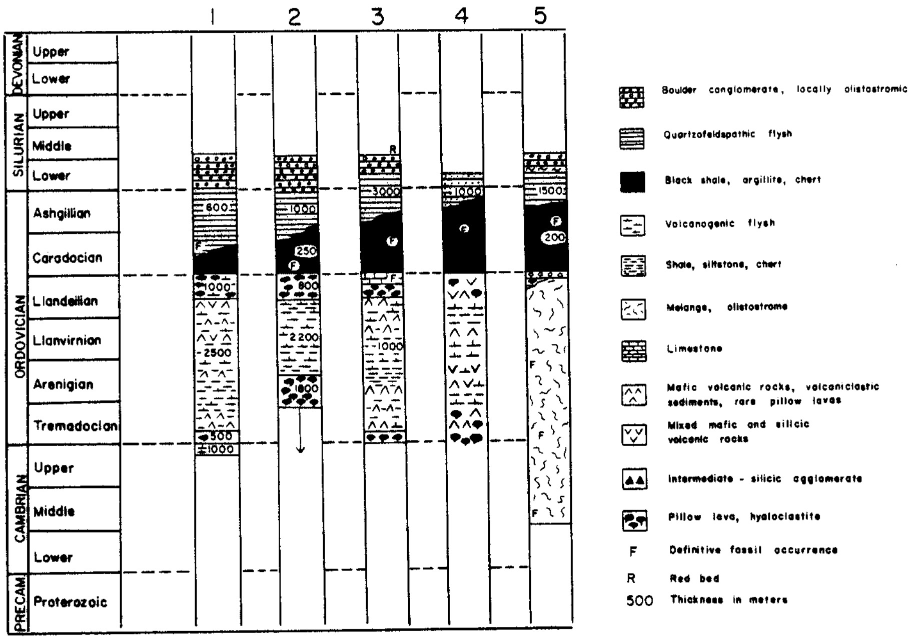


Figure 6.1. Revised regional stratigraphic correlation chart showing the Frozen Ocean Group as pre-Caradocian in age (compare with Figure 1.2), and displaying its similarity to other well mapped Exploits Terrane strata.

the Frozen Ocean Group and other well-mapped pre-Caradocian sequences (Figure 6.1). In order to assess any differences or similarities between the Frozen Ocean Group and these other sequences, rocks of the Wild Bight Group, New Bay Group, Tea Arm Volcanics, Lawrence Head Volcanics and the Roberts Arm Belt were observed during reconnaissance surveys in the field.

Wild Bight Group

Rocks of the Wild Bight Group lying to the north of the Frozen Ocean Group area, on the coast of Notre Bame Bay, were mapped in considerable detail by Nelson (1979), and a comparison between the Frozen Ocean Group and these rocks reveals their many striking resemblances (Figure 6.2).

Nelson (1979) assigned the stratigraphically lowest rocks in the Seal Bay area to the Omega Point Formation (Dean, 1978), consisting of red and green volcaniclastic sediments and silty slates. This grades into the Corner Point Formation which is nearly 2 km thick and contains abundant silicic and mafic volcanic rocks, as well as minor intercalated volcaniclastic sediments. The stratigraphically lowest member of the Frozen Ocean Group, the Lewis Lake Formation, consists of mixed mafic and silicic lavas, with the mafic flows being more abundant than the silicic volcanic rocks. Because the suites of lithologies in these two formations appears to be identical it is suggested that the two are correlatives (Figure 6.2).

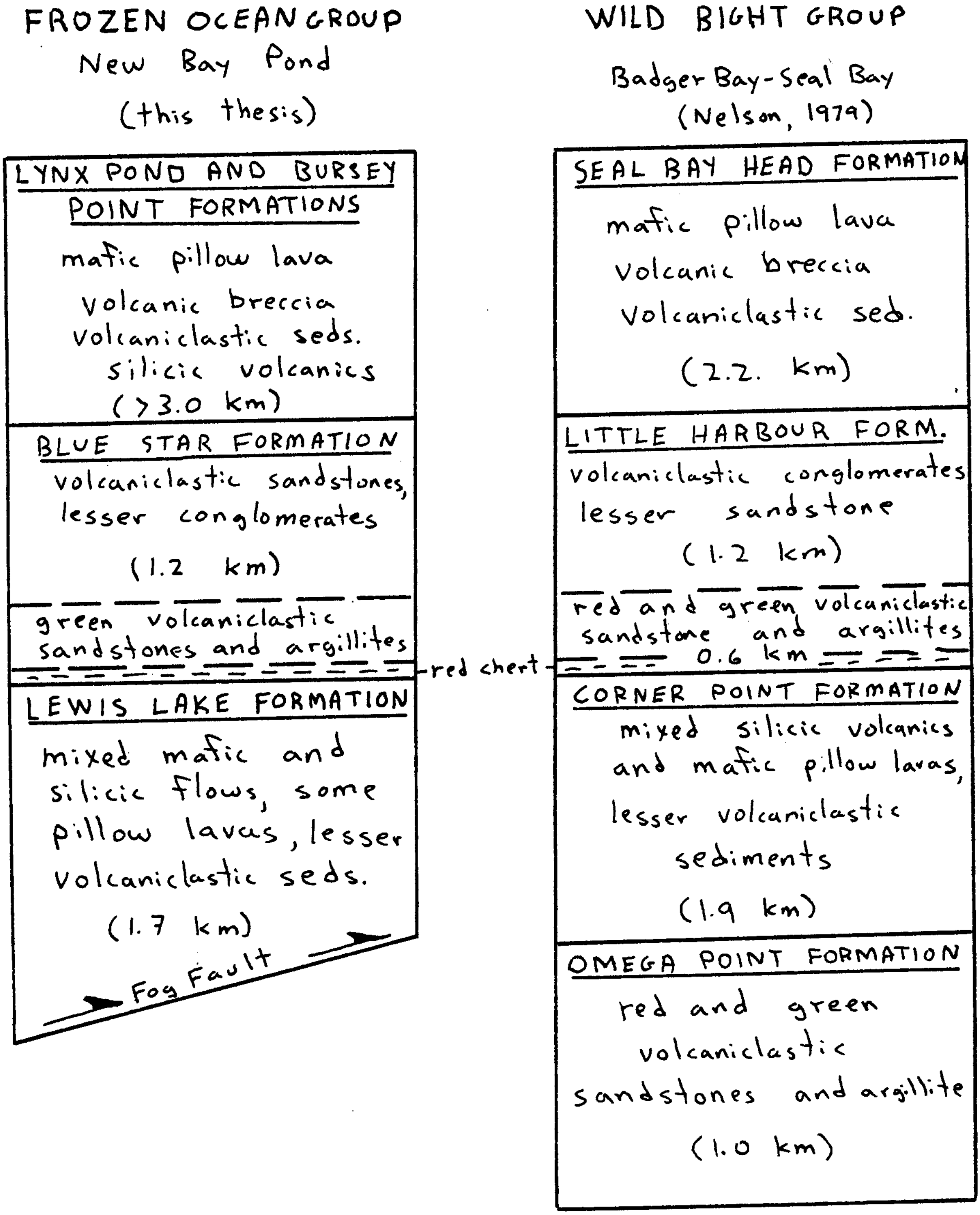


Figure 6.2. Comparison between the Frozen Ocean Group (this study) and the Wild Bight Group (after Nelson, 1979).

In the light of the rapid facies variations in both the Corner Point Formation and the Lewis Lake Formation, the relative abundances of the mafic and silicic volcanic rocks is not regarded as evidence against this hypothesis.

The Little Harbour Formation overlies the Corner Point Formation in the Badger Bay/Seal Bay area. The base of the Little Harbour Formation is marked by a distinctive bright red slate horizon (Nelson, 1979), and this grades up into a sequence of red and green volcaniclastic sandstones, conglomerates and argillites. In the Frozen Ocean Group area the Blue Star Formation overlies the Lewis Lake Formation. Like the Little Harbour Formation, the base of the Blue Star Formation is marked by a very distinctive red chert and siliceous shale layer, and its upper portions consist of red and blue-green volcaniclastic sandstones, conglomerates and argillites. This strongly supports the correlation of these two units (Figure 6.2).

The top of the Wild Bight Group In the Badger Bay/Seal Bay area is marked by the Seal Bay Head Formation, containing mafic pillow lavas, volcanic breccias and volcaniclastic sediments. This formation is here correlated with the Bursey Point , and, perhaps the Lynx Pond Formation of the New Bay Pond area (Figure 6.2). The only significant difference between these two sequences is the local presence of subaerially-deposited silicic volcanic rocks in the Lynx Pond Formation of the Frozen Ocean Group. However, some ignimbrite-like silicic volcanic rocks have been described from the upper parts of the Wild Bight Group in areas between Seal Bay and New Bay Pond (Kean et al., 1980); it is therefore possible that this difference is only a result of lateral variations in volcanic facies.

The correlation of the Wild Bight Group and the Frozen Ocean Group is further supported by the extension of the Fog Fault below this section (see Plate 2).

Nelson (1979) correlated his stratigraphy with the New Bay Group. This correlation is retained in a loose sense here, in terms of the relative timing of volcanism and sedimentation. However, the significant facies variations between the New Bay Group and the Wild Bight and Frozen Ocean Group (e.g., grain size) suggests they may have been deposited in separate basins which had different amounts of clastic supply (W.S.F. Kidd, personal communication).

Exploits Group

Tea Arm Volcanics

The Tea Arm Volcanics is the name given by Helwig (1967, 1969) for a 1500 meter-thick sequence of mafic pillow lavas, volcanic flows, breccias, tuffs and volcaniclastic rocks that outcrop around Tea Arm off the southern part of South Arm (Plate 3). The presence of interstitial pink calcite, abundant jasperitized volcanic breccias, and minor crinoidal limestones in the Tea Arm Volcanics (Helwig, 1967), and their paucity in the Frozen Ocean Group suggests that the two can not be closely correlated, despite similar stratigraphic positions between the Tea Arm Volcanics and the Lewis Lake Formation. This is supported by the presence of silicic volcanic rocks in the Lewis Lake Formation, and their absence in the Tea Arm Volcanics (Helwig, 1967, 1969).

New Bay Formation

Rocks of the New Bay Formation were examined along Route 352, from south of Phillips Head to north of Point of Bay (Plate 3). The New Bay Formation was found to consist predominantly (70-80%) of black silty argillites (Figure 6.3). About 6 miles north of Phillips Head some coarser-grained sandstone beds were noted. These contain clasts up to 2 cm in diameter, composed of mafic and silicic volcanic material, as well as some occasional mudstone rip-up clasts. Bottom structures such as groove and flute casts are abundant throughout the New Bay Formation (Figure 6.4), and consistently indicate transport of sediments from the northwest (Helwig, 1967). Some Bouma-type sequences were noted, and these deposits are interpreted as distal turbidites. Because the average clast size of the New Bay Formation is much smaller than that in the Frozen Ocean Group, there is a preponderance of mudrocks, and volcanic rocks are much less abundant in the former (cf. Helwig, 1967, 1969), these are not interpreted as direct lithologic equivalents to the Frozen Ocean Group.

Figure 6.3. Interbedded black argillites and fine sands, interpreted as turbidites, of the New Bay Formation.

[Bill Kidd; Sharon Poissant]

Figure 6.4. Bottom marks in New Bay Formation: these indicate southeastward flowing currents.

Lawrence Head Volcanics

The Lawrence Head Volcanics overlie the New Bay Formation and are directly overlain by lower Caradocian black shales (Helwig, 1967, 1969; Dean, 1978). They outcrop around New Bay and the Fortune Harbour Peninsula (Plate 3) and are characterized by pillow lavas and volcaniclastic rocks exhibiting rapid lateral facies variations; massive channel-fill conglomerates, volcanic flows and sills are also common (Helwig, 1967). The conglomerates contain mafic and silicic volcanic clasts. Pillow lavas of the Lawrence Head Volcanics range from 10 cm to 1 m across and often contain calcite- and epidote-filled vesicles. Blue cherts which may contain high amounts of Cu and Ni typically form the interstices between these pillows (Figure 6.5) and geopetal structures may be found in these interstices. One of these interstices displays features which suggests a sequence of events whereby a layer of blue chert was first deposited on the base of the void, then a layer of calcite was precipitated around the edges of the entire interstice. This was followed by the precipitation of a layer of sulfide minerals around the entire space. Steps two and three were repeated, and then mud and calcite filled the remaining space. These events suggest that the Lawrence Head pillow lavas were deposited near a source of anomalously high dissolved sulfide minerals. Modern environments exhibiting these features may be found near submarine hot springs

Figure 6.5. Vesicular pillow lavas of the Lawrence Head Volcanics with interstitial blue chert.

(black smoker chimneys) along ridge axes. Cherts of this type were not observed in the Frozen Ocean Group, suggesting that the two are not strict lithologic correlatives.

Roberts Arm Group

The Roberts Arm Volcanics (Espenshade, 1937) form an arcuate belt to the west of the Frozen Ocean Group area (Plate 3). They are predominantly basalts, pillow lavas and volcanic breccias, although some chert, siltstone, volcaniclastic graywacke and silicic volcanic rocks occur as well (Bostock, 1978). I examined outcrops of the Roberts Arm Group on the Trans-Canada highway between Badger and Springdale (Plate 3), but found little resemblance between these rocks and the Frozen Ocean Group. Therefore, the Roberts Arm Group is not regarded as a lithologic correlative to the Frozen Ocean Group, despite the claims of Dean (1977, 1978) that they do belong to the same Group.

CHAPTER VII

TECTONIC HISTORY OF NORTH - CENTRAL NEWFOUNDLAND

Introduction

Since Bird and Dewey (1970) first analyzed the Newfoundland Appalachians in terms of plate tectonics, most workers have agreed that central Newfoundland has preserved within it an early to middle Ordovician (and possibly late Cambrian) island arc complex, and that this island arc collided with the continental margin of eastern North America in middle Ordovician times causing the Taconic Orogeny. Pre-Caradocian rocks of the Exploits Terrane, including the Frozen Ocean Group, are regarded as those deposited on the back-arc side of the Taconic island arc. However, less agreement has been reached on the subsequent development of the tectonostratigraphic zones as we see them preserved today.

Consequences of the Taconic Orogeny

Some previous tectonic models for the Newfoundland Appalachians had assumed post-Caradocian volcanism in central Newfoundland, and various tectonic scenarios were dreamed up in order to explain the presence of late Ordovician - early Silurian volcanics in the New Bay Pond area, as reported by Dean (1977, 1978), Dean and Kean (1980), and Strong (1977). This thesis has demonstrated that a conformable contact between rocks of the Frozen Ocean Group and structurally underlying sequences cannot be shown anywhere in the region, and that this contact is in fact faulted at every observable location. Field (and microscopic) scale structures indicate that the thrusting event which emplaced rocks of the Frozen Ocean Group over other early to middle Ordovician rocks and a contemporary flysh sequence was directed towards the south, and is related to a regional back-thrusting event post-dating ophiolite obduction in western Newfoundland. The early Silurian geometry of what is now central Newfoundland is here suggested to have resembled the present day geometry of the back-arc region of the Sunda Arc (see appendix 4). Continued post-collisional convergence between the Appalachian Ocean and the Taconic-modified margin of North America was apparently accomodated along a series of back-thrusts; the Fog Fault is the thrust fault most distal from the arc so far recognized. From the arc into the contemporary flysh basin, these faults include the Lukes Arm - Sops Head Fault, the Toogood Fault, the Cobbs Arm Fault and the Fog Fault (Figure 7.1). It is possible that the Chanceport - Lobster Cove Fault is coeval with these thrusts, but no persuasive geological evidence exists to prove this, despite the claims of Dean and Strong (1977). Movement along the Fog Fault was mostly along bedding planes, although the faults closer to the arc seem to have

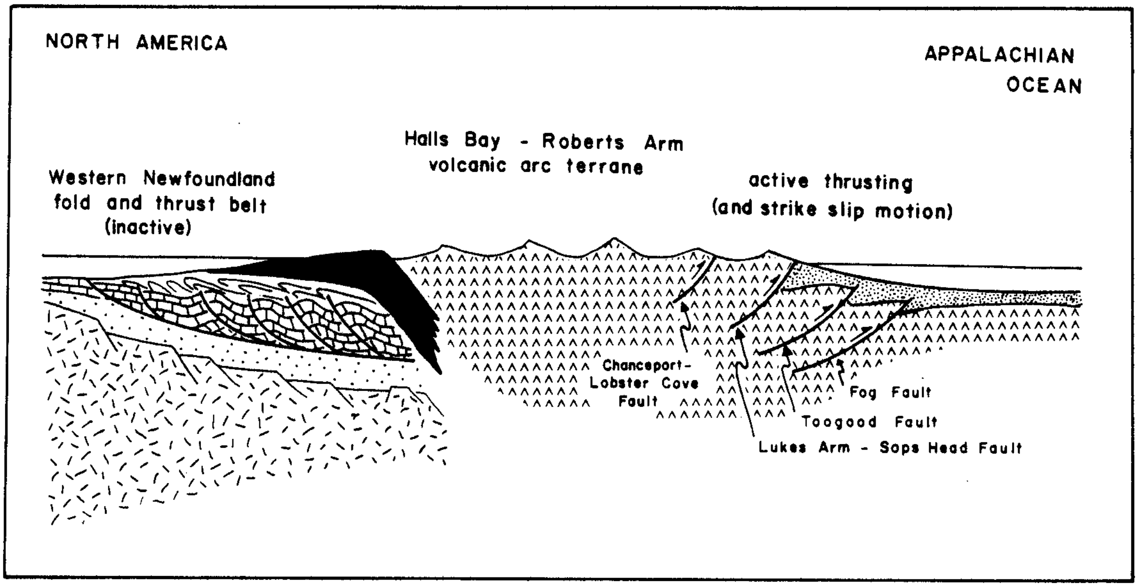


Figure 7.1. Schematic Late Ordovician - Early Silurian reconstruction showing back-thrustingg in what is now central Newfoundland. This event accomodated continued convergence between the Taconic modified margin of North America and the Appalachian Ocean, and commonly emplaced rocks of island-arc/back-arc basin affinity over similar rocks and a contemporaneous flysch sequence generally known as the Sansom Graywacke (fine stipple). Several examples of these thrust faults are shown, including the Fog Fault (new), which separates the Frozen Ocean Group from Sansom-equivalent rocks in the New Bay Pond area (modified from Nelson, 1979).

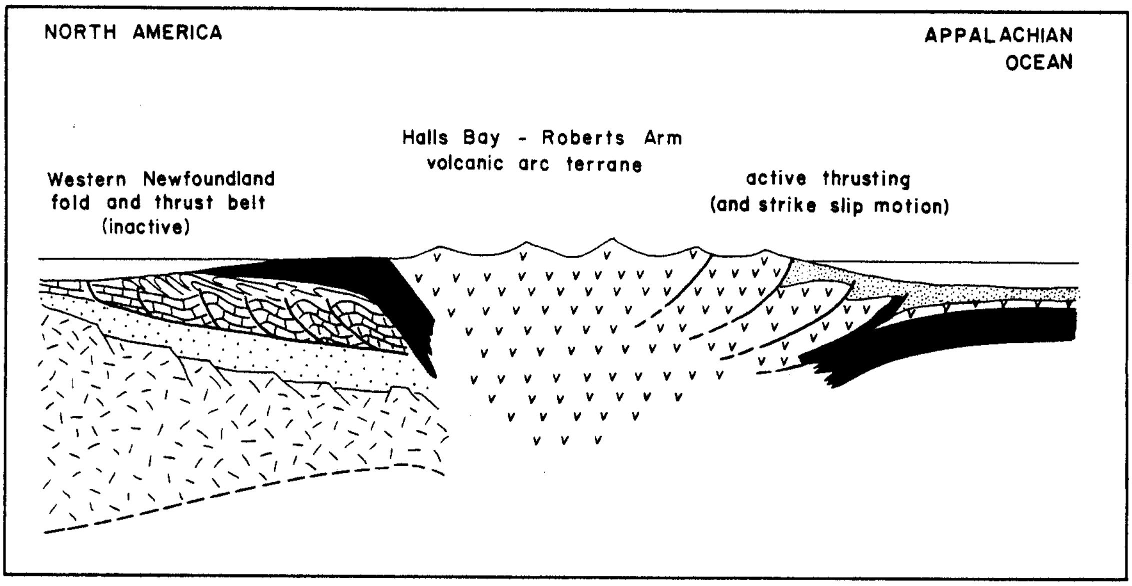


Figure 7.2. If the South Lake "Ophiolite" can be shown by subsequent study to be a slice of oceanic/island arc basement uplifted along the Fog (or a similar) fault during this back-thrusting event, then some amount of oceanic crust may have been subducted during the early Silurian.

had steeper attitudes (cf. Nelson, 1981). Analysis of lineaments on a regional scale (Plate 3) suggests that numerous nappe-like folds may have been associated with these thrust faults; in fact, the northern Exploits Terrane resembles a fold and thrust belt turned on its side.

The Fog Fault is suggested to extend to the vicinity of South Lake (Plate 2), where oceanic/island arc - type basement of the South Lake Igneous Complex is preserved (Lorenze and Fontain, 1980). Examination of Plates 1 and 3 reveals numerous footwall ramps under the Fog Fault; the presence of ophiolitic-type basement, possibly above the Fog Fault at South Lake, suggests the presence of hanging wall ramps as well (Figure 7.2).

The age of this thrusting event is constrained by the age of the associated flysh-type sediments (Sansom correlative strata and the Goldson Conglomerate), which several authors (Twenhofel and Shrock, 1937; Williams, 1962; Helwig, 1967) have shown to be Llandoverian. This is based on the preservation of corals, brachiopods, trilobites and other fossils within limestone boulders in olistostromic horizons in the flysh, on graptolites in the slates, and on brachiopods in the slaty matrix to olistostromes (Mckerrow and Cocks, 1977).

The Location of the Appalachian Ocean Suture in Newfoundland

Introduction

Even though the Acadian Orogeny is usually regarded as "the main" deformation episode to have affected rocks of the Appalachian Orogen, it is still imperfectly understood. In particular, the location of the suture marking the place where the Appalachian Ocean closed has still not been adequately defined. The Northern Arm Fault separates the Exploits and Botwood Tectonostratigraphic Zones in central Newfoundland (Dewey, Kennedy and Kidd, 1983) and it is correlated with the Reach Fault to the north, Noel Paul's and the Cape Ray Faults to the south (Figure 1.1 and Plate 3) (McKerrow and Ziegler, 1972; Brown, 1973). Because this fault system was suggested to separate vastly different faunal provinces (Mckerrow and Cocks, 1976, 1977) it has often been regarded as the suture zone marking the place where the Appalachian Ocean finally closed in the Devonian during the Acadian Orogeny. More recently, other workers have (1) doubted that the faunal evidence requires a suture zone in this area (Stouge, 1979, 1980a, 1980b), (2) ignored any possible geologic consequences of large-scale displacements across this fault zone (Karlstrom, 1983), or (3) have suggested that the Northern Arm - Reach Fault system is a relatively late orogenic feature with only minor displacements associated with it (Karlstrom et al., 1982; Williams, 1984).

The structural analysis of the Northern Arm Fault presented in chapter 3 demonstrated that this fault has a right lateral strike-slip sense of offset. Structural observations along the Reach Fault suggests that it too is a right lateral strike slip fault (Janos Urai, personal communication). In order to elucidate the significance of this fault, differences in regional stratigraphy on either side of the fault must be examined.

Stratigraphic Summary of Exploits, Western and Eastern Botwood Tectonostratigraphic Zones

Sutures are recognized by zones of complex structure, often containing ophiolitic slivers, which separate zones of different stratigraphic, paleontologic, structural and other histories (cf. Dewey, 1977). The stratigraphy of the Exploit's, Western and Eastern Botwood Zones are all markedly different, and detailed descriptions of each may be found in Dewey et al., (1983), Nelson (1979), Dean (1978), and Helwig (1967), amoung others. Figure 7.3 summarizes the stratigraphy for each of these areas.

As discussed in previous chapters of this thesis, the Exploits Zone is characterized by an upper Cambrian to middle Ordovician (Caradocian) sequence composed predominantly of mafic volcaniclastic sediments, shales and cherts. These are interbedded with scarcer mafic and silicic lavas which are locally pillowed, and the entire thickness of this sequence is intruded by numerous mafic dikes and sills. These rocks are believed to represent

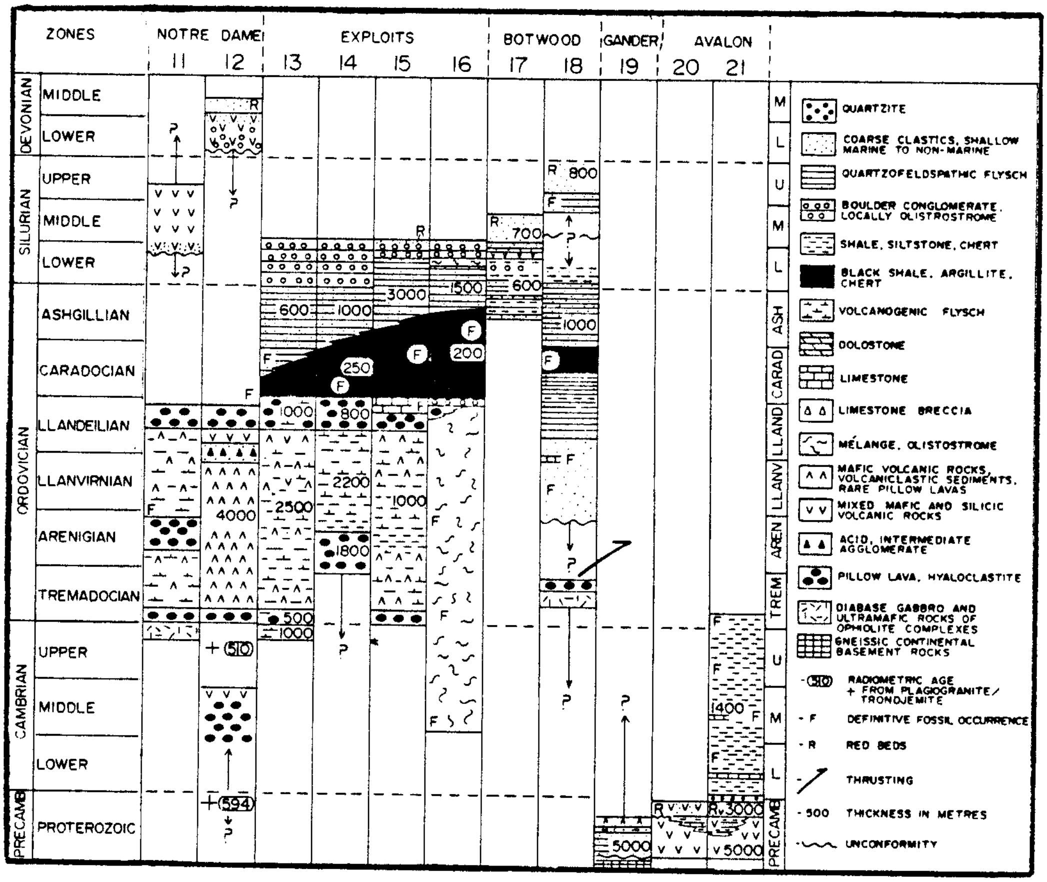


Figure 7.3. Stratigraphic columns for the Exploits, Gander, Western and Eastern Botwood Tectonostratigraphic Zones (modified from Dewey et al., 1983). Specific locations for each section are listed in Dewey et al (1983).

material largely eroded from, or related to, the Taconic volcanic arc(s) now preserved in the Notre Dame and Fleur de Lys Zones to the west (Dewey et al., 1983). This arc flanking sequence of the Exploits Zone is ubiquitously overlain by a well dated Caradocian black shale unit, in turn overlain by an upward coarsening flysh-type sedimentary sequence whose base youngs towards the southeast (Figure 6.1). This demonstrates the diachronous nature of flysh progradation into the Sansom Basin.

Rocks of the Eastern Botwood Zone unconformably overlie ophiolitic rocks correlative with the Gander River Ultramafic Belt. The lower Ordovician sequence generally consists of coarse- to fine-clastic rocks that largely represent distal turbidites (Dewey et al., 1983), and contain metamorphic and ophiolitic detritus probably eroded from early Ordovician tectonic highlands to the east (Kennedy and McGonigal, 1972). These grade into a flysch-type sequence, in turn apparently succeeded by Caradocian black shales. The upper Ordovician and Silurian rocks of the eastern Botwood Zone contain flysch similar to that in the Exploits Terrane, and are locally overlain by redbeds at the top of the sequence (Figure 7.3). Thus, the stratigraphy of the eastern Botwood zone appears to be generally similar to that of the Exploits Terrane, although sedimentary facies indicate that it represents a more distal environment. Marked differences exist between the stratigraphy of the eastern Botwood Zone and the Gander

Zone, and no correlation is possible between these two (cf. Dewey et al., 1983).

Ordovician and Silurian rocks of the Western Botwood Zone differ from those of both the Exploits and Eastern Botwood Zones in that they locally contain a large amount of subaerially erupted volcanic rocks, especially along the margin of the zone, and the sediments are highly heterogeneous in nature. The top of the Western Botwood Zone stratigraphy is also marked by red beds. The stratigraphy of the western Botwood Zone is easily divided into two subgroups with different characteristics. The basal section is volcanic-rich with abundant immature sedimentary intercalations. The sediments have been shown to locally coarsen towards the basin's edges (Williams, 1967), suggesting local derivation (Figures 7.4 and 7.5). This lower section is overlain by a thinner, finer grained, entirely sedimentary section that outcrops over a larger area than the basal section.

Because rocks of the western Botwood Zone exhibit many characteristics of rocks deposited in rifts (cf., Burke et al., 1985) and is bound on two sides by strike slip faults, I suggest that the western Botwood Zone represents a pull-apart basin (cf. Mann et al., 1983). The geometry of this basin is consistent with this interpretation: it falls between a right step in a right lateral strike slip fault system, and the general shape of the basin is that of a "rhomb graben". Rocks of the Botwood Group within this suggested pull-apart basin have yielded a fossil age of

Figure 7.4. Subaerially-eroded caliche breccia from the Western Botwood Zone containing mafic volcanic fragments.

Figure 7.5. Pillow lavas of the Lawrenceton Formation containing interstitial red micaceous sandstone.

Ludlovian (Twenhofel and Shrock, 1937; Kay, 1967), constraining the timing of basin formation. The fact that the Northern Arm Fault cuts the Hodges Hill Pluton (which is presumed to be Devonian in age) indicates that movement continued, or was re-initiated along the Northern Arm Fault subsequent to the formation of the Botwood Pull-apart basin.

As this discussion has demonstrated there are differences between the stratigraphy of the Exploits, western, and eastern Botwood Tectonostratigraphic zones; however, they all seem to be related to lateral facies variations developed at different distances from a single island arc complex. The Botwood pull-apart basin apparently formed within this region while it was being sliced apart by strike-slip faulting prior to the Acadian Orogeny; other dextral faults of this age (D_2)are recognized from the New Bay Pond area. Thus, the change from fold and thrust tectonics to right lateral strike-slip faulting in central Newfoundland occurred during the middle Silurian. Subsequent to Acadian compression and folding, the region experienced another episode of right-lateral strike-slip faulting, forming the present Northern Arm Fault and its correlatives (Plate 3).

The fact that the stratigraphy of the Exploits, western, and eastern Botwood are all relatable to variations around a single island-arc complex suggests that the Northern Arm Fault does not represent the suture marking the place where the Appalachian Ocean closed and, thus, this suture zone must be sought in areas further to the east. Highly deformed rocks preserved along the Gander River Ultramafic Belt, including the Carmanville Melange (Figure 7.6), seem a more likely candidate to mark the place where this ocean closed.

Figure 7.6. Highly strained metapelites with metapsammitic lenses and serpentinite flakes (light colored) in the Carmenville melange at Aspen Cove. Could this and its lateral equivalents represent the Appalachian Ocean suture?

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APPENDIX 1

COMMENT ON "REINTERPRETATION OF NEWFOUNDLAND GRAVITY DATA AND ARGUMENTS FOR AN ALLOCHTHONOUS DUNNAGE ZONE"

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Many workers in Newfoundland have regarded the Notre Dame, Exploits and Botwood tectonostratigraphic zones (Dunnage Zone of Williams, 1978) to be generally underlain by oceanic and island arc type crust and lithosphere. However, Karlstrom (1983) has recently suggested that most or all of the Dunnage Zone is allochthonous and underlain by continental-type crust, because the published Bouguer gravity anomalies over this zone are lower than would be expected if the area were underlain by "normal" oceanic crust and lithosphere. It is our opinion that the geologic evidence and the gravity data from central Newfoundland do not support this conclusion.

We suggest that it is inappropriate to model the gravity of the entire "Dunnage Zone" as a single tectonostratigraphic unit because it is known that the "Dunnage Zone" can be divided into several different zones of strongly contrasting character (e.g., Bird and Dewey, 1970; Williams, Kennedy and Neale, 1972; Dewey, Kennedy and Kidd, 1983). Further complications are introduced by the large strike slip translations that are proposed within the Dunnage Zone (Kay, 1967, 1972), particularly along the Northern Arm-Reach Fault Zone. This, and its continuation to the southwest, has been identified on both lithotectonic and palaeontologic evidence as the site of a suture (McKerrow and Cocks, 1977; Kennedy, 1975), or more accurately, a major fault that has by large-scale strike slip movement removed the central section of the suture zone, juxtaposing in this way originally well separated portions of the two sutured terranes. If this is correct the Dunnage Zone cannot, for this reason alone, overlie an autochthonous slab of continental crust unless the overthrusting is younger than the suturing. Since the suturing in question is Devonian, it seems unlikely that this is the case.

Karlstrom notes that the gravity data could equally well be interpreted as the signature from autochthonous oceanic lithosphere that was in part serpentinized. He then suggests that "large areas of unaltered mafic and ultramafic rocks on the surface" of the Dunnage Zone negates this possibility. We would like to know where these supposedly unaltered rocks are, as it is our experience that these mafic rocks are generally metamorphosed to the greenschist or prehnite - pumpelleyite facies (locally higher), and the ultramafic rocks are almost ubiquitously serpentinized, or worse. This alteration significantly lowers the density of these rocks, and presumably also strongly affects the Bouguer anomaly values from the Dunnage Zone.

Karlstrom also notes that the gravity data may be reconciled by the presence of a large amount of granitoid rocks in the zone, which would effectively dilute the gravity signature of the (higher density) mafic and ultramafic rocks. Despite the large volume of granitoid rocks and low density sediments exposed in this zone Karlstrom does not choose this rather plausible hypothesis. We restate the observation that the composition of granitoid rocks in the Dunnage Zone, is on the average, more mafic than in the surrounding zones that are clearly underlain by continental crust. As Dewey and Kidd (1974) pointed out, and Strong (1977) repeated, this strongly implies that the Dunnage Zone is underlain by mafic oceanic and island arc - type crust, and not by rocks of continental affinity.

The composition of some xenoliths in intrusive igneous bodies may reflect the nature of the underlying basement, but xenoliths from rocks intrusive to the Dunnage Zone are, to our knowledge, nowhere of continental basement origin, but rather are always relatable to the near surface geology of the zone, or are mafic to ultramafic in composition. Specifically, we cite some examples that lie very close to the line of the gravity profile used by Karlstrom (1983) to model the Dunnage Zone as overlying continental basement (Figure 1). Church and Stevens (1971, p. 1464) report that "xenoliths of altered ultramafic rock, along with mafic and silicic schists comparable to schists of the Fleur de Lys metamorphic complex occur in the Brighton Igneous Complex (Long

Island Tonalite: A - Figure 1) of Long Island north of the Lukes Arm Fault." Field observations of these outcrops by J.F. Dewey (personal communication) and one of us (W.S.F.K.) recorded numerous xenoliths of gabbros and diabase, serpentinized ultramafic rocks and some of strongly foliated amphibolite but no xenoliths of possible continental basement, nor silicic schists, were observed. These xenoliths are thus wholly mafic or ultramafic in composition. The Coaker Porphyry which cuts the Dunnage melange near the causeway across Dildo Run on New World Island (B - Figure 1) contains numerous small ultramafic xenoliths, which could be derived from the basement although at least some are autolithic aggregates related to the phenocryst phases in the porphyry. The large Devonian Twin Lakes/Hodges Hill diorite - granodiorite pluton (C - Figure 1) contains numerous xenoliths of local country rocks and amphibolite (Dean, 1977), and on the northeast shore of New Bay Pond (D - Figure 1) a spectacular intrusion breccia associated with this pluton contains a wide assortment of country rock "clasts", but in no place known to us does this or any other part of this plutonic suite contain any xenoliths of possible continental basement origin, nor to our knowledge do any of the Acadian plutons in the Dunnage Zone.

Helwig et al. (1974) report xenoliths of lamprophyres, local Wild Bight Group volcanics and olivine gabbro from the Jurassic Budgell Harbour Stock (E - Figure 1). They noted the similiarity of this to other intrusive breccias on Exploits Island (F - Figure 1), where Heyl (1935) reported inclusions of olivine gabbro, dunite, peridotite and eclogite, suggesting that an ophiolitic/ mafic-type basement extends to great depths below the Dunnage Zone. Nelson (1979) reported a Mesozoic lamprophyre dike from the mouth of Seal Bay (G - Figure 1) that is crammed with non-foliated granite xenoliths similar to Hodges Hill Granite, but no gneissic fragments were seen, despite We interpret this to indicate that much of the zone is indeed under density granitoid plutonic rocks (of largely Devonian age).

We do agree with Karlstrom that there was a period of Silurian thrusting in central Newfoundland, as was first clearly demonstrated by Nelson (1981). However, we think it unlikely that this event placed oceanic affinity rocks over continental basement, but generally emplaced Ordovician island arc assemblages over similar Ordovician rocks of island arc - back arc basin affinity, with accompanying flysch - type and olistostromic sedimentation. This thrusting event appears to have been directed towards the southeast (Nelson, 1981), contrary to what Karlstrom (1983) and Karlstrom et al. (1982) imply, and probably accommodated continued post - Taconic convergence and strike-slip motion between Silurian North America and the remaining open part of the northern Appalachian ocean (McKerrow and Ziegler, 1972).

We find the "lower than expected" Bouguer anomaly over the Dunnage Zone to be readily explained by (1) alteration and decreased density of the mafic and ultramafic rocks, (2) a large proportion of interstratified/tectonically interleaved low density sediments and island arc lithologies, and (3) intrusion of a large amount of relatively low density granitoid plutons, besides the effect of a probable change or step in the Moho geometry below the Dunnage Zone (Sheridan and Drake, 1968; Miller, 1984). For these reasons, and the others discussed above, we think it is most improbable that the Dunnage Zone is underlain by a single extensive slab of continental crust originally attached to North America.

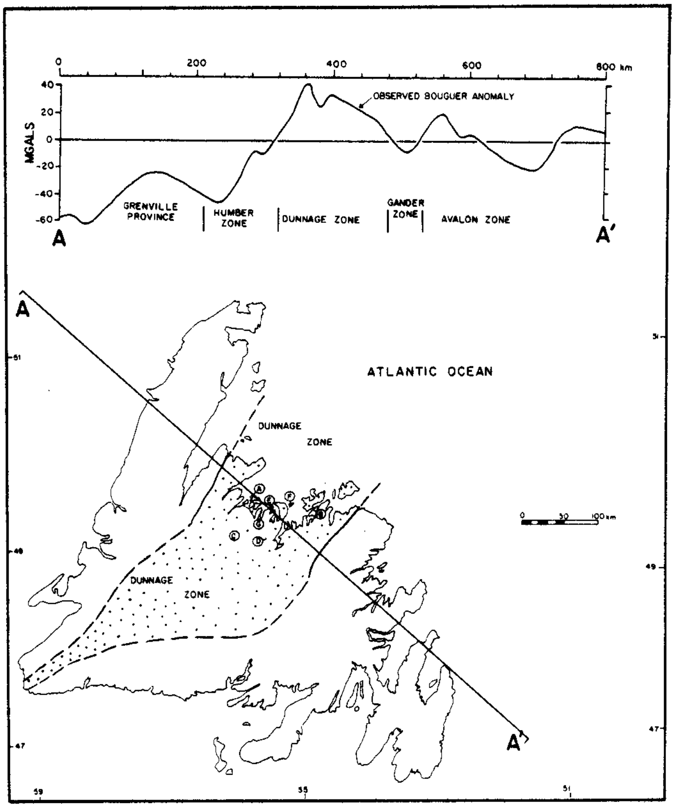

Figure 1. Bouguer gravity profile (A - A') across Newfoundland (Canada Dept. of Energy, Mines and Resources, 1980). Letters refer to localities discussed in text: A, Long Island Tonalite; B, Coaker Porphyry; C, Twin Lakes/Hodges Hill Batholith; D, intrusion breccia of C at New Bay Pond; E, Budgell Harbour Stock; F, Exploits Islands; G, Seal Bay lamprophyre dike containing granitic xenoliths. Intrusive rocks at localities A - F contain mafic to ultramafic xenoliths of probable ophiolitic/island arc derivation, and no trace of xenoliths possibly derived from continental-type crust, suggesting that the Dunnage Zone is underlain by mafic oceanic/island arc - type crust and lithosphere.

APPENDIX 2

DISCUSSION OF "MIDDLE ORDOVICIAN CONODONTS FROM THE BUCHANS GROUP, CENTRAL NEWFOUNDLAND, AND THEIR SIGNIFICANCE FOR REGIONAL STRATIGRAPHY OF THE CENTRAL VOLCANIC BELT"

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Canadian Journal of Earth Sciences
vol. 21, pp. 284-296

Nowlan and Thurlow (1984) have recently reported a latest Arenig - early Llanvirn age conodont fauna from the Buchans Group, central Newfoundland, and have suggested that this demonstrates that all volcanogenic massive sulfide deposits, and hence, associated volcanism in the Canadian Appalachians is of Caradocian or older Ordovician age. They go on to state that this requires substantial revisions of tectonic models for the Northern Appalachians.

We welcome this important contribution to the knowledge regarding the age of Robert's Arm Volcanic Belt (which includes the Buchans Group; Dean, 1977), but find their suggestion that current tectonic models for central Newfoundland are inadequate or erroneous to be somewhat misleading. Perhaps this is the case if the "tectonic" models they are referring to are those, for instance, of Dean (1977, 1978), Strong (1977) or Dean and Kean (1980). However, their results strongly support the tectonic models set out by Kidd et al., (1977), Nelson (1979, 1981), Nelson and Kidd (1979) and Dewey et al., (1983). These authors have clearly stated their view that Ordovician island arc related volcanism in central Newfoundland terminated by the Caradocian; in other words, the Robert's Arm and equivalents (Buchans Group included) are pre-Caradocian in age, in contrast to the views of Dean (1977, 1978). The cessation of arc-type volcanism by (or in) the Caradocian led to widespread thermal subsidence and the deposition of cherts and black carbonaceous, graptolitic shales over the flanking volcaniclastics of the island arc in the Exploits Zone.

Although the Buchans Group was previously regarded as Silurian by some workers, available age information from the rest of the Robert's Arm Belt indicates that it is pre-Caradocian in age, supporting the views of Nowlan and Thurlow. Specifically, Bostock et al., (1979) report a Rb-Sr age of approximately 455 Ma from silicic volcanics and a genetically related pluton from the Robert's Arm Group near Hall's Bay. Because these samples came from the upper part of the Robert's Arm Group and Rb-Sr age determinations commonly yield ages that are younger than those obtained by using other methods, we regard this as a minimum age for the Robert's Arm Group, and consider it most probable that the Robert's Arm Group was deposited over a long period of time, possibly begining as early as late Cambrian-early Ordovician if the Tremadocian volcanics reported by Kay (1972) for the Exploits Zone on New World Island are equivalents. Elsewhere on New World Island the Cobbs Arm Limestone represents fossil atolls that formed around volcanic islands related to the Robert's Arm volcanism (Fahraeus and Hunter, 1981). The volcanism was waning at the time of deposition of these limestones, and their Llandeilian age (Bergstrom et al., 1974; Fahraeus and Hunter, 1981) also suggests that all island arc related volcanism in central Newfoundland ended by the Caradocian. Thus, the early to middle Ordovician age that Nowlan and

Thurlow report for the Buchans Group is entirely reasonable and consistent with the now well established age of the correlative Robert's Arm volcanics to the north. This new data implies that there was not a diachronous migration of active volcanism towards the southwest, as suggested by Strong (1977), Dean (1977, 1978), Dean and Kean (1979) and others.

There remains one area in central Newfoundland where island arc-type volcanics have been stated to lie conformably over Caradocian and younger sediments (Dean, 1977, 1978; Dean and Kean, 1980). The rocks are the so-called Frozen Ocean Group (Dean, 1977) and are found in the Frozen Ocean Lake - New Bay Pond area. Recent, and as yet unpublished field work by us in this area has revealed that the Frozen Ocean Group does NOT conformably overlie medial Ordovician sediments as previously suggested, but is every where in demonstrable thrust fault contact with them (Fog Fault on Figure 1). The thrust faulting was directed towards the southeast, although in this area too the the fault has been subsequently folded and rotated into a vertical position (Kusky and Kidd, in prep.). This situation is similar to that reported by Nowlan and Thurlow for the Buchans area, by Nelson (1979, 1981) for the Notre Dame Bay area, and appears to be generally true for all of central Newfoundland. As Nelson (1981) pointed out, this geometry is a result of early Silurian south-eastward directed back-thrusting, and was apparently related to a continued component of convergence between the Taconic modified margin of North America and what is now the Exploits Terrane of central Newfoundland (Dewey et al., 1983; Kusky and Kidd, in prep.). Figure 7.1 is a schematic representation of the tectonic situation suggested for western and central Newfoundland in early Silurian times.

APPENDIX 3

NEW EVIDENCE SUGGESTS A POST-TACONIC, PRE-ACADIAN BACK-THRUSTING EVENT IN CENTRAL NEWFOUNDLAND

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Recent fieldwork in the Frozen Ocean Lake - New Bay Pond area, central Newfoundland (Exploits Zone) has revealed that volcanic and volcaniclastic rocks of the Frozen Ocean Group (FOG) are everywhere in fault contact with a structurally underlying flysh-type sedimentary sequence. The FOG was previously suggested to conformably overly these Caradocian and younger sediments and, hence, was regarded as late Ordovician - early Silurian in age (Dean, 1977, 1978; Dean and Kean, 1980). The Fog Fault, which separates these two contrasting sequences, is correlated with the Cramp Crazy Fault, exposing oceanic/island arc-type basement of the South Lake Ophiolite. After the effects of several episodes of later deformation are removed, sense of shear indicators along this fault zone consistently indicate that rocks of the FOG were thrust towards the south and over several ramp zones, emplacing them over a contemporaneous Silurian flysh sequence generally known as Sansom correlative strata. This thrust fault is believed to be coeval with several other similar structures within and bounding the Exploits Terrane, and is attributed to an early Silurian regional back-thrusting event which caused considerable crustal-thickening of the Taconic-modified margin of North America, and probably accomodated continued convergence between this terrane and the remaining, open part of the Appalachian Ocean.

APPENDIX 4

THE EASTERN SUNDA ARC AS A MODERN ANALOG FOR THE POST-TACONIC GEOMETRY OF CENTRAL NEWFOUNDLAND

It is intuitively obvious that any detailed study of an orogenic system will be facilitated by a comparison to similar less strained modern environments (Sir Charles Lyell, 1830-33, followed by Archibald Geikie, 1905). In an attempt to better-understand the post-Taconic events which occurred in central Newfoundland the geology of the back-arc region of the eastern Sunda arc will be briefly examined, because this region of the world is presently experiencing an arc/continent collision between Timor and Australia, and post collisional back-thrusting is well-documented from this region (MaCaffrey and Nabelek, 1984; Johnson and Jacques, 1980; Silver et al., 1983; Hamilton, 1977). Other places in the world where similar situations exist include the Caribbean side of the Central American arc behind Costa Rica and Panama, and possible behind northwestern Japan (Silver et al., 1983).

Silver et al., (1983) describe the geology of the eastern Sunda back-arc region (Figure A4.1) and conclude that it is a result of post-collisional back-thrusting and that the whole region is destined to become an accretionary prism formed above a zone of arc-polarity reversal. The structure of the region is dominated by arc-dipping thrust faults which bound fold packets scraped off the oceanic crust of the back arc region (Figure A4.2). This deformation is shown to be contemporaneous with flysh type sedimentation and where these thrusts are observed volcanism in the arc has generally ceased (Silver et al., 1983). Therefore, the back-arc region of the eastern Sunda arc appears to be a strict analog to the late Ordovician - early Silurian evolution of the northern Appalachian orogen.

APPENDIX 5

ABSTRACTS OF OTHER RESEARCH

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