TRANSPORTED SLICES OF THE COASTAL COMPLEX
BAY OF ISLANDS – WESTERN NEWFOUNDLAND

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by

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ABSTRACT

The thesis area, the southern portion of the Coastal Ranges, is underlain by six igneous structural slices. They have been defined as the Coastal Complex. They tectonically overlie an undifferentiated series of transported sedimentary rocks forming part of the Humber Arm Group. All igneous structural slices of the Coastal Complex, except one, are separated from the underlying sediments and each other by mélange zones of varying thicknesses and lithologies. The rock types and geological relationships can be correlated between structural slices.

Foliated amphibolitic gabbros are intruded by soda-rich granodiorites and quartz diorites. These are affected by a second tectonic foliation and are intruded and bordered by tectonically undeformed diabase dykes and dyke breccias, which are presumed to be the feeders for nearby similarly undeformed extrusive volcanics.

Contacts between deformed and undeformed rocks are always high angle. Zones of diabase dyke breccias and/or fluidized host rock invariably occur at contact areas and mar original relationships. The fresher volcanics and their associated feeder dykes are similar to and equated with volcanics and sheeted dykes and dyke breccias underlying part of the nearby ophiolitic complexes to the east.

The recognition that the Coastal Complex is geologically different and separate from the ophiolite complexes to the east requires a new interpretation for the Bay of Islands area.

The definition of the Coastal Complex to include the foliated gabbros, granodiorites and associated fresh volcanics, along with the redefinition of the Bay of Islands Complex to include only the four large igneous massifs has rendered it possible to regard the Bay of Islands Complex (newly defined) as representing oceanic lithosphere (ophiolites).

The Coastal Complex is interpreted as "captured" older crustal material incorporated within or above an evolving oceanic ophiolite domain during late Pre-Cambrian or early Paleozoic times.

TRANSPORTED SLICES OF THE COASTAL COMPLEX: BAY OF ISLANDS WESTERN NEWFOUNDLAND

TABLE OF CONTENTS

page

page

CHAPTER I

INTRODUCTION

Location and Size of Thesis Area

The thesis area is located in the central part of western Newfoundland, approximately 35 miles, by road, from the city of Corner Brook (see fig. I). It includes the area from the mouth of the Serpentine (Coal) River northwards to South Head, on the Gulf of St. Lawrence, and from South Head eastwards, along the Bay of Islands, to York Harbour. Its eastern boundary is delineated by a line from Brooms Bottom Cove to the mouth of the Serpentine (Coal) River.

Access

A gravel road links the area to Frenchmans Cove, to the east. From Frenchmans Cove, the nearest city, Corner Brook, is 15 miles east and connected by a paved road.

The western portion of the area from Lark Harbour to the Serpentine (Coal) River is only accessible by boat. Steep cliffs make foot-travel impossible in some places and dense vegetation hampers inland travel in many others. Trails are plentiful in most low-lying regions. Gentle flanks of hillsides are usually covered by low, thick spruce growth, but at the tops of hills, rock exposure is good. Coastal exposures are excellent although calm waters are necessary for their study.

Geological Setting

Newfoundland represents the most northerly extremity of the Appalachian mountain system. This system is abruptly truncated approximately 300 miles off-shore to the northeast, and it appears to have once been continuous with a similar mountain system on the west coast of Ireland. The province has been recently subdivided into nine tectono-stratigraphic zones (Williams, Kennedy and Neale, 1972) which are essentially a modification of Williams' (1964) original three-fold subdivisions. Williams' (1964) subdivisions of the Newfoundland portion of the Appalachians are as follows:

(a) a Western Zone or Western Platform (Kay, 1966) -- a stable area during Cambrian and lower Ordovician times, with carbonate deposits overlying basement rocks deformed during the Grenvillian orogeny.

(b) Central Mobile Belt -- composed primarily of now-altered rocks of an eugeosynclinal facies, and

(c) an Eastern Zone or Avalon Platform (Kay, 1966) -- another area exhibiting Cambro-Ordovician stability.

Cambrian and Ordovician rocks of the Western Platform, namely the St. George Group and the Table Head Formation, are interpreted as continental margin deposits which formed part of an evolving carbonate bank on the margin of the Cambrian-Ordovician North American continent (Rodgers, 1968). These deposits, which have been termed the "carbonate terrane" (Rodgers and Neale, 1963) are overlain by easterly derived clastic rocks (Stevens, 1970). These are in turn tectonically overlain by transported clastic rocks, the Humber Arm Group (Schuchert and Dunbar, 1934) or the "clastic terrane" of Rodgers and Neale (1963). The Humber Arm

Group is represented in several tectonic slices that are themselves structurally overlain by four large separate ophiolite masses in the Bay of Islands area, with accompanying volcanic-plutonic rock assemblages in smaller slices to the west.

Transported rocks at the northern tip of Newfoundland at Hare Bay (Rodgers and Neale, 1963) display a similar succession of thrust slices to those in the Bay of Islands area. The present study area is entirely underlain by transported clastic sediments of the Humber Arm Group and higher structural slices that are made up of plutonic and volcanic rocks.

Physiography and Glaciation

The Bay of Islands region has been subdivided by Cooper (1936) into four distinct physiographic zones, which are, from east to west:

(a) dissected upland east of the Bay of Islands.

(b) Bay of Islands Range - contains the highest point in Newfoundland (2672 feet, Lewis Hills).

(c) Brooms Bottom Lowland - a swamp and bush-covered area to the west of the Bay of Islands Range.

(d) the Coastal Ranges.

The thesis area includes parts of the Brooms Bottom Lowland and Coastal Ranges.

The Brooms Bottom Lowland never attains an elevation above 200 feet. Its maximum width is 3 miles, south of York Harbour. On the southern side of the Bay of Islands, this lowland extends as far south as Lewis Brook and reaches inland to Serpentine Lake in the form of a "finger" along the Serpentine (Coal) River. It is underlain by unconsolidated gravels and clays of Quaternary age (Brückner, 1966).

The Coastal Ranges form a belt 1/2 to 3 miles wide which extends from South Head to just north of the Serpentine (Coal) River. The topography is rugged, reflecting rock types and geologic structures, and local relief may be up to 1500 feet. The coastal scenery is magnificent, with steep cliffs attaining altitudes of 1000 feet from sea-level. Low-lying areas are swampy and topographically high areas are barren with good rock exposures. Slopes are usually wooded or extremely steep. The Coastal Ranges, as well as the Brooms Bottom Lowland are continuous on the north side of the Bay of Islands, and extend as far north as Bonne Bay.

Glaciation has been very active in western Newfoundland, as evidenced by large, deep, westerly-trending, fjord-like bays. These include, from north to south, Bonne Bay, Trout River Ponds, North Arm, Middle Arm, Humber Arm, Serpentine Lake and the Serpentine (Coal) River valley (see fig. 2). These are all characterized by deep, U-shaped topography. All suggest ice movement in a westerly direction towards the Gulf of St. Lawrence.

Erratics, in the thesis area are very scarce, but several different lithologies, such as quartzites, muscovite schists, and granites are present. They suggest a derivation from the Long Range (Grenville) crystalline basement (see fig. 3).

High-ground frost action, both in the thesis area and on the Bay of Islands Range complexes, has obliterated most glacial features, however, locally (Monkeyland and Virgin Mountain slices (see fig. 4)), rock exposures exhibiting roches moutonnées and stoss and lee features are present suggesting local ice movement southeastwards towards the large main glacial valleys, where ice movement was westerly.

Trumpet Cove valley is a typical steep-sided, U-shaped glacial valley. Soft serpentinite mélange, in this area, was easily scoured to form the topographically well-developed valley.

Beach Terraces

Raised beaches are present in the study area and suggest, several periods of sea-level fluctuations. Two beach terraces are cut in pyroclastic rocks at Bottle Cove (see Fig. 4).

Outwash Deltas

A raised gravel and sand delta, containing Pleistocene fossils, is located on the north side of the Little Port-Lark Harbour road, at an elevation of 100 feet. The fossils have been identified by Mrs. E.L. Patey as:

(1) Mollusca

a) Pelecypoda

i) Hiatella arctica Linné
ii) Mya arenaris Linné
iii) Mya truncata Linné
iv) Mya edulis Linné
v) Pecten islandicus Müller

b) Gastropoda

i) *Busycon* Sp.

ii) *Littorina saxtile* Olivi

iii) *Buccinum undatum* Linné

iv) *Skenea planorbis* Fabricius

(2) Arthropoda

a) Crustacea

i) *Balanus crenatus* Bruguiere

(3) Echinoidea

i) *Strongylocentrotus ? drobachiensus* Müller

These forms suggest an environment similar to marine conditions today (Stevens, 1965). A Quaternary cover deposit, composed of sands and gravels equivalent to the above fossiliferous deposits covers most of the Brooms Bottom Lowland in the thesis area.

Drainage

Drainage is accomplished by a series of small streams, linking "pater noster" ponds in the interior. Low-lying areas are poorly drained and covered by swamp and bog. Only one river is present in the thesis area, the Serpentine (Coal) River. It drains the waters of Serpentine Lake westwards to the Gulf of St. Lawrence.

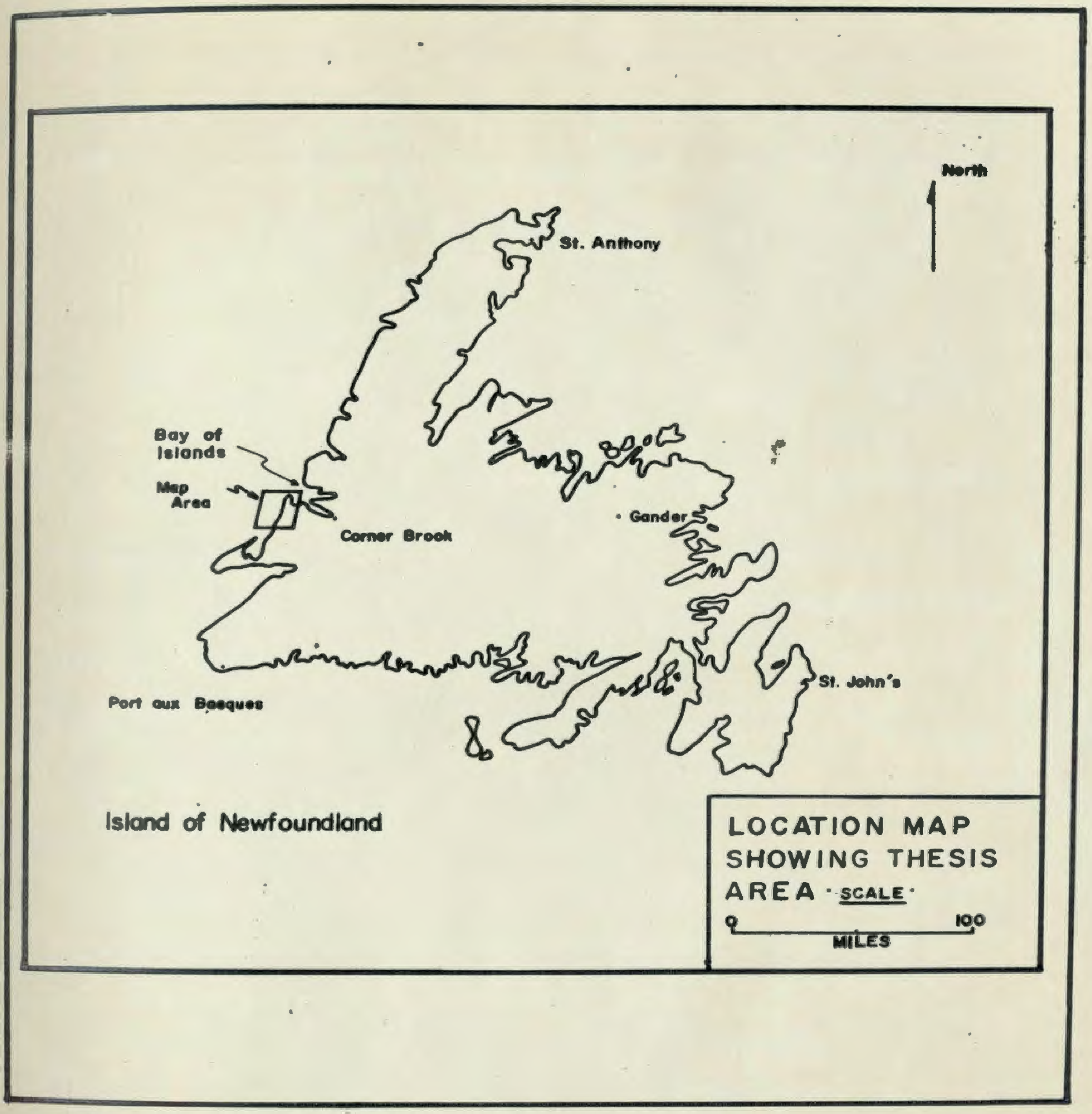
North
St. Anthony
Bay of
Islands
Map
Area
Corner Brook
Gander
St. John's
Port aux Basques
Island of Newfoundland
LOCATION MAP
SHOWING THESIS
AREA
SCALE
0
100
MILES

FIG 1

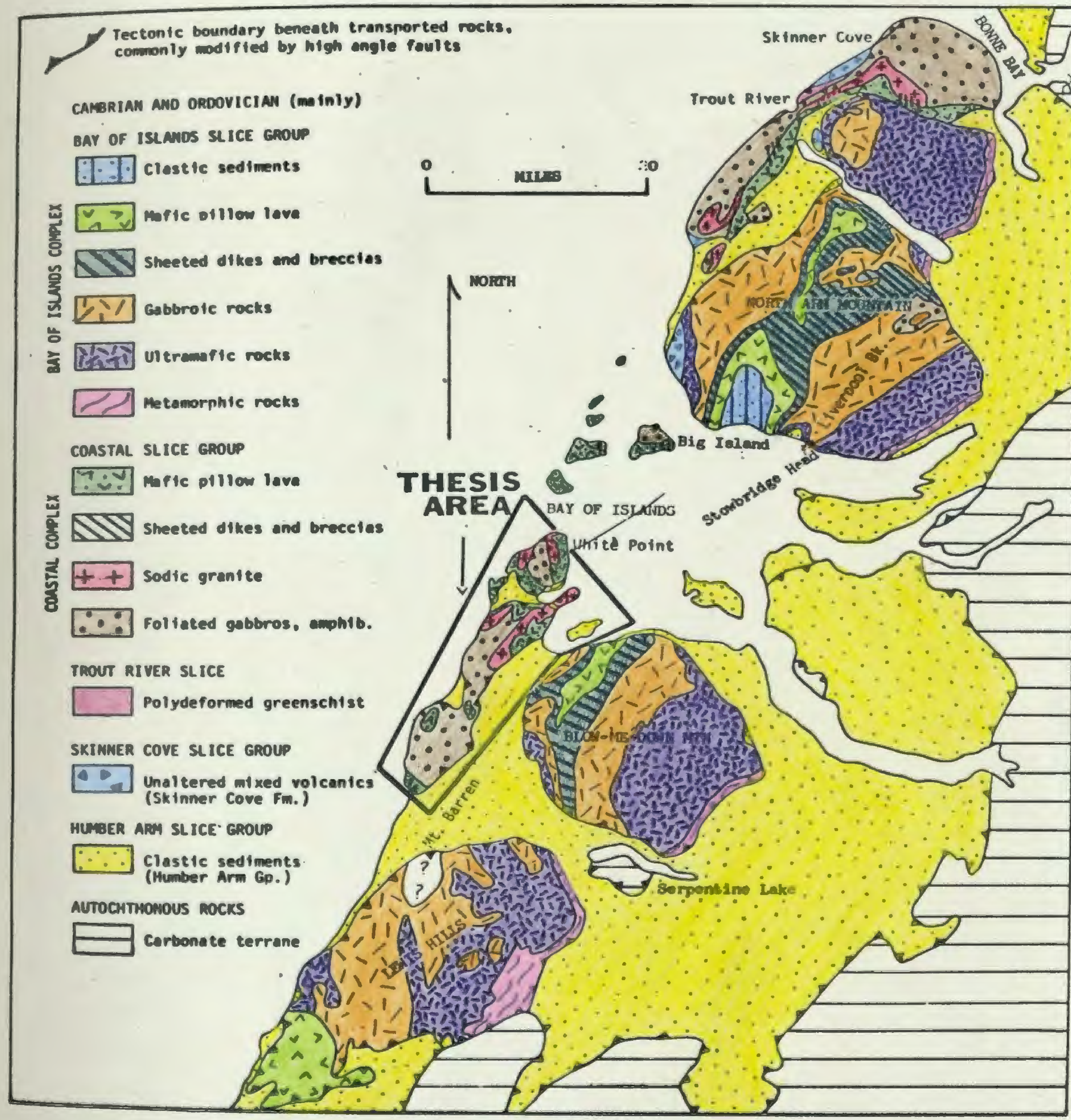

FIG 2

Geological Map of Humber Arm Klippe (after Williams, 1972).

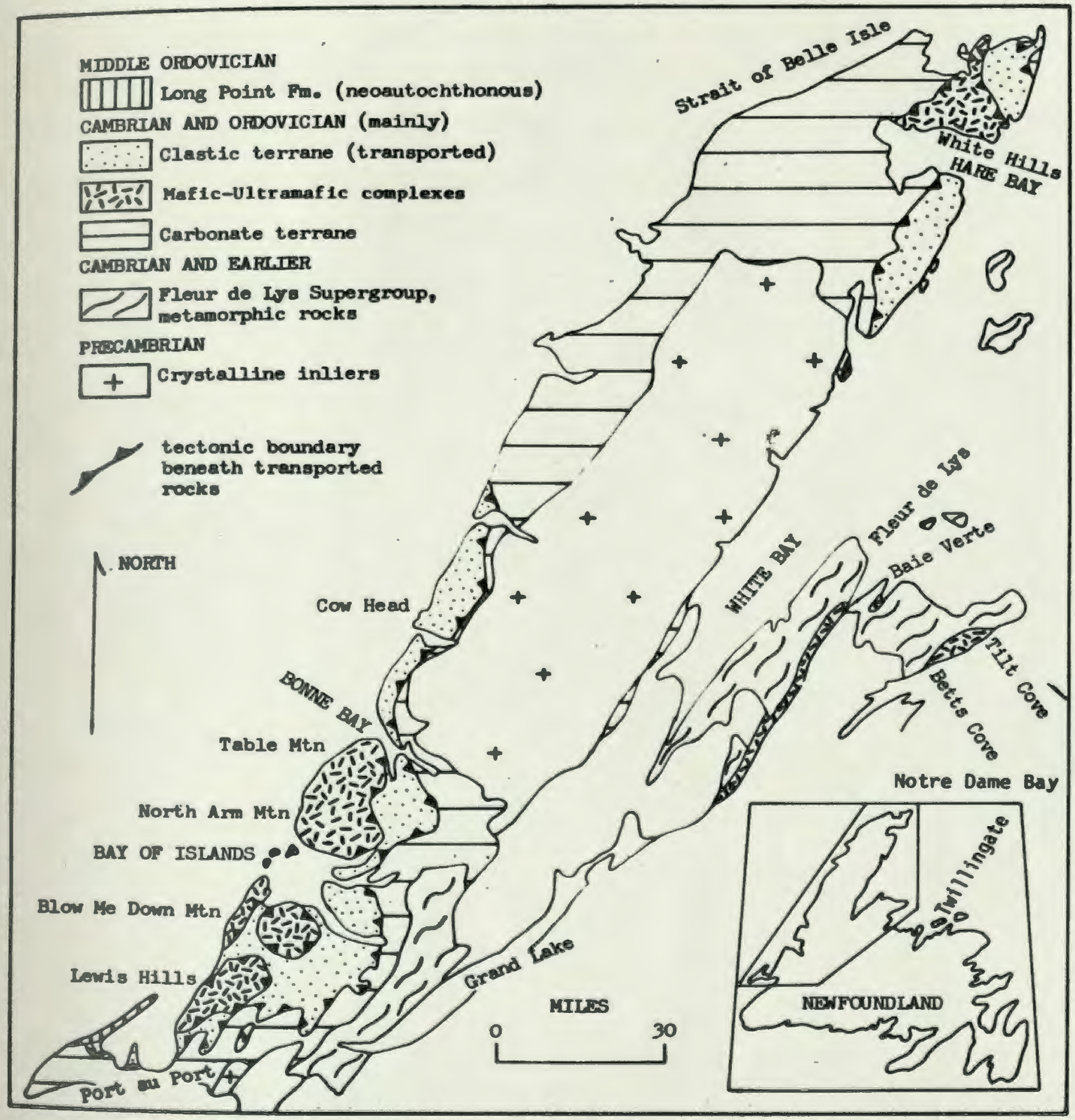

FIG 3

Geological Map of Western Newfoundland (after Williams, 1972).

Previous Work

History of Investigation

The first published account of the geology of western Newfoundland was made by J.B. Jukes (1842). More detailed discussions of the rock types were published by A. Murray and J.P. Howley (1881, 1918). Howley (1907) subdivided the igneous rocks of the west coast into: (a) serpentinites, diorites, dolerites, etc. and (b) trap, greenstone, etc. Schuchert and Dunbar (1934) used the exposures at Humber Arm as the type locality for their Humber Arm "Series", but paid little attention to the rocks of the Coastal Ranges which they referred to as "intrusions". Ingerson (1935) studied the northern portion of the Bay of Islands Complex while Cooper (1936) studied the southern portion. Included in Cooper's (1936) report is a map showing the geology of the Coastal Ranges from South Head to the mouth of the Serpentine (Coal) River. In 1958, Smith published the results of his petrological study for all of the Bay of Islands Complex, although excluding the Coastal Ranges, south of Lark Harbour.

The regional geology of western Newfoundland, including the Bay of Islands and Hare Bay areas, was summarized by Brückner (1966), Williams (1969, 1971), Kay (1969), and Stevens (1970).

Present work in the Bay of Islands region of Newfoundland includes the author's work, a detailed mapping and geochemical doctorate study of the northern portion of the Bay of Islands Igneous Complex by J.G. Malpas, and regional mapping by H. Williams.

As a result of two field seasons of mapping the west coast of Newfoundland, from Port au Port to Bonne Bay, Williams (in press) has redefined the Bay of Islands Igneous Complex, and has subdivided the transported rocks into five separate thrust groups (Williams, in press; Williams, Malpas and Comeau, 1972).

History of Geologic Thought

Until 1941, all rocks in the Bay of Islands area were thought of as being essentially autochthonous, i.e. all sedimentary rocks were thought to conformably overly each other as a normal succession. The mafic-ultramafic complexes (forming the high ground) were believed to be intrusive into the autochthonous succession (Schuchert and Dunbar, 1934; Hess and Buddington, 1937; Ingerson, 1935, 1937).

Most studies in the Bay of Islands centered upon the mafic-ultramafic complexes, due to both their size and economic interest. Mining interests resulted in many studies of the ultramafic portions of the four large mafic-ultramafic complexes that, from north to south underlie Table Mountain, North Arm Mountain, Blow Me Down Mountain and Lewis Hills.

Of chief concern were the basic features of the rocks, such as their extent and possible continuation between now-separated massifs, origin of primary banding, and shape of the intrusions, i.e. whether laccolithic, lopolithic, sill-like, etc.

Cooper (1936) was the only author prior to 1941 who questioned the autochthonous interpretation of the intrusive rocks. He showed that the peridotites of the Hare Bay region in northern Newfoundland (Cooper, 1937) were part of a thrust sheet and that the Lewis Hills pluton of the Bay of Islands Complex (Cooper, 1936) was at least in part, bottomed by a sub-horizontal fault or thrust.

Johnston (1941) and Kay (1945) were the first to suggest the possibility that the Humber Arm sedimentary rocks were transported and equivalent in age to the underlying carbonates. Rodgers and Neale (1963) worked out the implications of this idea, based mainly on similarities with the Taconic region of New York state. They believed that the transported rocks were derived from the east, in the Central Mobile Belt of Newfoundland. The Humber Arm series was interpreted to represent the off-shore facies equivalents of the St. George and Table Head Formations.

However, they did not separate the Bay of Islands Igneous Complex, nor the White Hills peridotite of Hare Bay from their transported sedimentary slices and they believed that the igneous rocks intruded the sediments at their place of deposition and that all were transported together by gravity sliding.

Stevens (1970) suggested that the Bay of Islands Igneous Complex (then including the Coastal Ranges), while transported, was not intrusive into the Humber Arm sediments. Ultrabasic debris found in the easterly-derived Blow Me Down Brook Formation of the Humber Arm Group (Lilly, 1967) indicated that the Bay of Islands Igneous Complex was located to the east of the Humber Arm terrane at deposition and was at least partly exposed during the deposition of the youngest Humber Arm sediments. Hence, the Bay of Islands Igneous Complex could not cut the Humber Arm Group. The Igneous Complexes must therefore have been transported as separate slices.

Williams (1970) found that the ultramafic portions of the main igneous masses, were tectonically deformed at their base and implied that underlying amphibolites, previously interpreted as metamorphosed Humber Arm rocks, represented a transported poly-deformed aureole structurally above the Humber Arm sediments.

The Bay of Islands Igneous Complex was interpreted as transported oceanic crust by most recent authors (Stevens, 1970; Church and Stevens, 1971; Dewey and Bird, 1971). Williams (1971) was noncommittal to the oceanic crust interpretation for several reasons:

a) relations at the base of the plutons, i.e. the polyphase deformed amphibolites at the base of the ultramafics.
b) relations at the top of the plutons, as described by Smith (1958) and Church and Stevens (1971), i.e. the gabbro intrusive between the peridotite and pillow lava units, and metamorphism of the pillow lavas.
c) and because, although some of the Bay of Islands Igneous Complex did resemble a typical ophiolite

succession, other rocks included in the Bay of Islands Igneous Complex (i.e. rocks of the Coastal Ranges) certainly did not.

Recent work (Williams, Malpas and Comeau, 1972; Williams, in press) indicates the presence of five structurally separate rock assemblages within the Bay of Islands region. Definition of the Coastal Complex and redefinition of the Bay of Islands Complex to include only the four large plutonic rock associations underlying the Lewis Hills, Blow Me Down Mountain, North Arm Mountain and Table Mountain, has now made it possible to consider the Bay of Islands Complex as representing oceanic lithosphere.

The Coastal Ranges are now recognized as being composed of two distinct rock assemblages (Williams, Malpas and Comeau, 1972; Williams, in press); an older granitic and gabbroic assemblage of rocks, unrelated to any other rock types in the Bay of Islands region, and a younger unit composed essentially of volcanics which surround the gabbros and granodiorites. Mafic feeder dykes, locally sheeted, cut both the gabbros and granodiorites. These are similar to the sheeted dyke horizon and volcanic zone of the newly defined Bay of Islands Complex (Williams, Malpas and Comeau, 1972; Williams and Malpas, 1972; Williams, in press).

Purpose and Scope

Prior to this study of the Coastal Ranges, only one published work showed geological subdivisions of the area

(Cooper, 1936). No written accounts of the thesis area have ever been published, except for incorporations in regional accounts (Williams, 1971).

The recognition of different rock assemblages (Williams, Malpas and Comeau, 1972; Williams, in press) within the Bay of Islands region, in particular the recognition that the Coastal Complex was different and separated from the four large ophiolite masses of the Bay of Islands Complex, prompted queries as to the origin and history of the Coastal Complex, as well as its relationship to the newly defined and recognized Bay of Islands Complex.

The purpose of this thesis was to study the geology of the southern Coastal Complex, to delineate the succession of structural slices that make up the Coastal Complex, and to determine the relationships among individual rock units.

The mapping was done using Government of Canada air photographs. Information was then transferred onto a 1:50,000 topography map.

Acknowledgements

The author wishes to express his appreciation to all those who contributed, directly or indirectly, towards the completion of the thesis.

Special thanks are expressed to the author's supervisor, Dr. H. Williams of Memorial University, without whose knowledge of Newfoundland geology, discussions and guidance, this thesis would have been impossible.

The author is indebted to Drs. M.J. Kennedy and S. Sutton of the Geology Department for their advice, help and ideas.

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CHAPTER II

GENERAL GEOLOGY

General Statement

All of the rocks in the study area are transported and constitute a number of lithologically distinct slices, in most places separated by extensive mélange zones. The lower structural slices consist of sedimentary rocks referred to the Humber Arm Group (Schuchert & Dunbar, 1934; Williams, 1971). These are overlain structurally by slices composed of a variety of intrusive rocks, volcanic rocks, and metamorphic rocks, referred to the Coastal Complex (Williams, in press).

Distinction between the higher structural slices is based primarily upon differences in rock lithologies, but also upon structurally intervening mélange zones.

Six separate igneous rock slices are delineated above the Humber Arm terrane. In most places these directly overlie the Humber Arm sedimentary rocks but, towards the north, near Lark Harbour, they partially overlie one another. The slices are as follows: (See Fig. 4).

(1) Lark Harbour slice.

(2) Virgin Mountain slice.

(3) O'Dwyer Mountain slice.

(4) Bottle Cove slice.

(5) Parker Beach slice.

(6) Monkeyland slice.

The largest structural slice is the Virgin Mountain slice, which extends from Tortoise Point (Lark Harbour Head),

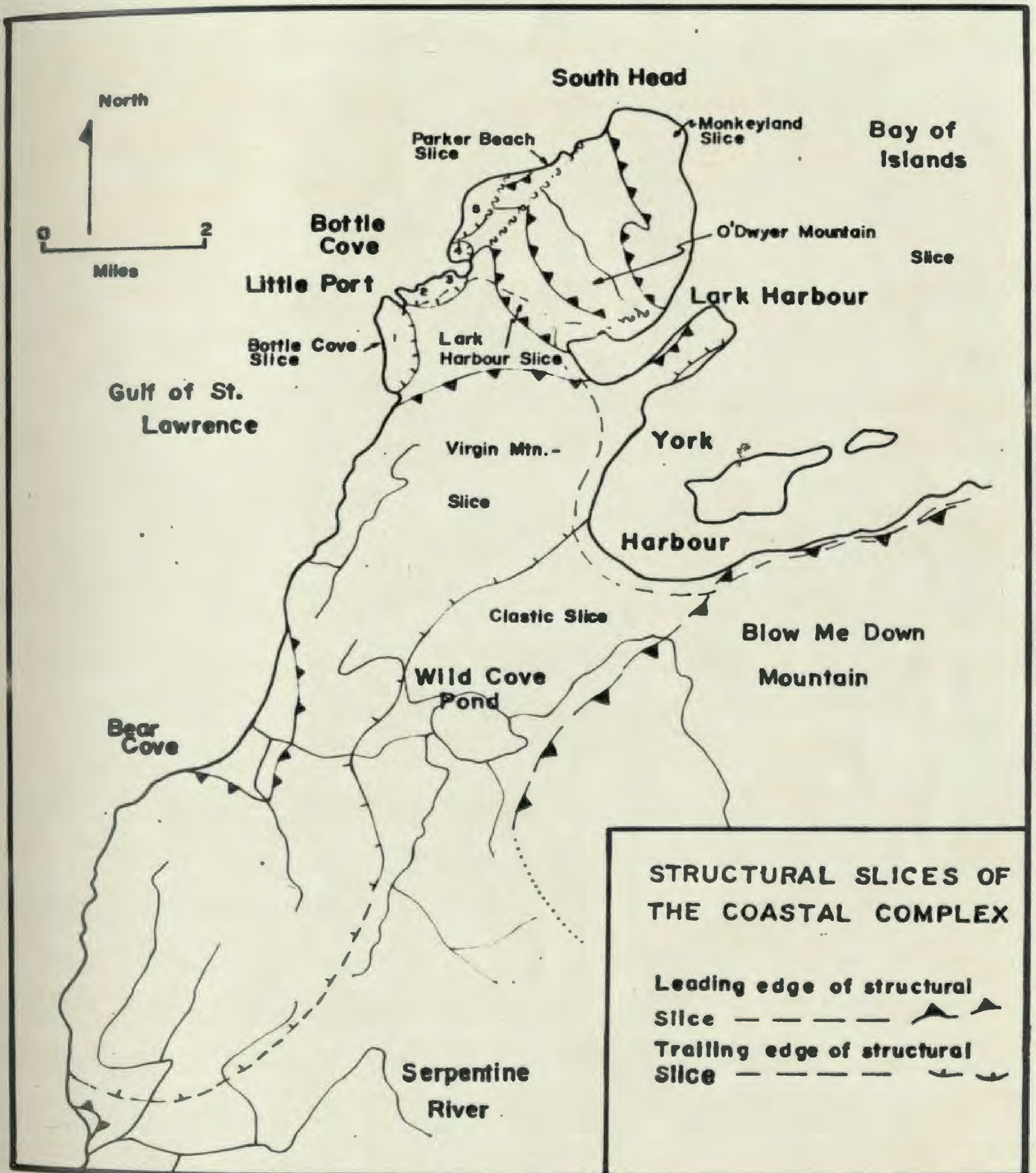

South Head
North
0
2
Miles
Parker Beach Slice
Monkeyland Slice
Bay of Islands
Bottle Cove
O'Dwyer Mountain
Slice
Little Port
Lark Harbour
Bottle Cove Slice
Lark Harbour Slice
Gulf of St. Lawrence
York
Virgin Mtn.-
Slice
Harbour
Clastic Slice
Blow Me Down
Mountain
Wild Cove Pond
Bear Cove
Serpentine River
STRUCTURAL SLICES OF THE COASTAL COMPLEX
Leading edge of structural Slice
Trailing edge of structural Slice

FIG 4

in the north, to Coal River Head, in the south; a distance of approximately 13 miles. It locally attains a width of 2-3 miles. The smallest slice is the Parker Beach slice which is approximately 1 mile long and 1/4 mile wide.

In the northern part of the thesis area, the igneous slices are superposed in structural succession. The Lark Harbour slice is tectonically overlain, along a thrust contact, by the O'Dwyer Mountain slice. This slice, in turn, is overlain by the Monkeyland slice. An intervening serpentinite mélange zone (Trumpet Cove Mélange Zone) separates the O'Dwyer Mountain slice from the Monkeyland slice.

The Lark Harbour, Parker Beach, Virgin Mountain and Bottle Cove slices are all underlain by sediments of the structurally underlying Humber Arm Group.

All structural slices in the Coastal Complex, with but one exception, are underlain by mélange zones, ranging from 20 feet to 2500 feet in thickness. The O'Dwyer Mountain slice has no basal mélange and it is in sharp thrust contact with the underlying Lark Harbour slice.

Several varieties of mélange occur between the structural slices. The commonest are composed of serpentinized ultrabasic and gabbroic blocks set in a sheared matrix of the same composition. Mélanges composed mainly of sedimentary clasts are also common, however, they are structurally overlain by igneous debris derived from the overlying igneous structural slices in most places. The sedimentary mélange zones are extremely deformed near the base of overlying igneous slices. This structural deformation decreases in intensity downwards and away from the tectonic contact. The mélange zones are underlain by relatively undeformed sediments of the Humber Arm Group.

Clastic rocks of the mélange zones are separated in most places from the overlying slice by a relatively thin serpentinite zone. Generally, the serpentinite zone is only a few feet thick, however, an anomalously thick serpentinite mélange zone (Trumpet Cove Mélange) is present between the O'Dwyer Mountain slice and the overlying Monkeyland slice.

The Trumpet Cove Mélange Zone is composed of an extremely thick (1/2 mile) accumulation of serpentinite boulders set in a serpentinite matrix. No sediments are present. The boulders are elongated parallel to a shearing of the unit which strikes north and dips under the Monkeyland slice at 30^{o}. This shallow dip accounts for the wide surface exposure of the mélange zone.

Gabbros and granodiorites, within different slices, form the backbone of the Coastal Ranges and are continuous for most of the distance between Serpentine (Coal) River, in the south, and Bonne Bay in the north. The gabbroic rocks are foliated throughout their exposure. The foliation is the result of a flattening deformation, and locally, an amphibolitic mylonite has resulted. The fabric parallels primary banding in the gabbros, although Williams (1971) has reported fabrics that cut across the banding in some places. Granodiorites of the

Coastal Ranges cut the gabbros to the north of the thesis area at Big Island (Williams, 1971).

Both gabbros and granodiorites in the thesis area are cut by mafic dykes and are older than nearby relatively undeformed mafic flows and pyroclastic rocks. The dykes are locally sheeted, and also cut the nearby volcanics.

All of the igneous and metamorphic rock types have been affected to various degrees by an internal brecciation which exhibits itself in the form of short, thin veinlets composed of finely brecciated portions of the host rock. Its most intense manifestation is along the contacts between either the gabbros or granodiorites and volcanics and it is well exposed in the Bottle Cove slice.

It is a most unusual phenomena which also affects the sheeted dyke zone of the ophiolites to the east (Williams and Malpas, 1972). Its implications and significance are still largely in doubt. Locally large expanses of volcanic rock have been affected by this feature. Highly brecciated and fragmented volcanics are present along coastal exposures from Devil Head to Caplin Cove, along the eastern portion of the Monkeyland slice, and at two localities in the Virgin Mountain slice.

An amphibolitic mylonite forms part of the O'Dwyer Mountain slice. The mylonite is the result of intense flattening of the gabbroic portion of the slice, and is restricted to this structural unit. Locally, small scale folding is present in the mylonite, and it is cut by small ultramafic intrusions and feldspar porphyries.

The Bottle Cove slice lies directly on sedimentary rocks of the Humber Arm Group and is composed of 5 disoriented units, numbered 1 through 5, all separated from each other by sedimentary rocks. Rotation and fragmentation of portions of the structural slices as displayed here appears to have been a common phenomenon during transportation.

Part of the Virgin Mountain slice at Virgin Mary Rock has also rotated with respect to the main bulk of the slice. The granodiorite there is surrounded by younger volcanics that are now below the granodiorite and presumed feeder dykes to the volcanics are horizontal in attitude. A "knocker" of granodiorite, to the east of Caplin Cove, has either remained stationary or else rotated to a lesser degree than the granodiorite at Virgin Mary Rock. It is separated from the main granodiorite mass to the southwest by a zone of highly sheared volcanic material.

The individual structural slices will be described in detail, according to their structural position. The intervening mélange zones will be dealt with separately.

TRANSPORTED SEDIMENTARY SLICES: THE HUMBER ARM GROUP

Introduction

Transported Humber Arm sediments underly all of the igneous rock slices that form the Coastal Complex. They outcrop in topographically low-lying areas and compose the lowest structural slices of all of the transported rocks. (Map in jacket).

The largest expanse of sediments is in the Brooms Bottom Lowland where they extend from Governors Island, in the Bay of Islands, to the base of the Lewis Hills ophiolite mass, in the south. Numerous sedimentary exposures are present at the base of most structural slices and are usually located in indentations along the coastline. The lowland at Little Port forms the second largest area underlain by sedimentary rocks of the lowest structural slices. The bases of most igneous rock slices occur at sea-level, hence, sedimentary exposures are restricted to near sea-level.

The sediments of the transported Humber Arm Group form a broad apron upon which the igneous structural slices were emplaced, thus, where erosion has now reached the bases of the igneous structural slices (approximately sea-level, in most cases) sediments are exposed. The fact that sediments occur at sea-level in many small areas indicates that the igneous slices have relatively flat basal tectonic contacts.

No separate structural slices have been delineated within the transported clastic terrane underlying the Coastal

Complex. The description of the sediments will therefore be dealt with according to geographic location.

Brooms Bottom

Extent

Sedimentary rocks are exposed at Brooms Bottom between Blow Me Down Mountain and the base of the overlying Virgin Mountain slice to the west. Governors' and Seal Islands are underlain by the same rock types.

Due to a Quaternary cover (Brückner, 1966) composed of sands and gravels, overlying most of the area, exposures are sparse and restricted to coastal outcrops at Little Neck and Governors' and Seal Islands.

Cooper (1936) showed the Brooms Bottom sediments to continue andappear on the southwest side of Blow Me Down Mountain, and several British Newfoundland Exploration Company maps show similar sediments protruding from underneath Blow Me Down Mountain continuously around its western edge. Topography suggests that these rocks extend as far south as the Serpentine (Coal) River.

Lithology

The rocks underlying Brooms Bottom Lowland, Governors' Island and Seal Island are primarily coarse grits and sandstones with local conglomeratic units and minor shales. They are greyish on fresh surfaces and generally weather to a greyish yellow or buff. They are poorly indurated and without cleavage in most exposures.

Clasts are primarily potash feldspars and quartz (commonly blue quartz), subrounded to rounded, set in a finer grained matrix. Calcite is the chief cementing material. Grain sizes average from 1/4" and less to locally 1 inch or more. Some sandstone units contain shale flakes ripped up from underlying beds, and these locally attain lengths of 8-10 inches, as seen on Seal Island. Serpentinite fragments, chromite grains and broken pyroxene crystals, were identified in a few places, indicating the presence of ultrabasic rocks in the source terrane (Stevens, 1970).

Sedimentary Features

Primary sedimentary features such as graded bedding, cross-bedding and locally flute casts are present. Graded bedding is most conspicuous in the arkosic and conglomeratic units. Cross-bedding is locally quite common along coastal exposures of the base of the northern portion of Blow Me Down Mountain as well as in exposures in several brooks flowing at right-angles to the contact between the gabbros of Blow Me Down Mountain and the underlying sediments. Flute casts are exposed along the north-eastern coast of Seal Island and along the southeast shore of Governors' Island. Slumping and convolute bedding are present near Blow Me Down Mountain.

Exposures of grits and sandstones in places display successive horizons composed of graded beds. Usually the coarser lower layers are grit size while the top layers of the same unit are within the range of medium to fine-grain sandstones.

Commonly clasts of platty shales and locally (Brooms Bottom Cove area) serpentinite fragments are aligned parallel to bedding.

Planar cross beds and/or trough crossbeds are common within the sandstones and grits. Exposures along the coast north of Blow Me Down Mountain, display trough beds within the main sandstone units that attain a thickness of 10 feet. At this locality, they are usually reddish in color, poorly consolidated and shaley in part. Sandstone units are locally 60 feet thick.

Red, green and dark grey shale units that are present within the dominant sandstones are generally 10 feet or less in thickness. Pyrite concretions are common at Little Neck and possible worm burrows are present in the dark shales near Brooms Bottom.

Structure

The sedimentary rocks at Brooms Bottom, Governors' and Seal Islands are offset by numerous small joints, and several larger faults, however, generally the beds strike northeast and dip southeast beneath overlying igneous structural slices.

Sediments on Governors' and Seal Islands as well as sediments just below the western extremity of Blow Me Down Mountain display opposing dip directions suggesting a northeasterly-trending anticlinal axis, just to the west of Blow Me Down Mountain.

Correlation & Provenance

The rocks at Brooms Bottom Lowland have been referred to as the Blow Me Down Brook Formation (Bruckner, 1966; Lilly, 1967; Williams, in press) and represent the highest stratigraphic formation of the Humber Arm Group. Stevens (1965) has interpreted these units as shallow water deposits, possibly top-set deltaic deposits or deep water proximal flysch deposits.

The source lay to the east and included

(a) a granitic terrane with possible off-shore volcanic and sedimentary rocks.

(b) ultramafic rocks like those of the Bay of Islands ophiolite complex.

Stevens (1965) and Lilly (1967) speculate a thickness of approximately 400 feet for the Blow Me Down Brook Formation.

Serpentine River

Extent

The area from Fish Head southwards to the base of the Lewis Hills, just east of Shag Island, is underlain by sediments. Two distinct units are present within this area and are separated by an east-west striking fault along the Serpentine (Coal) River.

Lithology & Structure

South of the Serpentine (Coal) River, alternating bedded limestones and purplish black limy shales make up the coastal exposures. Green shale interbeds are fairly abundant and small scale cross-bedding features in many units at Serpentine (Coal)

River are good indicators of stratigraphic tops. Locally limestone breccias are present.

North of the Serpentine (Coal)River, sediments are composed of greywackes, red, green and black shales with minor red, fissile, micaceous shales.

The rocks south of Serpentine (Coal) River are highly deformed and disrupted by many small fractures. Numerous isoclinal anticlinal and synclinal closures, plunging either east or west, are exposed along the beach. However, the plunge angle remains fairly constant at 30° to the horizontal. The absence of cleavage, axial planar or otherwise suggests that the deformation is related to the transport of the rocks before they were completely consolidated.

The sediments north of Serpentine (Coal) River are folded into an anticline with the surface exposure approximately 1/2 mile long. The sediments underlie brownish-green fragmental volcanics containing screens of massive brecciated limestones elongated along a northwest plane of shearing. Many of the screens are composed of limestone breccias, similar to the ones at Bear Cover and to the Cooks Brook Formation (Stevens, 1965). Some of the limestone screens attain thicknesses of approximately 200 feet.

Stratigraphically upwards, exposures of this unit are more complex structurally and are discussed under "Mélange Zones".

Age and Correlation

The sediments at Serpentine (Coal) River are in many respects similar to the Cooks Brook Formation (Stevens, 1965;

Lilly, 1967) of the Humber Arm Group. Graptolites found in the dark limey shales south of the Serpentine (Coal) River include the following Tremadocian forms (Kindle & Whittington 1965).

<u>Dictyonema</u> <u>sp.</u>

<u>Bryograptus</u> <u>sp.</u>

<u>Staurograptus</u> <u>sp.</u>

Trilobites found further south in coastal exposures, have been identified by Kindle & Whittington (1965) as:

<u>Bienvillia</u> <u>cf.</u> <u>corax</u>

<u>Geragnostus</u> <u>sp.</u>

<u>Apatokephaloides</u> ? <u>sp.</u>

<u>Richardsonella</u> ? <u>sp.</u>

<u>Theodenisia</u> <u>sp.</u>

<u>Zacompsus</u> ? <u>sp.</u>

<u>Loganopeltoides</u> <u>sp.</u>

<u>Leiobeinvillia</u> <u>sp.</u>

According to Kindle & Whittington (1965), these fossils occur at the Cambrian-Ordovician boundary and thus suggest that the shale and limestone exposures represent older rock sequences southwards.

Graptolites found by the author, at the mouth of Serpentine (Coal) River are of Tremadocian age.

Bear Cove

Extent

Sedimentary rocks at Bear Cove are exposed along a stretch of coastline from just south of Fall River to Bear Cove and extend inland for approximately 1/4 mile along the banks of Wild Cove Brook. They generally strike northeast and dip at relatively shallow angles beneath the Virgin Mountain slice.

Sediments similar to those exposed at Bear Cove are present locally on the eastern shore of Lark Harbour, at Little Neck. These also dip beneath an igneous structural slice. (See Map in jacket for place names).

Lithology

Sedimentary rocks at Bear Cove occur in distinctive conformable units characterized by colour, mineral composition, differences in stratification, degree of induration, percentage and type of matrix, grain size and the presence or absence of blue quartz grains. The individual units range from 30 feet to over 300 feet in thickness and are composed of beds from a few inches to a few feet thick. The sediments are exposed in a gently plunging open syncline and are little disturbed except for exposures near the overlying igneous structural slice.

Generally the sediments are composed of quartz-rich sandstones, grits, red, brown, and dark green shales, greywackes, limestone breccias and oolitic limestones. The quartz-rich sandstones and the limestones distinguish this group of sediments from the sediments at Brooms Bottom and those at the Serpentine (Coal) River.

Quartz-rich sandstones exposed along the shores of Bear Cove vary slightly in color and are generally either white to light yellowish grey, light grey, dark grey or brownish grey, depending upon the amount of clastic quartz present. Slight color differences also reflect different percentages of dark clasts and/or argillaceous matrix. The percentage of matrix appears to have a direct bearing upon the degree of induration of the rock. Highly indurated sandstones are generally poor in the argillaceous component.

The clasts in the sandstones are primarily quartz and generally well-rounded to sub-rounded feldspars. Both plagioclase and potash feldspar are present, and also shale and metamorphic rock clasts. Blue quartz is common as a constituent although it appears restricted to the relatively argillaceous-free units. It is common in sandstones exposed at the mouth of Wild Cove Brook.

The chief difference between sandstone units of the Bear Cove succession is the degree of induration and color. Both, however, are dependent upon mineral composition and the more highly indurated varieties reflect a more compact, quartz rich matrix as compared to other units, whose matrix contains more argillaceous material. Blue quartz appears restricted to the more highly indurated varieties.

Quartz-rich grits and sandstones at the mouth of Wild Cove Brook are contrasted with similar-looking sandstones by a quartz content which averages between 90 and 95%. Other sandstone units near Wild Cove Brook, are more friable due to a greater percentage of non-quartz matrix. These are in places characterized by small red (1/16 inch - 1/8 inch) spots resembling iron oxidation spots, which are associated with small shaly clasts. Grain size is generally 1/16 - 2 mms. although shale clasts can attain lengths of 10 inches and widths of 5-6 inches locally.

Red, brown and dark green shales in units from 20-60 feet thick form the major portion of the Bear Cove exposures. The red and brown shales are more thickly bedded and much more fissile than the green shales. Friable and non-friable grey to brown micaceous shales with limestone concretions (1-1½ feet in diameter)are common towards Fall River where shales predominate and display more and more limestone interbeds stratigraphically upwards.

Exposures along Wild Cove Brook are predominantly dark shales with minor interbeds of green shales. The latter are more and more abundant toward the east and green shales containing numerous sandstone boulders occur near the overlying Virgin Mountain slice. Sandstone boulders increase in abundance near the base of the slice, and directly beneath the slice gabbroic boulders are present in a shaly matrix.

Near the Bear Head portion of the Virgin Mountain slice, exposures of red shales become abundant but give way to sandstone units which contain pods and blocks of fine-grained limestone and limestone breccias. Alternating dark grey and brown shales and greyish limestones, both very thin (2-3 inches) are faulted into the sequence. The limestones are very fine-grained, finely laminated and are whitish grey in color. Limestone breccias composed of limestone slabs (4-5 inches) set in a sandy, pyriticrich matrix are also present. This unit is tightly folded and characterized by numerous small faults and fractures.

Stratigraphically upwards, large blocks of fine-grained, limy sandstone, brownish grey in color appear at Bear Cove, and the matrix changes from the limestone-shale unit to predominantly an alternating series of black and green shales, locally highly iron-stained.

Two small islands, the White Rocks, are located off-shore from Bear Cove. They consist of limestones and limestone breccias. One of the islands, Grassy Rock, is composed of three different lithologies:

(a) massive oolitic limestone.

(b) greyish, massive oolitic limestone with a pitted surface containing a small percentage of fine-grained sub-angular limestone clasts, up to 4-5 inches in length.

(c) lime-breccias. Fragments are composed of oolitic limestone and massive fine-grained limestones.

The other island, Barren Rock, to the north, is composed mostly of:

(a) well-bedded limestone breccias.

(b) minor finer-grained breccias.

(c) massive oolitic beds.

(d) pisolitic bands with large clasts.

Sedimentary Features

Sedimentary features of the Bear Cove exposures include graded bedding, slumping, planar cross-bedding, trough cross-bedding, interference ripple marks, worm burrows (?) and convolute bedding.

Graded bedding is very common and is well displayed in sandstones exposed at the mouth of Wild Cove Brook. Generally the graded beds are quite thick (up to 8-10 inches). Locally the lower portions of the graded beds contain shale clasts up to 6-8 inches. As a generality, darker clasts seem to be restricted to the lowest and therefore the coarsest zone.

Planar cross-bedding and trough cross-bedding are also quite common. Just to the north of the mouth of Wild Cove Brook, a poorly indurated sandstone unit, approximately 11 feet thick, is composed exclusively of trough bedded structures averaging 2 feet, both in breadth and thickness. In places one or more troughs cut across other troughs with the resulting exposure resembling planar cross-beds.

Structures resembling interference ripple marks and worm burrows are present in a well-indurated light-grey quartz-rich sandstone at Split Rock cliff. The average amplitude of the ripples (?) is 2-3 inches. Small scale slumps (2-3 inches) are present in dark grey, poorly indurated sandstones at Wild Cove Brook.

Structure

The sediments of Bear Cove are folded into gently plunging open anticlines and synclines. A broad upright anticlinal structure, located to the south of Wild Cove Brook, trends at N 70° E. A similar synclinal feature is present to the north of Wild Cove Brook, and causes a repetition of sediments.

The sediments display more intense deformation and highly contorted beds near the base of the Virgin Mountain slice. Faulting, on a small scale, is also common.

Just to the north of Split Rock Cliff several plunging closures are present in a tightly folded rock assemblage composed of dark grey, purplish black, red and green shales, with alternating grey limestone bands (4-5 inches). Shales at the nose of folds are highly contorted while limestones are easily traceable, reflecting competency differences in the rocks. Farther north, the rocks are essentially composed of complexly folded shales.

It is difficult to ascertain whether this folding is tectonic or represents mega-slumps related to transport and gravity sliding. The latter is postulated, as no definite cleavage is present in the rocks. This unit is faulted against shales and sandstones to the north and south.

Due to their position underneath the Virgin Mountain slice, the more complex structures associated with the sediments will be discussed under the section on mélange zones.

Age and Correlation

Trilobites found in clasts in the limestone breccias at White Rocks have been identified by Kindle & Whittington (1965) as:

Parabolinoides	_sp._	
Pseudagnostus	_cf._	_Prolongus_
Bathyholcus	_sp._	
Buttsia	_sp._	
Oligometopus	_sp._	
Pterocephalia ?	_sp._	
Cheilocephalus ?	_sp._	
Dunderbergia	_sp._	

These are Franconian (Middle Upper Cambrian) in age. Similar rocks of the same general type occur in the Cooks Brook Formation of the Humber Arm Group (Stevens, 1970; Williams, 1971). If the limestone breccias at White Rocks are part of the sedimentary succession at Bear Cove, then most of these rocks are probably Cooks Brook equivalents.

TRANSPORTED IGNEOUS AND METAMORPHIC SLICES: THE COASTAL COMPLEX

Igneous rock slices are composed of gabbros, granodiorites, quartz diorites, mafic dykes and pillowed and massive volcanics; all referred to as the Coastal Complex. Minor ultrabasic and acidic intrusions are also present. Locally, in the O'Dwyer Mountain slice, a protomylonite or mylonite has been derived from the gabbros.

All of the rock types can be lithologically correlated from one structural slice to another. The Virgin Mountain slice, the Monkeyland slice and the Parker Beach slice contain examples of all rock types; the Lark Harbour slice is composed solely of volcanic rocks while the Bottle Cove slice contains gabbros and volcanics. The O'Dwyer Mountain slice contains all rock types, with the exception of the granodiorite.

Gabbros and granodiorites are cut by relatively undeformed diabase dykes interpreted to feed nearby equally undeformed pillow lavas and pyroclastics. The dykes and volcanic flows are similar to sheeted dykes and volcanic rocks at the top of the Bay of Islands ophiolite complex.

Rocks of two different ages are represented in the Coastal Complex. The gabbros, and locally the granodiorites, are highly metamorphosed, altered and tectonically deformed, whereas the dyke rocks and nearby volcanics are relatively fresh and exhibit no tectonic fabrics. This implies that the rocks of the Coastal Complex are not a coeval and consanguineous assemblage and therefore do not constitute a typical ophiolite succession. This fundamental relationship serves to contrast the Coastal Complex from the nearby ophiolite succession of the Bay of Island Complex (Williams, in press).

Virgin Mountain Slice

Extent and Boundaries

The southern half of the thesis area is composed of one main slice, the Virgin Mountain slice, which extends from Tortoise Point (Lark Harbour Head), in the north, to the Serpentine (Coal) River, in the south; a distance of approximately 13 miles.

It is bounded to the east by sediments of the Brooms Bottom Lowland and, to the north by sediments underlying the lowland at Little Port. Its western boundary is the Gulf of St. Lawrence, except at Wild Cove (Bear Cove), Little Neck and the Serpentine (Coal) River, where underlying sediments are exposed. Sandstones and shales underlie its northern basal contact at Little Neck. Limestones and limestone breccias underlie its southern boundary, south of the Serpentine (Coal) River. It is approximately 4 miles wide, at its widest, and locally thins down to 1/4 mile at Little Neck. It is by far the largest of the structural slices and underlies nearly 60% of the thesis area.

Rock Types and Their Distribution

The different lithologies represented in the Virgin Mountain slice include granodiorites, foliated, banded and massive gabbroic rocks, fragmented, brecciated volcanics, pillow lavas and mafic pyroclastics. All rock types are intruded by undeformed mafic dykes, locally in swarms, and minor serpentinized ultramafic rocks. The gabbros and granodiorites form the bulk of the slice.

The granodiorites extend from Tortoise Point (Lark Harbour Head) southwards, to just northwest of Wild Cove Pond and from Caplin Cove to Fall Brook. Both granodiorite masses are internally separated by volcanic rocks into two portions. The granodiorites diminish in areal width, northeastwards.

Much of the remainder of the Virgin Mountain slice is composed of foliated gabbros. They extend from Coal River Head, northwards, to the northern exposure of the basal thrust zone, south of Lark Harbour.

Basaltic lavas and mafic pyroclastics form the eastern flank of Virgin and Great Mountains and underlie the southern coast of Caplin Cove. These younger volcanic rocks surround the granodiorites and gabbros. Highly fragmented volcanic rocks are present at Bear Head.

Brecciated mafic volcanics, with large incorporated screens of fragmented limestone and limestone breccia, are present north of the Serpentine (Coal) River and extend, along the coast, to Coal River Head.

Granodiorites and gabbros in the Virgin Mountain slice are intruded by numerous mafic dykes. The dykes lack a tectonic fabric, but internally they are brecciated and altered. The basic dykes are interpreted to have been feeders for nearby undeformed volcanic flows. Dykes are common throughout the slice and occur in swarms at Virgin Mary Rock, Virgin Mountain, Little Mountain and at Lark Harbour Head.

Description of Rock Types

Gabbroic rocks in the Virgin Mountain slice are commonly banded and in most places display a penetrative tectonic fabric. Massive varieties are rare. Non-banded varieties range from medium to coarse-grained and are mainly composed of diallage clinopyroxenes (augite now altered to actinolite) and plagioclase approximating labradorite in composition. Locally, very coarse grained pods or stringers attain crystal sizes of 3-4 inches. Usually the plagioclases are highly altered on weathered surfaces. Finer-grained gabbros are a dark grey in color. Many gabbro samples display primary mineral alignment, however, it tends to be masked by the penetrative tectonic fabric.

Banded gabbros are mainly restricted to coastal exposures. Alternating dark and light bands reflect differences in mafic minerals with the gabbros ranging from troctolite to anorthosite. Individual bands are continuous along strike and vary in thickness from a maximum of 14-15 inches to an average of 3-4 inches. The tectonically deformed gabbros exhibit flattened crystals parallel to a penetrative fabric. Banded gabbroic rocks in coastal exposures have a tectonic fabric that trends northeast and parallels the banding and the long dimension of the Virgin

Mountain structural slice. Williams (1971) has reported that, on Big Island, the tectonic fabric in gabbroic rocks crosses the banding at high angles.

Granodiorites form the second most common rock type in the Virgin Mountain slice. They are chalky white on weathered surfaces and dull pinkish white on fresh surfaces. The rocks are medium-grained and composed of quartz, albite-oligoclase and minor potash feldspars. Mafic minerals are hornblende and brown and green biotite. Apatite is a common accessory mineral. Late-stage pink aplite dykes, generally 6-8 inches wide, are common.

Locally the granodiorite exhibits thin brecciated zones. These are randomly orientated and rarely attain widths greater than 4-5 inches. They are texturally similar to tuffisite veins described from the Holyrood granite (Hughes, 1971).

Basaltic flows are both massive and pillowed and contain interbedded mafic pyroclastics. Most are fine-grained, dark green, brown or grey, vesicular and porphyritic. The mafic volcanics are brecciated near contacts with either granodiorites and/or gabbros and brecciated dyke rocks are present in the contact zones. Elsewhere the mafic dykes are fine-grained, grey, massive and locally internally brecciated. They are 1 foot wide in most places and are interpreted to be contemporaneous with the nearby volcanic rocks.

Relationships Between Rock Types

Granodiorites of the Coastal Complex cut amphibolitic gabbros at Big Island (Williams, 1971). An intrusion breccia is developed at the contact wherein granodiorite surrounds foliated gabbro fragments. The granodiorite contains a later penetrative tectonic fabric indicating that the gabbros were deformed prior to the granodiorite intrusion.

In the Virgin Mountain slice granodiorite bodies are surrounded and flanked by a series of pillowed and massive lavas composed of alternating amygdaloidal and porphyritic basalts and more silicic porphyritic flows.

The granodiorite at Virgin Mary Rock is intruded by diabase dyke swarms. The dykes average 1 to 2 feet in width. They are identical to diabase dykes at South Head (discussed under Monkeyland slice) and are interpreted to feed nearby lavas. The topographical lowness and anomalous attitudes of the mafic volcanics at Caplin Cove, in conjunction with the horizontal nature of the diabase intrusions, suggest a tilting or overturning of the main granodiorite mass underlying Virgin Mary Rock.

Contacts between volcanics and granodiorites on Virgin Mountain and Virgin Mary Rock are invariably masked by zones, locally quite extensive, of diabase dyke breccia. Nowhere do younger volcanics directly overlie older granodiorites and/or gabbros. Exposures of basaltic flows assume a brecciated nature near granodioritic and/or gabbroic exposures. In the southern portion of the Virgin Mountain slice, at Bear Head, brecciated, massive and pillowed volcanics occupy topographically high ground and possibly unconformably overlie deformed gabbroic rocks.

The gabbros and granodiorites of the Coastal Complex are cut by diabase dykes and surrounded by younger mafic volcanics. They, therefore appear to be large inclusions or "rafts" within the younger volcanic rocks. This relationship is present on a smaller scale at Bear Head, where gabbro inclusions (40-50 feet wide) are completely surrounded and intruded by diabase dyke breccias.

Bottle Cove Slice

Extent

The Bottle Cove slice is composed of five (5) separate isolated remnants of a once continuous slice. It extends from Devil Head in the north to Caplin Cove in the south. The separate structural units have been designated, from south to north, by numbers 1-5. They are separated from each other by sedimentary and/or serpentinite mélange zones and are bordered on their western edges by the Gulf of St. Lawrence. To the east, they are bounded by the sediments of the Little Port Lowland and volcanic rocks of the Lark Harbour slice.

Unit number 1, the largest, extends from Caplin Cove to Little Port. Units number 2 and 3 extend from Little Port to Bottle Cove (approximately the centre of the slice). Units 4 and 5 extend from the northern shore of Bottle Cove northwards to Devil Head. Units 3 and 4 are by far the smallest members of the slice and could be considered as large disrupted blocks.

The detached individual units of the slice have also been rotated with respect to each other, as is evident from both their topographic expressions, and the geological discontinuity of rock units between them. The attitude of the basal thrust differs from unit to unit.

Rock Types and Their Distribution

Gabbros and volcanics are the main rock types represented in the Bottle Cove slice. The gabbroic rocks occur at the coast in the extreme western portions of all separate units of the slice from Caplin Cove to Devil Head. The gabbros are both banded and non-banded and display an increase in fragmentation eastwards toward their contact with volcanic rocks.

The volcanic rocks comprise approximately 85-90% of the Bottle Cove Slice and they are almost everywhere brecciated and fragmented. The volcanic rocks are mainly of two types; massive and pillowed flows, and pyroclastics. Minor pyroclastics exposed at Bottle Cove display poorly developed graded-beds, with varying lithologies represented in the clasts suggesting water transport. Pyroclastics are exposed at Caplin Cove and Bottle Cove. Massive and pillowed volcanics are mainly restricted to units 2 and 4 of the Bottle Cove slice. Pillowed volcanics, fragmented volcanics, and coarse tuffs are present along the northwest coast of Crow Cove.

Description of Rock Types

Gabbros of the Bottle Cove slice are both banded and non-banded. The non-banded variety is light-green in color.

They are medium to coarse-grained and locally contain pods of coarser-grained material. Clinopyroxenes (diallage) are now altered to amphiboles (actinolite). In places gabbros are cafemic-poor and are anorthositic in composition ($<10\%$ mafic minerals). Well-developed primary igneous banding composed of alternating light and dark bands is restricted to coastal exposures. Individual bands range from 2 inches to 1 foot thick and are fairly consistent along strike. They are offset by numerous small perpendicular fractures.

The gabbros contain a tectonic fabric resulting from flattening. Feldspars are flattened and elongated several times their original lengths. This pervasive tectonic fabric parallels primary igneous layering and its trend parallels the coastline while varying from northeast to northwest. The gabbro displays increasing fragmentation near its contact with the volcanics. Gabbroic rocks exposed at the contact are highly broken and brecciated and thin veinlets of cataclastic gabbro are common throughout the gabbros of the Bottle Cove slice.

Volcanic rocks of the Bottle Cove slice include pillowed and massive basalts, slightly more silicic flows, mafic pyroclastics, reworked mafic pyroclastics and highly brecciated and fractured volcanics. This brecciation has obliterated most primary volcanic features. Massive and pillowed volcanic rocks, basaltic and andesitic (?) in composition, are exposed at Crow Cove at unit R, and in one exposure a light-grey, coarse-grained, porphyritic pillowed andesitic (?) flow conformably overlies a massive, dark purple basaltic flow. The contact is horizontal. The flows are 40-50 feet thick and have not been brecciated as have most rock types in the Bottle Cove slice. They are faulted against the foliated amphibolitic gabbros and brecciated volcanics nearby.

Pyroclastic rocks are best exposed at Bottle Cove and Caplin Cove. Agglomerates at Caplin Cove are composed of diorites, fine and coarse-grained gabbros, amygdaloidal basalts and massive basalts. Jasper fragments and limestone pods are locally present in the mélieu. Locally red and green shales are interlayered with the pyroclastics. Isolated individual pillows, suggestive of pillow breccias, are present. Water worked units are rare.

Brecciated massive volcanics near the gabbro-volcanic contact of the Bottle Cove slice are light green in color. Structures suggestive of pillow features are locally present. Sheared and slickensided surfaces are abundant and cherty fragments are present in places. Calcite fills much of the interstitial areas. Fine-grained and locally porphyritic diabase dykes cut both the gabbros and volcanics.

Relationships Between Rock Types

Gabbros and volcanics of the Bottle Cove slice are in contact from Devil Head to Caplin Cove. The contact is steeply dipping and marked by intense brecciation of both rock types. This zone of intense brecciation can vary in width from 6 inches to 4-5 feet.

At Bottle Cove, the contact is marked by a 6-12 inch wide zone of light-green, yellowish grey "tuffaceous-looking" rock, composed of intensely brecciated material derived from the host volcanic unit. Away from the contact, it grades into medium to coarse-grained fragmented volcanics and pyroclastics.

The zone is characterized by randomly distributed "veinlets", up to 2 inches wide, of crushed volcanic material. The veinlets, even though restricted to a zone on the gabbro-volcanic contact, are quite erratic within this zone. Numerous veinlets branch out away from the main zone into the volcanics. Isolated randomly distributed veinlets are also present within the volcanic rock and decrease in abundance away from the contact.

Thin sections of this zone display highly granulated and pulverized rock which in places appears "streamed" or flow-banded. Larger inclusions within the finer-grained material are volcanic rocks or crystal fragments. Almost all of the groundmass and inclusions have been replaced by prehnite.

The gabbroic rocks display no chilled zone or cutting relationships where in contact with the volcanics. The contact is sharp and regular in attitude and does not vary within each unit of the Bottle Cove slice. The light-colored, prehnite-rich contact zone is interpreted as being the result of fluidization or intense gas brecciation of the original volcanics. The contact between the gabbros and volcanics was a local zone of weakness, and was thus more susceptible to migrating fluids and/or gases than the more massive rocks away from the contact.

This zone is interpreted as a non-faulted junction between older gabbros and younger volcanic rocks. Yet it is not an unconformity in the classical sense as the junction is not thought to represent an old erosional surface. Rather, the older rocks are interpreted as "rafts" surrounded by younger volcanic material so that the junction represents a broken, or "raw" edge of the gabbroic rocks, along which brecciation took place. Elsewhere mafic dykes, locally sheeted, are abundant in this zone.

Correlation

The rock types and the topography suggest that all five (5) now separate units in the Bottle Cove slice were originally continuous. The attitudes of the gabbro-volcanic contact changes from unit to unit and is a good indicator of the amount of rotation each portion has undergone.

The gabbroic rocks of the Bottle Cove slice are identical to those of the Virgin Mountain slice. Both are tectonically deformed and intruded by undeformed diabase dykes. Volcanic rocks are also identical in both slices.

The gabbro-volcanic contact, although not exposed in the Virgin Mountain slice, is thought to have the same significance there. In the Virgin Mountain slice, the contact appears to be sub-horizontal, south of Wild Cove Brook, while the contact in the Bottle Cove slice is vertical. The Bottle Cove slice probably represents a detached and rotated portion of the Virgin Mountain slice.

Lark Harbour Slice

Extent

The Lark Harbour slice extends from the village of Lark Harbour westerly to Grassy Gulch where it is fault-bounded. The base of the slice is not exposed and its eastern contact with the Humber Arm Group has been inferred. The Lark Harbour slice is tectonically overlain by broken, fragmented gabbros of the O'Dwyer Mountain slice with a relatively sharp thrust contact.

Rock Types and Their Distribution

The Lark Harbour slice is composed of pillowed and massive basalts, slightly more silicic flows and mafic pyroclastics. These are well exposed at Corbett Cove in Lark Harbour. The basalts are commonly amygdaloidal, however, porphyritic varieties are present. Rarely, thin black and brown shales are interbedded with the volcanics and are exposed in a stream valley NE of the Little Port road. Diabase dykes are common in the slice.

Description of Rock Types

Mafic pillow lavas of the Lark Harbour slice are fine-grained, dark green on fresh surfaces and weather to a deep rusty brown. The lavas are characteristically intergranular in texture and locally contain intersertal glass. Amygdules contain clear calcite, epidote and chlorite.

Pillows attain diamaters of 6-7 feet and locally display zonal and concentric fracturing. This feature is accentuated by weathering. Late stage calcite fills fractures in the rocks.

The more silicic flows are interlayered with the basalts and are basaltic-andesites in composition. No interstitial glass is present in those rocks, however, minor quartz is present in the ground mass and the texture is trachytic or pseudo-trachytic. These rock types are highly altered and primary features are difficult to interpret.

The mafic pyroclastics are composed of basaltic lithic fragments and, along with the silicic rocks, form a minor portion of the Lark Harbour slice. Successive mafic volcanic exposures near the top of the Lark Harbour slice, display increased degrees of shearing. Primary features become obliterated and a strongly sheared fine-grained brown rock is exposed at the contact with the overlying O'Dwyer Mountain slice. At Lark Harbour it strikes east-west and dips 30° to the north.

The contact between the Lark Harbour slice and the overlying O'Dwyer Mountain slice is also exposed just north of the Little Port road. Intermingled volcanic and gabbroic blocks form a zone, approximately 30 feet thick, separating the two slices. The gabbros of the overlying O'Dwyer Mountain slice are highly sheared for approximately 50 feet above the thrust contact.

Correlation

The Lark Harbour slice differs from nearby slices of the Coastal Complex in that it is composed almost entirely of volcanic rocks. Similar volcanic rocks of comparable thickness and lithology are represented in the Virgin Mountain slice.

Parker Beach Slice

Extent

The Parker Beach slice extends from Trumpet Cove to Devil Head in the northern part of the thesis area. It is approximately 1½ miles long and 1/4 mile wide. Rocks of both the O'Dwyer Mountain and Lark Harbour slices abut its eastern flank. The slice is bounded by high-angle faults on all sides except to the west (?).

Rock Types and Their Distribution

The Parker Beach slice includes granodiorites, quartz-diorites, brecciated, fragmented volcanic rocks, foliated amphibolitic gabbros, diabase dykes and dyke breccias. Coastal exposures of medium to coarse-grained granodiorite and quartz diorite are present for one-half the distance between Devil Head and Trumpet Cove. They are present above a well-exposed basal mélange. Randomly distributed cataclastic veinlets, resembling tuffisite veins (Hughes, 1971) are characteristically developed in the granodiorites. Minor pink aplite dykes cut the granodiorites. The gabbros form only a minor portion of the slice and are only exposed near sea-level at Parker Beach. Brecciated volcanic flows abutting against the granodiorite are exposed north of Parker Beach. Diabase dykes and dyke breccia cut all rock types in the Parker Beach structural slice.

Relationships Between Rock Types

Relationships between rock types in the Parker Beach slice are identical to those exposed in the Virgin Mountain slice.

Granodiorites are interpreted to cut the gabbros (Williams, pers. comm.) and younger volcanic rocks surround the granodiorites, again suggesting that the older rocks of the Coastal Complex are "rafts" surrounded by younger volcanic rocks.

Volcanics abut against granodiorite just north of Parker Beach. The contact is masked by diabase dyke breccia, intrusive porphyritic felsites and late-stage shearing. Volcanics near the granodiorites are highly brecciated. The contact strikes easterly and dips 45^{o} to the north.

Correlation

The chronological order displayed by the rocks underlying the Parker Beach structural slice is identical to that of the Virgin Mountain slice. The gabbros and granodiorites are similar and are correlated between the two slices. The dykes and volcanic rocks of the two nearby slices are also correlated.

<u>O'Dwyer Mountain Slice</u>

Extent

The O'Dwyer Mountain slice structurally overlies the Lark Harbour slice along a sharp thrust contact and it is separated from the Parker Beach slice by a high-angle fault. It strikes northwest and dips northeast at 30^{o}. It extends from Lark Harbour to Grassy Gulch. The slice is separated from the overlying Monkeyland slice by serpentinites of the Trumpet Cove Mélange Zone. The basal gabbroic portion of the slice is well-exposed along a fault coincident with the 1400 Brook (See Map in jacket).

Rock Types and Their Distribution

The O'Dwyer Mountain structural slice is mainly composed of foliated gabbros and their mylonitic derivatives. The gabbros are both banded and non-banded. Diabase dykes are abundant in the gabbroic rocks, however, they are absent in the mylonites. Minor ultrabasic and acidic intrusions are also present.

The gabbros are restricted to the structural base of the slice, and form a continuous unit from the 1400 Brook fault eastwards to Lark Harbour. Gabbroic rocks are absent west of the 1400 Brook fault. The gabbros grade into a thick unit of amphibolitic mylonite that occupies the northeast portion of the slice and that part west of the 1400 Brook fault. The tectonic fabric in both the gabbros and mylonites parallels the northwest structural trend of the O'Dwyer Mountain slice.

Where diabase dykes cut the gabbroie portion of the slice they are locally more abundant than the gabbroic rocks. The dykes strike northwest and dip gently either northeast or southwest.

Several serpentinized ultramafic bodies are exposed at O'Dwyer summit and near the headwaters of the 1400 Brook. Ultramafic dykes are also present nearby. Small feldspar-porphyry bodies, 10-20 feet wide, that intrude the amphibolitic mylonites, are present along the northeastern boundary of the slice.

Rock Descriptions

The gabbroic rocks above the basal thrust contact of the O'Dwyer Mountain slice are leucocratic and mesocratic and tectonically brecciated and fractured. They become more coherent away from the contact. Foliated gabbros are most common elsewhere and are medium to coarse-grained and characterized by a penetrative tectonic fabric. Coarse-grained pods with crystals attaining 5 inches in length are locally present.

The penetrative tectonic fabric in the gabbros increases in intensity towards the northeastern portion of the O'Dwyer Mountain slice. A reduction in the grain size of the constituent crystals also occurs. Augened "eyes" of amphibolitized diallage augite are plentiful and other mineral constituents exhibit an increased degree of flattening. Feldspar crystals exhibit 4-5 fold increases in length. Mylonitic rocks, gradational with the gabbros occur east of the 1400 Brook fault.

Ultramafic rocks and quartz-feldspar porphyries occur in the mylonite zone and display similar mylonitic fabrics. Locally, tectonically deformed ultramafic dykes contain inclusions of mylonitic gabbro suggesting an intrusive activity overlapping with mylonitic deformation.

The amphibolites strike to the northwest (N 60° W-NS) and dip steeply to the northeast (70-90°). They are composed of amphiboles (hornblende-actinolite) and albite-rich plagioclases. Minor accessory apatite, epidote and magnetite are also present. The rocks are fine-grained and dark greenish grey in color. Locally large porphyroblastic plagioclases are present and exhibit granulated borders. Carbonate streaks are also present and possibly result from the release of Ca during the alteration of the plagioclases.

The above mylonites exhibit alternating light and dark, thin, discontinuous bands or lenses. The lighter bands are composed of finely granulated plagioclase and the darker bands are primarily hornblende. The bands are discontinuous and cannot be traced along strike for more than several inches, however, locally some thicker (3/4 inch) bands are more continuous. The more continuous bands are interpreted to represent primary igneous layering. This fabric is interpreted to be the result of flattening. The flattening deformation is considered to be the same which affected the underlying gabbros.

Locally, at O'Dwyer summit, the fabric in the mylonites is folded about near-vertical, northwest striking, axial planes. The folds are 1 foot or less in amplitude and plunge 55° to the north. The axial planes dip steeply east. Parasitic folds with amplitudes of 1 inch are plentiful.

More intense local folding is exhibited by the mylonites west of the 1400 Brook fault. Exposures on Grassy Hill display complex tectonic folds resembling sedimentary slumps, but of consistent orientation. This complex folding diminishes in intensity outwards. Small kink features in the mylonites plunging 5° to the east (105°) are exposed on Grassy Hill. The tight folding may represent areas of weakness in the developing mylonite and the highly complex folding on Grassy Hill may be localized at tight anticlinal or synclinal structures, or perhaps areas of intersecting conjugate kink planes.

Two slightly elongate amphibolitic inclusions occur in the mylonites at 1400 Brook. Each is approximately 5 inches in length. One of the inclusions has a tectonic fabric at right angles to that of the host mylonite and this fabric is bent at the margins of the inclusion and conforms with the fabric of the host mylonite. The inclusions are similar to the host rock and are interpreted as rotated blocks of earlier mylonitized gabbro that acted as stress resistant areas during a single, but prolonged, episode of deformation.

Massive medium-grained dull grey diabase dykes with chilled margins and dyke breccias intrude the gabbros in numerous localities. The dykes are gabbroic in composition consisting of labradorite and augite. Locally exposures are composed of nearly 50% dyke rock, however, nowhere do diabase dykes cut other dykes. They are one foot or less in width and locally are highly fragmented, in a manner similar to the more extensive brecciated diabases in other slices. Thin brecciated zones are associated with the diabase dykes and predominate at or near the intrusive contacts. The dykes are offset by numerous small shears or fractures.

Exposures of serpentinized ultramafic rocks ranging from near dunite to werhlite in composition and acidic porphyries are present within the mylonitic domain. Both have been affected by the penetrative deformation responsible for the development of the mylonites.

A five hundred (500) foot wide ultramafic exposure at the 1400 Brook is bordered to the northeast by mylonitic gabbros and to the southwest by amphibolitic mylonites. Primary igneous banding is present in the centre of the mass. Individual bands attain thicknesses of 1 foot or more. The rock in the centre of the exposure is undeformed and bands are persistent along strike. Successive ultramafic exposures near the mylonitic rocks display a gradational increase in tectonic foliation. The tectonic fabric parallels the igneous banding and obliterates it near the outer edges of the exposure. The tectonic bands or streaks are 1 inch to 2 inches thick but locally are extremely thin. Diallage clinopyroxenes locally form augens and are bent, broken and granulated. Diallage partings have been folded and warped parallel to the tectonic fabric. Locally small (3-4 inches) ultramafic inclusions display primary igneous banding that is curved parallel, near its outer edges, to the tectonic fabric of the surrounding rock but which is at an angle to the tectonic fabric within the centre of the inclusion.

Several small dyke-like ultramafic intrusions are exposed 1000 feet north of 1400 Brook. They intrude mylonitic gabbros. They range from less than 1 foot to approximately 30 feet in thickness with the thicker varieties displaying banding. They have been altered to a bright bluish-green serpentinite. Inclusions of gabbro are common. The gabbroic inclusions are slab-like and are at an angle to the banding in the ultramafics. Generally the ultramafic dykes parallel the fabric in the surrounding mylonitic gabbros. They are structurally deformed and locally display isoclinal folds whose axial planes dip 45° S and plunge 42° to the east.

A 300 foot exposure of serpentinized ultramafics present on the O'Dwyer summit is surrounded by amphibolitic mylonites, however, no contacts are exposed. The ultramafics contain a tectonic fabric parallel to the mylonitic fabric. They are thus interpreted as pre-mylonitization intrusions.

Pale pink, chalky weathering quartz-feldspar porphyries are exposed to the northwest of the O'Dwyer summit. No contacts with the surrounding rocks are exposed. Quartz and feldspar phenocrysts up to 1/4 inch in diameter are set within a finer-grained matrix of the same composition. The rock is tectonically foliated parallel to the fabric in the amphibolitic mylonites, thus, again interpreted as a pre-mylonitization intrusion.

All intrusive activity and all tectonic deformation occurred pre-transportation of the Coastal Complex. Nearby underlying similarly transported sediments are free from any penetrative tectonic fabrics, thus indicating that the deformation in the Coastal Complex did not occur post-transportation.

Relationships Between Rock Types

Successive gabbroic exposures underlying the northeastern portion of the O'Dwyer Mountain slice display more intense degrees of tectonic foliation and fragmentation. Crystals are sheared, granulated, pulverized and decrease in grain size. The rocks grade from recognizable mylonitized gabbros to amphibolitic mylonites within 50-100 feet. The contact is not exposed. The mylonitic rock is interpreted as a vertical belt within the gabbros resulting from intense lateral tectonic pressures.

Massive and brecciated diabase dykes intrude the gabbros but are absent in the mylonites.

Planar ultramafic intrusions cut the mylonitic gabbros and are parallel to the tectonic fabric displayed by them. Thin dark zones in the wallrock gabbros, as well as tectonically foliated gabbroic inclusions in the ultramafics, are suggestive of a hot intrusive episode during deformation.

The larger ultramafic masses on the O'Dwyer summit and at the headwaters of the 1400 Brook display no contact relationships with surrounding rocks. Igneous banding in the ultramafics is suggestive of small differentiated intrusive bodies. Tectonic fabrics exposed on their edges suggest that they were intruded prior to the deformational episode.

The quartz-feldspar porphyry bodies display no contacts with the surrounding mylonites. They are interpreted as pre-deformation in age since they are affected by the mylonitic fabric.

Correlation

The amphibolitic gabbros of the O'Dwyer Mountain slice and diabase dykes can be directly correlated with similar units in the Virgin Mountain, Bottle Cove and Monkeyland slices. They are identical except for the greater degree of deformation displayed by the gabbros in the O'Dwyer Mountain slice. Ultramafic dykes are also present in the Virgin Mountain slice. Mylonitic equivalents to those exposed in the O'Dwyer Mountain slice are not present in other structural slices of the southern Coastal Complex.

The Monkeyland Slice

Extent

The Monkeyland slice forms the highest structural slice of the Coastal Complex and extends from South Head, to just northeast of Lark Harbour and forms the northernmost portion of the area.

It overlies serpentinites of the Trumpet Cove mélange to the south and is bounded by the sea to the northeast. Its basal contact is rather irregular due to different degrees of weathering. It strikes northwest and dips northeast at 30°.

Rock Types and Their Distribution

The Monkeyland slice is composed of medium to coarse-grained biotite-hornblende granodiorites and quartz diorites exposed at South Head, White Point and underlying the northwestern portion of the slice. Several small coastal exposures of granodiorites are present along the southeastern portion of the slice.

Gabbros are present along the coast near the mouth of Rocky Brook and above the basal thrust contact north of Lark Harbour. Amygdaloidal and massive pillow lavas, pyroclastics and massive volcanics are present along numerous coastal exposures from Lark Harbour to White Point. Brecciated and fragmented volcanics are present and well exposed near Fleming Point.

All rock types are intruded by fine-grained diabase dykes and dyke breccias. Diabase dyke breccia is invariably present along contacts with granitic rocks and nearby mafic volcanic rocks. Great expanses of this rock type are present between White Point and South Head.

Description of Rock Types

The granodiorites are medium to coarse-grained, light pink in color and composed of quartz and soda-rich plagioclases. Mafic minerals are biotite and hornblende. Randomly distributed cataclastic veinlets are common.

Gabbroic rocks are only locally banded and most are non-banded, tectonically foliated light green amphibolitic gabbros. Their grain size approximates grain sizes of other gabbroic rocks in other structural slices. Coarse-grained gabbros are present near the base of the slice.

The volcanic rocks are basaltic in composition and comprise amygdaloidal basalts, massive and pillowed basalts and mafic pyroclastics. Locally they are highly brecciated.

The granodiorites, gabbros and volcanics are intruded by fine-grained, grey diabase dykes which locally occur in swarms, at White Point and South Head. The dykes are both massive and brecciated.

Relationships Between Rock Types

The relationships between rock types in the Monkeyland slice are equivalent to those displayed in other structural slices, notably the Virgin Mountain slice. Diabase dyke swarms, both massive and brecciated, intrude the granodiorite at South Head and White Point. The granodiorite is surrounded and separated from nearby massive volcanics by an extensive zone of diabase dyke breccias and nowhere intrudes the volcanic rocks.

Small exposures of tectonically foliated gabbro, north of Rocky Brook, are completely surrounded by granodiorite and are suggestive of inclusions incorporated within the granodiorite. The gabbros are interpreted as being intruded by the granodiorite. Coastal gabbroic exposures are separated from nearby fresh volcanics by diabase dyke breccias similar to those surrounding the granodiorites. The tectonically foliated gabbros are also cut by tectonically undeformed diabase dykes which are interpreted to be coeval with nearby massive volcanics.

The volcanic rocks are inferred to abut against the gabbros and granodiorites. Diabase dyke intrusions were then common along this zone of weakness. Thus, the granodiorites and gabbros are interpreted to represent giant inclusions completely surrounded by fresher, younger dykes and volcanics.

Correlation

The granodiorites, quartz diorites, gabbros, volcanics and dykes are similar in composition and structure to their counterparts in the Virgin Mountain slice and are correlated with them. Relationships, observed and inferred, are identical.

CHAPTER III

MELANGE ZONES BETWEEN SEDIMENTS AND OVERLYING IGNEOUS AND METAMORPHIC SLICES

Mélange zones are everywhere present between relatively undeformed transported clastic sedimentary rocks of the Humber Arm Group and overlying structural slices of the Coastal Complex. Mélange zones also occur between higher structural igneous slices, except for the contact between the O'Dwyer Mountain and Lark Harbour slices, which is a sharp thrust.

The mélanges consist either mainly of sedimentary and volcanic blocks in a black shaly matrix, or of serpentinized gabbroic and ultramafic blocks in a serpentinite matrix. Sedimentary mélanges are well exposed at Bottle Cove, Bear Cove, and Little Neck. Serpentinite mélanges overlie the sedimentary mélange zones in most areas. The Trumpet Cove mélange is composed almost entirely of serpentine.

The Trumpet Cove mélange, which separates the O'Dwyer Mountain slice from the overlying Monkeyland slice is 1 mile wide and is by far the most extensive in the study area. It consists primarily of serpentinized ultramafic boulders set in a sheared serpentinite matrix.

Wild Cove Brook Mélange

The mélange zone at Wild Cove Brook separates the Virgin Mountain slice from underlying sediments of the Humber Arm Group, and is exposed along the coast at Bear Cove, Fall

Brook and upstream along the banks of Wild Cove Brook. The actual zone is no more than 200-300 feet thick at these localities, and is composed of a sedimentary mélange overlain by a serpentinite mélange. No serpentinite mélange is present at the Wild Cove Brook exposures. The Bear Cove exposures are the most extensive. The contact between the mélange zone and underlying sediments is gradational.

The northern exposure of the sedimentary mélange zone, south of Fall Brook, strikes northerly and dips easterly at 50°. At Wild Cove Brook, the strike is northeast and dips at 30° to the east. Exposures of the mélange zone at Bear Cove strike east-west and dip 30° to the south. In all cases the mélange zones dip under the overlying Virgin Mountain slice.

A serpentinite mélange overlying the sedimentary mélange zone is present just north of Fall Brook where it dips 30° east, and along lake shore exposures, approximately 1 mile inland from Fall Brook, where it dips 70° to the east. Serpentinites at Bear Cove dip to the south at 30°.

Fall Brook

Highly contorted, fissile red shales are exposed near the Fall Brook section of the Virgin Mountain slice. They are overlain by a 10 foot thick schistose chloritic volcanic zone, which is in turn overlain by green, slickensided gabbros at the base of the Virgin Mountain slice.

A serpentinite zone, interpreted to locally overlie the sedimentary melange, is exposed just north of Fall Brook. It is composed of sheared serpentinized gabbroic blocks, presumed to be derived from the overlying Virgin Mountain slice.

Wild Cove Brook

Black, red and green shales containing sandstone and limestone blocks (1-2 feet) are exposed along the banks of Wild Cove Brook. Green shales increase in abundance stratigraphically upwards towards the Virgin Mountain slice. Exposures near the base of the Virgin Mountain slice display an increasing number of sandstone boulders. Deformation in the shales is more intense near the basal thrust. The sediments do not exhibit any cleavage, therefore, the deformation is interpreted as a soft sediment feature. Gabbroic boulders up to 2 feet in length are incorporated within the shales below the thrust contact.

Bear Cove

Dark grey and green shales containing fine-grained brownish grey limestone and sandstone blocks (1-2 feet) are exposed along the shore at Bear Cove. Upwards in the section, 3-4 feet long limestone streaks are present.

The sediments are overlain by elongate serpentinized ultramafic boulders set in a sheared comminuted serpentinite matrix. They are in turn overlain by two hundred feet of bright green serpentinite, composed of large serpentinized ultramafic boulders (10-15 feet). Foliated, leucocratic gabbro boulders of similar size are interlayered with the serpentinite. These are overlain by a 100 feet thick unit of interlayered, sheared serpentine and light-green gabbros. The gabbros contain a tectonic fabric parallel to a thin sparse banding. This zone is overlain by gabbroic rocks of the Virgin Mountain slice.

Serpentine River Mélange

Sediments composing the Serpentine River Mélange zone are exposed to the north of the mouth of the Serpentine (Coal) River. They are separated from the limestone-shale unit south of the Serpentine (Coal) River by a westerly-trending fault. Red, green and black shales, greywackes and red micaceous fissile shales form the basal mélange zone to the Coal River Head portion of the Virgin Mountain slice.

These sediments underlie green fragmented volcanics which contain screens of brecciated limestone and limestone breccias. The volcanic-limestone zone strikes at 170° and dips approximately 20° to either side of vertical. Inland, the limestone screens are not present and the rock is composed solely of fragmented volcanics.

The volcanic-limestone zone extends from south of Friar Rock to just south of Coal River Head (See Map in Jacket). South of Coal River Head it swings from its predominantly north-south strike to north-northwest and turns out to sea (330°-340°).

The volcanic-limestone horizon is overlain by a 200-300 feet thick sequence of sheared brown, greyish-green shales and fragmented volcanics which contain large (50 feet) blocks of fragmented, foliated light-green gabbros. Gabbros of the Virgin Mountain slice overlie this unit. The contact is irregular but appears to represent an original thrust contact modified by later high angle faults at right-angles to the original contact.

Lark Harbour Mélange

The Lark Harbour mélange zone incorporates all rock units, whether sedimentary, volcanic or metamorphic underlying the Lark Harbour slice and the northern portion of the Virgin Mountain slice. It is well exposed at Lark Harbour and Little Neck (See Fig. 4). The sedimentary mélange on the eastern shore of Little Neck is composed of volcanic, limestone and coarse grit blocks set in a fissile, locally lime-rich shaly matrix. A volcanic unit, similar to the one exposed in the Serpentine (Coal) River area, overlies the sediments and is similar to volcanics underlying the area south of the lowland at Little Port. The sedimentary mélange zone at Little Neck dips northerly (50-60°) and is locally overturned.

The mélange zone on the eastern shore of Lark Harbour is composed of folded black, green and red shales containing subangular limestone boulders and lenses up to 2 feet in length. Sandstone blocks similar to the quartz-rich sandstones at Bear Cove are common. On the western shore of Lark Harbour the exposed mélange zone is composed of folded red micaceous shales.

The chaotic sediments of the Lark Harbour mélange are overlain by a serpentinite zone composed of elongate serpentinite boulders (2-3 feet) set in a finely crushed and sheared serpentinite matrix exposed near Lark Harbour Head (Tortoise Point) and just northwest of Little Mountain.

Parker Beach Mélange

The Parker Beach mélange is sparsely exposed approximately at sea-level at Parker Beach. The mélange unit is composed of black, red and green shales containing numerous limestone and sandstone inclusions. Pyrite concretions are plentiful in the dark shales. The sediments strike northeast and dip 50° to the southeast. The contact with the allochthonous rocks of the Parker Beach slice is covered by a granodiorite scree.

Bottle Cove Mélange

Exposures of the Bottle Cove mélange are present in low-lying coastal areas separating different units of the Bottle Cove slice and are present at Miranda Cove, Bottle Cove, Little Port, and separating units 2 and 3 of the Bottle Cove slice.

A schistose argillaceous shale containing numerous subangular to subrounded inclusions, locally 10 feet in length is exposed at Miranda Cove. The inclusions are composed of amygdaloidal basalts, limestone, sandstone, limestone breccias, pyrite concretions and conglomerates.

Dark shales, containing inclusions, up to 15 feet in length, composed of fine-grained green tuffaceous volcanics, amygdaloidal basalts and limestones are present on the north shore of Bottle Cove. To the west, limestones, limy shales and water-reworked pyroclastics predominate as inclusions. They are overlain by dark green volcanics containing massive limestone screens. Westerly exposures display an increase in the number of limestone screens. Mafic pyroclastics and pillowed basalts are faulted into the sequence above the limestone-screen unit. This is interpreted as the base of the Bottle Cove slice. The mélange strikes at 135-170^{o} and dips 80^{o} E to vertical.

Brown shales overlain (?) by serpentinites separate units 2 and 3 of the Bottle Cove slice. Exposure is restricted to ≈ 10 feet and is highly sheared. The zone strikes north-south, is vertical and is interpreted to be the result of intense grinding between the two units.

Dark grey and green shales and dark green pillowed amygdaloidal basalts exposed at Little Port form the lowest stratigraphical section in the mélange zone. Massive limestone and limestone breccia inclusions are incorporated within the shales nearing the base of the slice. They are overlain by a complex, intermingled volcanic mélange containing several granodiorite slivers. The more competent but brecciated volcanics of unit 1 overlie the volcanic rubble. It strikes north-south, is vertical and faces east.

MELANGE ZONES BETWEEN IGNEOUS AND METAMORPHIC ROCK SLICES

The Trumpet Cove mélange zone separates the O'Dwyer Mountain slice from the overlying Monkeyland slice, and is the thickest mélange zone in the Coastal Complex.

Trumpet Cove Mélange

Area

The Trumpet Cove mélange zone extends southeasterly from Trumpet Cove to just north of Low Point in Lark Harbour (See Map in jacket) and forms by far the thickest mélange zone.

It separates the O'Dwyer Mountain structural slice from the overlying Monkeyland slice to the northeast. The mélange zone is much thinner in coastal exposure than inland due to a northeasterly-trending dextral (?) fault on the northwest coast. The mélange zone attains a thickness of 1/2 mile inland. The mélange strikes to the northwest and dips to the northeast at 30°.

Rock Types

The Trumpet Cove mélange zone is composed of serpentinized ultramafic boulders incorporated within and surrounded by a sheared, fissile serpentinite matrix. Large "slabs" of diorite, locally exhibiting a bleached appearance, are also present. The ultramafic boulders are dark massive green and the serpentinite matrix displays numerous small shiny slickensided surfaces. Elongated serpentinized ultrabasic blocks at Trumpet Cove are up to 6-7 feet in length. The diorite slabs are orientated in the direction of the shearing.

A large amphibolitic mylonite inclusion is present at the base of the northwestern coastal exposure of the mélange zone. It is interpreted to be derived from the mylonite zone of the underlying O'Dwyer Mountain structural slice. The mylonitic inclusion is intruded by dykes of different ages, some affected by the mylonitic fabric, others free of any fabric.

The inland equivalents to the diorite inclusions are represented by low ridge-like features surrounded by ultra-mafic rubble. The bleaching phenomena common to the diorites on the coast is not exposed inland. The ridges are up to several hundred feet long, although their widths never exceed more than 50 feet. Low-lying areas in the Trumpet Cove Valley are invariably underlain by ultramafic rubble locally displaying primary igneous banding.

Contact with Monkeyland Slice

The contact with the overlying Monkeyland slice is a sinuous one, reflecting the effect of erosion on a relatively flat surface. Locally, shearing in the ultramafics is very intense, especially near dioritic inclusions, where the greater competency of the diorite was compensated for by a greater degree of flowage and deformation in the nearby serpentinites.

The contact between the Monkeyland slice and the serpentinite mélange is poorly exposed to the southwest of

Rocky Brook. It is composed of a lower, highly sheared, brownish weathering, slickensided serpentinite zone, grading upwards into a more massive, but still highly sheared zone, containing large (1/2 inch) enstatite augens. This unit is in sharp contact with the overlying gabbros of the Monkeyland structural slice.

Exposures of the basal contact at Low Point in Lark Harbour contain gabbro boulders within the serpentinite. These were presumably derived from the overlying Monkeyland slice.

Origin and Tectonic Significance

The Trumpet Cove mélange zone is interpreted to represent an accumulation of serpentinized ultramafic boulders derived from the erosion of an easterly exposed ultramafic source. The mélange zone is interpreted to have been originally much thinner.

The movement of the Monkeyland slice over the serpentinite boulders resulted in thickening due to a "bulldozing" effect. The serpentinite was scraped up and accumulated in front of the moving slice, thus greatly increasing its thickness. Eventual overriding of the serpentinite by the Monkeyland slice occurred and produced the present setting.

A somewhat similar modern analogy is present at Trout River. A felsenmeer composed of ultramafic boulders, derived from Table Mountain to the east, covers most of the surrounding area. If the ultramafic felsenmeer was overridden by the Table Mountain pluton it would form a mélange similar to that at Trumpet Cove.

CHAPTER IV

BRECCIATION

Phenomenon and Distribution

Igneous and metamorphic rocks of the Coastal Complex, in the thesis area, have been affected by a phenomenon which resulted in mild to extreme fracturing and brecciation. This phenomenon is not evident in sedimentary rocks of lower structural slices.

The phenomenon differs in different rock types. The granodiorites and gabbros are characterized by thin (1 inch - 2 inches) randomly distributed irregular veinlets composed of finely fragmented portions of the host rock. At Virgin Mary Rock, the veinlets attain a width of 6 inches. The fragments composing the veinlets in the gabbros and granodiorites are unsorted, angular to subrounded and relatively unaltered. A common megascopic size range is 1/16 mm to 2 mms and in isolated exposures they resemble sedimentary rocks. The matrix is more finely comminuted host rock and fragments display an increase in roundness with decrease in grain size.

Brecciation is most widespread and intense among the volcanic rocks. Large portions of the thesis area are underlain by brecciated extrusive volcanic rocks. Most of the Bottle Cove slice is composed of such rock units, as are large expanses underlying Bear Head. The intensity of brecciation in the volcanics increases towards gabbro contacts. Gabbro-volcanic contacts in the Bottle Cove slice and granodiorite-volcanic contacts in the Virgin Mountain slice are marked by highly brecciated and fragmented volcanic zones.

The volcanics contain much more finely comminuted material than do either the granodiorites or gabbros, which seem to have acted in a more resistant fashion.

Diabase dyke breccia occurs as single intrusions and as wide expanses (separating gabbros and granodiorites from younger volcanics). Brecciated, fragmented diabase dyke rock is well exposed along the coast from White Point to South Head.

Rocks Affected

Granodiorite

Brecciation of the granodiorites is restricted to narrow irregularly distributed gash-like veinlets composed of granulated host rock. The veinlets average 1 inch- 2 inches in width but locally attain widths of 6-8 inches. Extremely thin (1/16 - 1/8 inch) veinlets appear as fine dark lines erratically running through the host rock. The veinlets are irregular in shape and distribution, hence, are not governed by any major joint pattern within the granodiorite.

Veinlets at White Point and Virgin Mountain come in contact, along strike, with volcanic inclusions. The veinlets do not cut the volcanic material but follow the inclusion-host rock contact until reaching what would appear to be its natural continuation had the inclusion not been present.

The finer-grained material forming the veinlets is primarily composed of plagioclase and quartz crystals. Very little ferromagnesians are present. The plagioclases are bent and broken and displaced albite twinning is common. Quartz crystals, generally fresh, but sometimes stretched and sutured are present. Williams (1971) has reported amphibolite inclusions within the veins.

Gabbros

Thin irregular veinlets composed of fragmented host rock are also common in the gabbroic rocks of the Coastal Complex. Coarse-grained fragments are angular to sub-rounded and the degree of rounding appears to increase with decreasing grain size. A fine banding is present in many veinlets. This banded feature is suggestive of particle flow. Thin veinlets bifurcate around host rock inclusions and rejoin along strike.

The contact between the gabbros and younger volcanic rocks is exposed along the seaward side of all five units of the Bottle Cove slice and is especially well exposed on unit 3. The gabbro near the contact is composed of angular blocks whose internal tectonic fabric is orientated differently within individual blocks. This indicates rotation of individual blocks with respect to each other. The brecciated gabbro extends for several feet away from the volcanic contact where it then resumes its more massive appearance. Boulders of both gabbro and volcanic rocks are intermingled at the actual gabbro-volcanic contact. These features suggest that the brecciation phenomenon was most intense in gabbro-volcanic contact zones. Prehnite alteration is common in the gabbros at Bottle Cove.

Volcanics

Volcanic rocks form the widest expanse of brecciated rock in the Coastal Complex, as well as the most intensely brecciated rock type in the area. Brecciated and fragmented volcanic rocks are exposed up to 1/4 mile away from gabbro-volcanic contacts.

Volcanic rock fragments, range from microscopic to fist size, and are cemented by more intensely granulated material of the same lithology. The rocks are generally featureless, however, bomb-like structures and features resembling deformed pillows are present. On Devil Head, the brecciated volcanics contain inclusions of angular gabbro and granodiorite.

The gabbro displays no signs of intrusive activity. There is no chilled margin nor any apophyses of gabbro into the volcanic material.

The contact between the gabbros and the volcanics, best exposed in the Bottle Cove slice, is occupied by a 6-12 inch light-yellow zone of intensely fragmented and brecciated volcanic material. The attitude of this zone differs between different units of the Bottle Cove slice but strikes out to sea at 155° and is vertical, at unit 3 of the Bottle Cove slice where it is well exposed.

The intensely crushed zone is restricted to the volcanic rocks although it doesn't always separate volcanics from gabbros. Locally, volcanic blocks are incorporated within the gabbro unit and conversely gabbroic blocks are present within the volcanic unit.

Finely granulated and pulverized volcanic material, crisscrossed by thin veinlets of similarly crushed fine-grained particles form the contact zone. Sub-parallel sinuous bands composed of finely crushed rock and larger fragments are abundant. The matrix is light-brown in color and appears highly saussuritized. Roundness increases with decreasing grain size. Particles in the matrix and the larger fragments are composed of both rock fragments and single crystals. Most rock fragments are present in various stages of separation from the more massive volcanics. Veinlets of crushed material diverge and completely surround larger (1/4-1/2 inch) fragments of the host rock.

The thin veinlets can be either restricted to the contact zone or may originate in the zone and strike into the less deformed volcanics away from the gabbro contact. Isolated veinlets are also present within the less deformed volcanic rocks.

Saussuritization is the main alteration phenomenon affecting the fragmented brecciated volcanic rocks. Prehnite is a common alteration mineral in the highly pulverized zone at the gabbro-volcanic contact. Prehnite replaces isolated single fragments as well as ground mass. Locally single prehnite crystals alter both groundmass and fragments (Williams, pers. comm.). Prehnite also occurs in thin cross-cutting veinlets and as blebs in the volcanic rock. Prehnite exhibits a radial growth pattern from the outer edges of the fragments towards their centres. The complete radial symmetry of the prehnite suggests a post-brecciation alteration. The large amount of prehnite in the zone results in the light-yellow color of the rock.

Diabase Dykes

Brecciated diabase dykes intrude all rock types of the Coastal Complex except the sediments of the underlying Humber Arm Group. Intrusive diabase dyke breccias are well exposed at South Head, White Point and along coastal exposures of the Virgin Mountain slice. An extensive coastal exposure between White Point and South Head is composed of diabase breccia. These larger expanses of dyke breccia are interpreted to represent numerous intrusions. Diabase dykes predominate at or near contacts between older granodiorites, gabbros and younger volcanics. Locally sheeted dykes are present.

Dyke fragments range in size from microscopic to 10 inches. In thin section, fragments are surrounded by still more comminuted material. The larger fragments are generally angular but rounding increases with decreasing fragment size. Locally the dykes, even though brecciated, exhibit grain size increases towards their centres, suggesting a minimum of movement of individual fragments.

Williams and Malpas (1972) have reported examples of dyke breccias exhibiting a mixing of fragments and a variety of dyke rock fragments. They suggest that this texture implies transport of the fragments. They draw analogies with tuffisites developed in igneous rocks by fluidization (Reynolds, 1954; Hughes, 1970).

Interpretation

The phenomenon which was responsible for the brecciation of all rock types in the Coastal Complex is interpreted to be the result of gas brecciation or fluidization. This phenomenon is suggested by the restriction of brecciation to narrow zones or to single rock types. Brecciation in the diabase dykes does not affect surrounding host rock, thus suggesting that the dykes acted as "channelways" for the brecciating agents and that the brecciation occurred at or about the same time as the intrusion. The intensely brecciated volcanics which locally display banded features are restricted to zones at gabbro or granodiorite-volcanic contacts where diabase dykes are present. The contacts were areas of weakness and easily susceptible to escaping gases.

The ophiolites forming the Bay of Islands Complex are characterized by a zone of diabase dyke breccia separating overlying volcanics from underlying gabbroic rocks. The breccias are similar in all respects, except degree of metamorphism, to the dyke breccias of the Coastal Complex (Williams and Malpas, 1972).

Williams and Malpas (1972) have interpreted the dyke breccias as the result of gas brecciation or fluidization by supercritical water. The ophiolites are interpreted as representing early-Paleozoic oceanic crust and the dyke breccias and sheeted dyke zone were formed at an accreting plate boundary (ocean ridge). Williams and Malpas (1972) suggest the possibility of sea-water being the fluidization agent.

CHAPTER V

PETROLOGY

Gabbros

The gabbros form the largest percentage of igneous rock types exposed in the area and are second in volume only to the sedimentary rocks of the basal clastic slices. The gabbros are both banded and non-banded, and always display one tectonic fabric which is the result of intense flattening strains. The deformation in the gabbroic rocks of the O'Dwyer Mountain slice produced extensive mylonites.

Composition

The gabbros range in composition from troctolite to almost pure anorthosite in the banded varieties. Locally, although rare, quartz gabbros are present. This suggests that the gabbros possibly represent different levels of an originally much thicker unit.

The crystals are usually euhedral and the rock varies from fine-grained to locally pegmatitic. Thin sections of gabbro display cumulate textures. Relatively undeformed specimens show ophitic textures, especially in coarser varieties.

The main constituents are plagioclase (An_{65}-An_{85}); clinopyroxenes (diallage augite); amphiboles (hornblende-actinolite); olivine, apatite and magnetite. The relatively minor orthopyroxene present appears to be mainly restricted as an exsolved form along the cleavage planes of clinopyroxene crystals. Primary orthopyroxene is relatively rare but occurs in some sections.

Parallel alignment of plagioclase laths is common suggesting primary layering. These crystals tend to develop a polygonal or pseudo-polygonal fabric when in contact with other plagioclases.

The clinopyroxenes are characterized by diallage parting which almost obliterates the cleavage planes. In areas where ophitic texture is well-developed, the clinopyroxenes are always much larger (sometimes 10 to 15 times) than the feldspars which they enclose.

Olivine, where present, is relatively fresh and locally displays good polygonal fabrics where in contact with other olivine crystals.

Magnetite is quite common throughout the gabbros, both as a primary precipitate and as a secondary mineral. The iron-ore, where present as an alteration product is mainly restricted to clinopyroxenes. Where it occurs within feldspars, it is as a cumulate phase only. The cumulate iron-ore, where present, is aligned parallel to the banding.

Some of the magnetite displays a symplectic intergrowth texture and suggests a secondary origin.

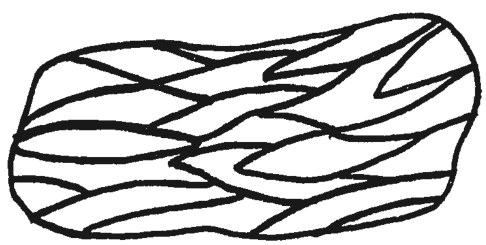
Alteration

Clinopyroxenes

Almost all clinopyroxenes are altered and locally this has obliterated all primary textures. The alteration has been mainly a hydrous one resulting in the formation of various forms of amphibole.

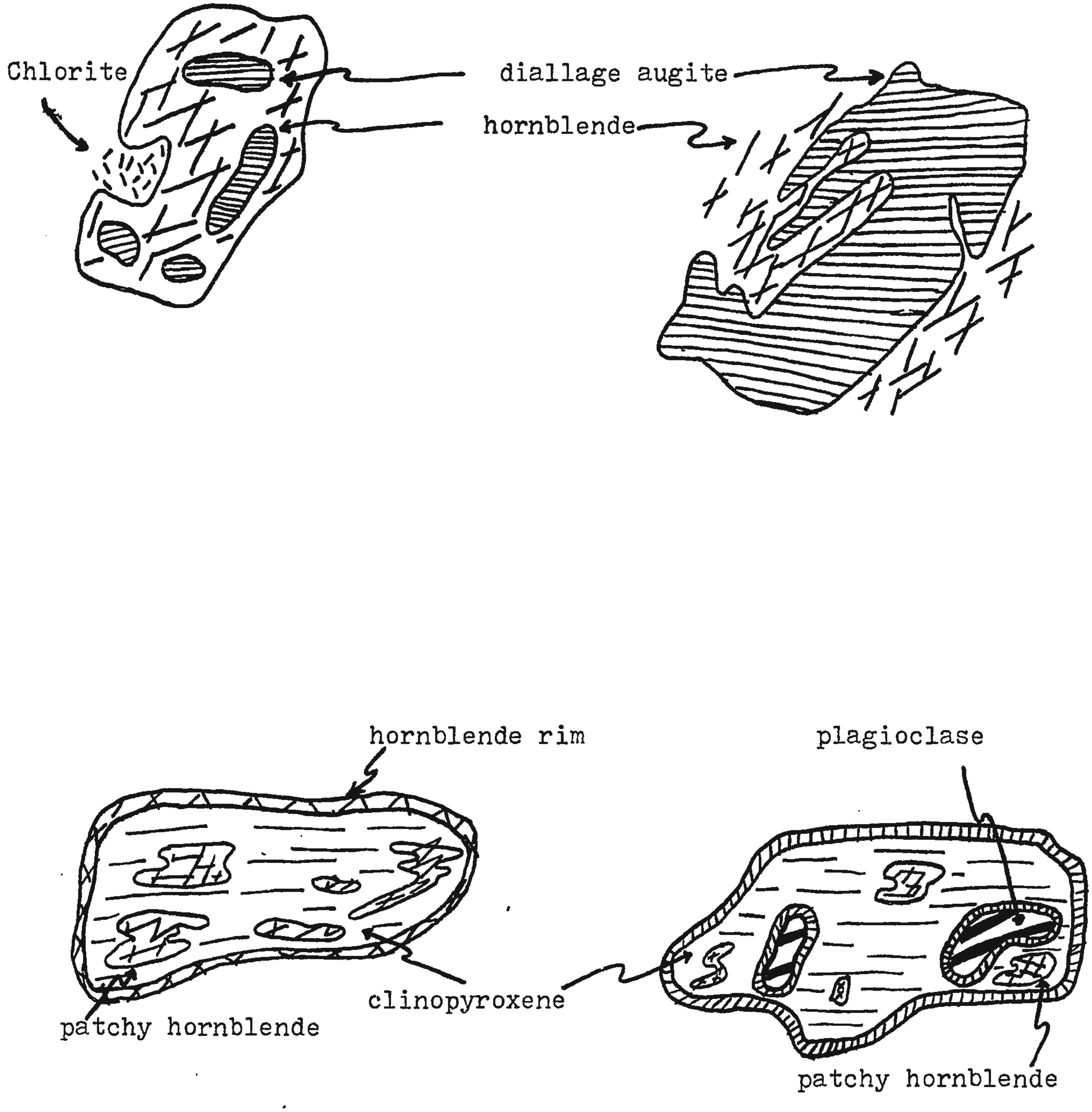
Many clinopyroxenes contain hornblende or actinolite rims and the interior of the crystal is altered or replaced by fine and coarse-grained blade-like actinolite (uralite). Relatively fresh unaltered clinopyroxenes contain deformed zones which have been uralitized, suggesting replacement along areas of weakness.

The following sketches display different types of alteration that affected the clinopyroxenes. In many cases the diallage parting is still preserved following the alteration of clinopyroxene to amphibole.



Mag: 80X

URALITE - Bladed actinolite replacing clinopyroxene. Original outline still preserved.



Magnification 80X

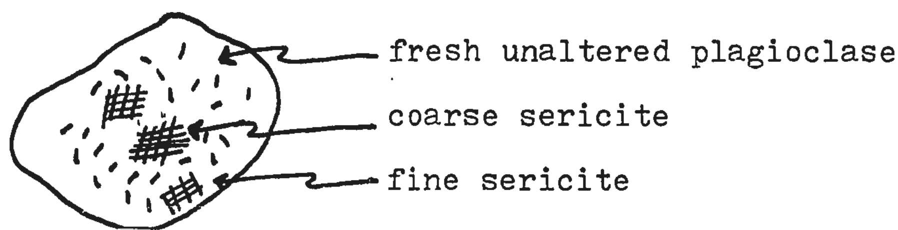
Replacement of Clinopyroxene by Hornblende in Gabbros.

Plagioclase

Generally the plagioclase crystals have been altered to a fine aggregate of sericite with local coarser portions and also to epidote and zoisite (saussuritization). Prehnite replacement is present. The smaller crystals of plagioclase appear to be the first ones to undergo sericitization. Locally sericitization appears to have proceeded inwards from the edges of the crystals.

All gradations in saussuritization are evident in the plagioclase crystals, as well as differences in coarseness of the epidote and zoisites, even within single host crystals.

Mag. 20X



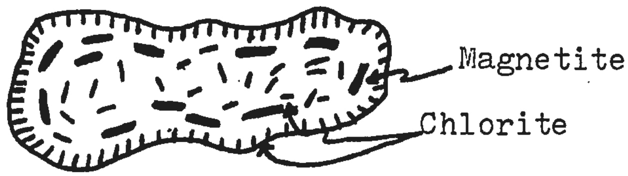
Locally small pockets between plagioclase crystals are filled with prehnite.

Accessory Minerals

Magnetite appears to be the result of exsolution due to the alteration of the clinopyroxenes. In such cases the magnetite is restricted to the cleavage planes of the crystal. Magnetite, where altered, is replaced by leucoxene and brown fibrous chlorite.

Chlorite pods are rimmed by minute crystals of magnetite, suggesting that the chlorite has almost completely replaced it. Most magnetite shows some embayment by chlorite.

Mag: 40X



Protomylonite, Protocataclasite, Flaser Gabbro

The gabbros of the Coastal Complex have undergone a flattening deformation and this is represented by a coarse fabric throughout most of their exposure. Locally the rocks are very highly deformed (O'Dwyer Mountain slice) and can be termed flaser gabbros or proto-mylonites.

Diallage parting in the clinopyroxenes and albite twinning in the plagioclases are bent and warped. The borders of many crystals are granulated to much finer-grained material. All clinopyroxenes are bordered by green hornblende and locally almost complete alteration has occurred. Where the clinopyroxenes in the flaser gabbro display pinch and swell features, actinolite has replaced the areas of constriction.

The plagioclases are mildly saussuritized and show a much higher degree of fracturing and granulatization than the clinopyroxenes. Sometimes large granulated areas are composed of only two or three small unfractured crystals while the host it highly granulated and much finer-grained. A common feature of the plagioclases is "comet-like" pressure shadows. Magnetite forms similar features and is present as long streaks altered to brown fibrous chlorite and outlining plagioclase and pyroxene grains.

Granodiorites

The granodiorites, along with the gabbros, form the major rock types in the thesis area. They are exposed in the Virgin Mountain, Parker Beach and Monkeyland slices.

Composition

The granodiorites are generally medium to coarse-grained, and are locally crushed and fragmented to a much finer grain size. Pink aplite dykes are common.

Almost all plagioclases are soda-rich (An_{10}-An_{30}) and normally euhedral. Twinning is common, although destroyed in the albitized portions, as is "ghost" oscillatory zoning. Fracturing and dislocation of twin planes is common.

The quartz crystals in the granodiorites are generally anhedral and the same size as the feldspars. Locally quartz is highly crushed and fractured and stressed quartz crystals are characterized by thin fractured zones. In thin section these small strings of intensely crushed quartz are viewed end-on and appear semi-circular. Lobate quartz grains are intergrown, and contact solution features are common.

Biotite and hornblende are the prominent ferromagnesian minerals and the rock should properly be termed as biotite-hornblende quartz-diorite. The biotite is sometimes green in color but iron-red biotite is predominant.

The major accessory minerals are magnetite, chlorite, and apatite. Magnetite, the only oxide, is generally euhedral, and contains numerous chlorite-filled embayments. It appears restricted to the chlorite with only minor amounts found outside this domain. Chlorite is sometimes present as pods within quartz grains and in this state, the quartz is fractured in a radiating manner, away from the chlorite. Apatite is relatively rare and restricted to extremely small crystals.

The feldspars are the only mineral constituents which seem to show any appreciable amount of alteration. The alteration is mainly saussuritization, reflected by fine and coarse-grained epidote and zoisite. The fine-grained alteration mask all primary features of the grains while the coarser aggregates of epidote and zoisite tend to follow along the cleavage planes of the original feldspar.

Amphibolitic Mylonites

The amphibolites are exposed along the northeastern portion of the O'Dwyer Mountain slice. The only other known occurrence of similar rocks in the thesis area is the inclusions within the base of the overlying Trumpet Cove mélange zone.

The amphibolites are fine to medium grained. The banding within these rocks is composed of crushed remnants of originally larger massive crystals or accumulations, and pinches out along strike.

Locally, especially near ultramafic bodies, amphibolites have undergone a period of folding. Folds are restricted to amplitudes of inches. Locally slump-type tectonic folding is well developed.

The folds most likely represent the products of intense load and directed pressures upon the gabbros and are often referred to as "protomylonites".

Composition

The protomylonites are primarily composed of hornblende and plagioclase. Other common minerals include carbonate, chlorite, sericite, epidote, zoisite, magnetite, garnet and apatite. Zoisite commonly displays bright "Berlin blue" birefringence colors and the carbonate is interpreted as being derived from the alteration of the plagioclases. These rocks contain no quartz and unaltered clinopyroxenes are very rare.

The fabric in the amphibolite is well-developed with the parallel alignment of hornblende crystals. The plagioclases locally display straight boundaries when in contact with the amphiboles. The feldspars are all fine-grained as a result of the stresses applied to the rock and most tend towards polygonal triple-point stability. Locally large "porphyroblasts" of plagioclase are present and display granulated borders and "shadow pressure growth" along the fabric.

Late zoisite veinlets cut across the amphibolite and in some sections zoisite appears to be the main groundmass alteration product.

Structure

The foliation in the protomylonites is the result of intense stresses which resulted in a crushing effect. Crystals have been stretched-out, locally several times their original lengths, and have also been intensely fragmented and broken. Locally small boundinage features have developed and have been augened by the amphiboles. Magnetite appears concentrated along thin seams, much more continuous than other mineral phases, suggesting a more mobile nature during deformation.

Where deformation has not progressed to its extremes, individual streaked out original grains are still visible within thin sections. These are characterized by a disk-shape with a thinner outer rim. Most of these zones are now composed of an accumulation of altered albite-rich plagioclase grains and overlapping zones are a common phenomenon.

Alteration

Alteration in the amphibolites is limited and simple. Most of the crystals are fresh and represent new recrystallized minerals. The plagioclases are slightly altered to accumulations of epidote and zoisite. Only locally are original clinopyroxenes present.and are invariably surrounded by a hornblende rim.

Ultramafics

Ultramafics are restricted to serpentinite mélange zones, principally the Trumpet Cove mélange zone, and a few minor intrusions in the O'Dwyer Mountain slice. Serpentinization has been very active in the ultramafic rocks and varying degrees of alteration from minor to complete have occurred. The serpentinization renders identification of original matrix material difficult, especially where grinding and granulatization of the rock has resulted in a decrease in grain size.

Most rock types fall within the range of the lertzolite wehrlite realm. Locally, rock compositions approaching dunite are present. Pyroxenites are abundant.

Most of the ultramafic rocks have undergone intense shearing or mylonitization, and could be classified as protomylonites (10-50% matrix). The mylonitization is well displayed on the borders of some of the ultramafic intrusions and locally affects entire intrusions. Gradations from an interior gravity banded ultramafic to border-phase metamorphic banding is well displayed in the ultramafics of the O'Dwyer Mountain slice.

Straining of individual grains is reflected by curved and warped diallage partings and undulatory extinction. Clinopyroxene crystals commonly display crushed, granulated borders and pressure shadows.

Thin continuous bands of chromite are present in the mylonitized ultramafics. In most cases, the mylonitic banding is parallel to the primary banding.

Volcanics

Volcanic rocks of the highest structural slices are primarily composed of interlayered basalts, basaltic andesites and mafic pyroclastics. Alteration has been so complete that rock identification was based primarily on the presence or absence of olivine crystals, and trachytic or andesitic textures.

The most common megascopic structures of the volcanic rocks are pillow features. Individual pillows attain diameters of 5-6 feet. Most of the flow rocks are either massive fine-grained, porphyritic, amygdaloidal and amygdaloidal porphyritic. The mafic pyroclastics contain large amounts of glass.

The pyroclastics are very coarse and can be classified as lithic tuffs-lapilli tuffs (2mms - 64 mms.). Rock fragments and bombs composing the pyroclastic material are generally basaltic in composition. Most fragments contain abundant olivine crystals while the more massive flows are more silicic in composition. Intergranular texture predominates in the flows, however, locally some volcanics exhibit conglomerative accumulations of clinopyroxenes.

Where volcanic flows are relatively fresh they are composed of equal amounts of augite and andesine-labradorite. Olivine, sphene, magnetite, and pyrite are also present. The lath-shaped plagioclases are often ophitically surrounded by augite but generally an intergranular texture predominates.

Many volcanic flows are vesicular, with the vesicles usually occupied by secondary calcite or chlorite. The volcanic rocks commonly display an enrichment in iron and glass content on the borders of the vesicules, suggestive of rapid cooling. Vesicles are commonly "tad-pole"-like or stretched indicating flowage in the partly consolidated-partly molten flow.

All volcanic rocks are altered, the matrix intensely, so that differences between andesites and basalts, based on quartz content in the groundmass and plagioclase composition is difficult. Saussuritization and chloritization are common alteration phenomena as is prehnitization.

Sediments

As a consequence of the size of the area underlain by sediments, a considerable number of different lithologies are present. No attempt is made to describe each unit as it is encountered, but some of the more common lithologies are described.

The sediments are primarily composed of arkoses, conglomerates, grits, greywackes, impure sandstones, quartz arenites, dark, red and green argillaceous and micaceous shales, as well as dark, fine-grained limestones, limestone breccias and dark limy shales.

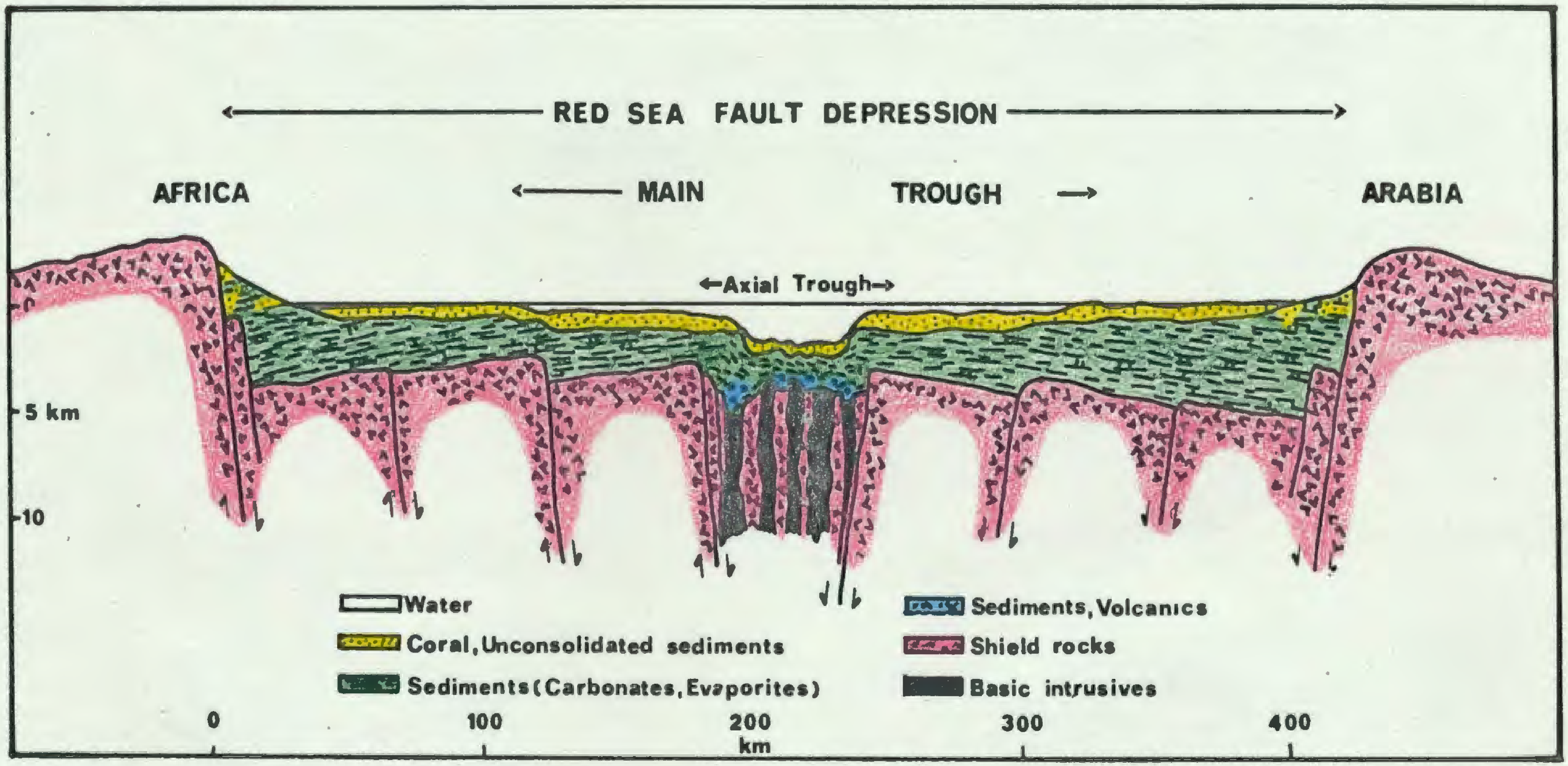
By far the most abundant rock types in the eastern portion of the thesis area are grits, arkoses, conglomerates, and shales of the Blow Me Down Brook Formation (Lilly, 1967). They are best exposed on Seal and Governor's Islands.

Composition

As a generality, the sediments are characterized by the absence or near absence of plagioclase clasts. Some units, however, exhibit predominance of plagioclase over alkali feldspar. The fragments are dominantly unsorted and sub-angular. Usually the matrix is the same composition as the clasts, cemented by carbonate. The clasts are composed of clear, undulose quartz, patch perthites, quartzite, microcline, muscovite, biotite, calcite, magnetite, pyrite, microgranophyric granites, greywackes, shale, glauconite, garnet, apatite and sphene. These suggest a granitic source area. The matrix is usually a "dirty" finer-grained representation of the larger clasts. Recrystallization of the carbonate matrix, in places, has resulted in large sparite crystals erratically distributed throughout the rock.

The western portion of the thesis area is characterized by quartz-rich sediments. Locally quartz pebble percentage nears 98% and blue quartz is common. The rocks are primarily quartz arenites although grits with large amounts of non-quartz clasts are also found. Sorting and rounding are moderate. The common grain size range is from sandstone to grits (1/16 mm - 2½ mms). The quartz arenites average greater than 90% quartz fragments with the remaining 10% being composed of fine-grain quartzite and felsite fragments. A small percentage of the clasts are composed of sphene, muscovite, plagioclase, calcite and pyrite. These rocks contain no appreciable matrix. When present, it is composed of light brown hematite-stained micaceous material. Conglomeratic facies are not very common.

These rocks suggest an active beach environment with sporadic sea-fluctuations resulting in shale and grit deposition.



Structural section of the northern part of the Red Sea inferred from geophysical data (from Drake and Girdler 1964)

FIG 5

CHAPTER VI

INTERPRETATION AND PROVENANCE OF TRANSPORTED SLICES IN THESIS AREA

Sedimentary Slices: Humber Arm Group

The Humber Arm Group has been described and interpreted by Stevens (1965, 1970) and summarized by Williams (1971). Stevens (1970) has interpreted the sediments as representing continental rise and continental terrace wedge deposits which developed east of the early Paleozoic North American continent (Rodgers, 1968). The lowest members (Summerside, Irishtown, and Maiden Point) were derived from the Canadian Shield to the west, as suggested by the presence of blue quartz and other plutonic-derived clasts. Serpentinite fragments, pyroxene crystals, and chromite grains are present in the top members of the Humber Arm Group (Blow Me Down Brook, upper Cow Head, upper Table Head), and were derived from the east. Williams (1971) suggests two possible sources for this mafic detritus:

a) Mafic-ultramafic complexes forming part of the Fleur de Lys metamorphic terrane (Kennedy and Philips, 1971).

b) The ophiolite complexes forming the Bay of Islands Complex (Williams, in press).

Williams (1971) suggests the Bay of Islands Complex to be the more likely source, due to its greater areal extent and also because the Bay of Islands Complex is interpreted to have been moving westwards during the deposition of the upper Humber Arm Group. It thus could continuously supply detritus to the depositional basins to the west.

The lowest unit, the Humber Arm Group, tectonically overlies lower Middle Ordovician limestones of the Table Head formation. The neoautochthonous upper Middle Ordovician Long Point formation, at Port au Port, overlies the Humber Arm Group, thus substantially reducing the time span for the klippe emplacement. Rodgers and Neale (1963) have postulated gravity as the transport mechanism for the Humber Arm Group. Such a mechanism prerequires uplift in the source area. During Ordovician times, rocks similar to those of the Humber Arm Group may have been only 10 to 20 miles east of the present position of the Humber Arm Klippe (Rodgers and Neale, 1963).

<u>Igneous Slices: Coastal Complex</u>

The Coastal Complex shares significant similarities and exhibits fundamental differences with the nearby Bay of Islands Complex. The latter consists of a typical ophiolitic sequence of rock units, and it has been interpreted by all recent workers (Dewey and Bird, 1970; Church and Stevens, 1970; Williams, in press) as early Paleozoic oceanic crust. Mafic volcanic rocks and dykes of the Coastal Complex are similar to volcanics and sheeted dykes of the Bay of Islands Complex. In addition, both display the same type of gas brecciation or fluidization so characteristic of the transported rocks in western Newfoundland.

Ophiolites are believed to be produced primarily at oceanic rifts or ridges with the production of new crust limited to a narrow axial zone. The sheeted dyke horizon, characteristic of ophiolitic sequences, and present in the Bay of Islands Complex represents the spreading or separation of the oceanic lithosphere and the subsequent addition of new crustal material.

The volcanic rocks and dykes of the Coastal Complex are identical to and equated with the volcanics and sheeted dykes of the ophiolites, suggesting that they were deposited during the same spreading episode which produced the Bay of Islands ophiolites.

The gabbros, quartz diorites and granodiorites of the Coastal Complex are tectonically deformed, locally exhibitng two separate tectonic fabrics. The volcanic rocks and associated feeder dykes surrounding and intruding the gabbros and granodiorites are not tectonically deformed, and hence are younger.

Since the volcanic rocks and dykes are interpreted as being produced in the oceanic rift environment responsible for the production of the Bay of Islands Complex, the older, more deformed gabbros and granodiorites must have been incorporated within this environment (possibly the narrow axial valley) during the formation of the ophiolite sequences. The gabbros and granodiorites, therefore, represent rafts of older crustal material which became "caught up" in an accreting plate environment.

In the Bay of Islands area, the Humber Arm Group, the Bay of Islands Complex, the Coastal Complex, the Skinner Cove slice group and the Trout River slice group (Williams, in press) are all interpreted as being transported from the east (Rodgers and Neale, 1963; Williams, in press). Thus, areas in the central

Mobile Belt exhibiting similar geologic relationships and rock types to those of the Bay of Islands must be considered as possible source areas. The Twillingate granite in eastern Notre Dame Bay exhibits a similar history to that of the Coastal Complex (Williams, Malpas and Comeau, 1972; Williams and Malpas, 1972; Williams, Kennedy and Neale, 1972). The Twillingate granite is cut by tectonically undeformed sheeted dykes that are interpreted to feed nearby relatively undeformed Ordovician volcanics (Lushes Bight Group). The Twillingate granite is locally highly deformed and exhibits strong tectonic fabric (Williams, Malpas and Comeau, 1972; Williams and Malpas, 1972; Payne, pers. comm.). It is therefore much older than surrounding Lushes Bight volcanics and is viewed as an older crustal remnant, similar to the Coastal Complex.

The Coastal Complex forms the fourth highest structural slice group in the transported Bay of Islands region (Williams, in press).

The igneous slices in the Coastal Complex are all underlain by mélange zones except for the sharp thrust separating the Lark Harbour slice from the overlying O'Dwyer Mountain slice. The lithologies displayed in the mélange zones are suggestive of an erosional origin. Most fragments incorporated within the mélange zones can be directly related to similar lithologies in the overlying and underlying slices, but some fragments are exotic. This fact implies that the mélange zones may be in part the product of denudation of the moving slices, as well as the breaking and fracturing of rock units immediately above and below the contact. The O'Dwyer Mountain-Lark Harbour slice contact is definitely a thrust contact.

Detachment of the igneous rock slices from the source area must have been accomplished by thrusting. Later movement may have been in part gravitational with the accompanying erosion of the igneous slices supplying debris which facilitated movement.

If one accepts Wilson's (1966) theory of a proto-Atlantic ocean, then a needed prerequisite is the formation of an initial break or rift where the formation of oceanic crust can commence. Gradual expansion and growth of the oceanic environment causes the "drifting apart" of the original rifted blocks.

The initial rift would probably not be a single break, but a series of block faults or graben-shaped structures such as is envisaged for the structure of the present-day Red Sea (Laughton, 1966; Drake and Girdler, 1964). (See Fig. 5).

Intrusion of oceanic type lithologies, derived from mantle material would occur over a fairly wide area, although primarily restricted to the axial valley, and "inclusions" of rifted rocks would most likely be incorporated. Due to differences in specific gravity, at least some of the debris, would not be assimilated within the upper mantle and would remain "afloat" in the simatic environment.

If, for any reason, ophiolite production ceases, the inclusions would essentially become frozen in place. Williams and Malpas (1972) suggest that the presence of older deformed rocks such as the Coastal Complex, within an ophiolite terrane, implies a small marginal basin origin (Bird and Dewey, 1971) where the destruction of incorporated material is minimal.

If the western Newfoundland ophiolites are representative remnants of ocean crust and all indications point to such, then the higher portions of the oceanic environment, that is, the sheeted dykes and pillow lavas, must have intruded and surrounded the gabbros and granodiorites of the Coastal Complex, while they were in this same oceanic environment. The gabbros and granodiorites of the Coastal Complex are suggestive of continental rather than oceanic material, and they may represent rocks which were basement to the Fleur de Lys group (Kennedy & Phillips, 1971).

Further evidence for rifting and incorporation of older material may be present on North Arm Mountain (Malpas, pers. comm.). A large anomalous amphibolitic gabbro "inclusion", identical to the gabbros of the Coastal Complex, is present as a screen within the diabase dyke breccia zone of North Arm Mountain. This "xenolith" could represent original pre-rift rock which has reached the lower parts of the sheeted dyke-gabbro complex.

CHAPTER VII

CONCLUSIONS

All of the rocks in the area are transported. Early Paleozoic sedimentary rocks of the Humber Arm Group form the lowest structural slices and are overlain by higher structural slices of igneous and metamorphic rocks, of the Coastal Complex. Transported rocks of the Coastal Complex comprise distinct slices, as follows:

(1) Virgin Mountain slice
(2) Lark Harbour slice
(3) Bottle Cove slice
(4) Parker Beach slice
(5) O'Dwyer Mountain slice
(6) Monkeyland slice

The Virgin Mountain, Lark Harbour, Bottle Cove and Parker Beach slices lie directly upon sedimentary rocks of the Humber Arm Group. The O'Dwyer Mountain and Monkeyland slices partly overlap and overlie one another.

Most slices trend northeast parallel to formational boundaries and tectonic fabrics within the slices. Three slices, the Monkeyland, O'Dwyer Mountain and Lark Harbour slices trend northwesterly.

The attitude of formation boundaries in adjacent slices indicate breakup and disorientation of the slices during transport.

All tectonic contacts between slices are marked by mélange zones composed of both sedimentary and igneous inclusions derived from overlying and underlying slices, except for the contact between the Lark Harbour and overlying O'Dwyer Mountain slices, which is a sharp thrust contact.

Dykes and volcanics of the Coastal Complex are similar to and equated with dykes and volcanics of the Bay of Islands Complex. The Bay of Islands Complex is recognized as a typical ophiolite succession (Church & Stevens, 1971; Dewey & Bird, 1971; Williams, in press). The ophiolites are regarded as representing an ocean-spreading episode, therefore, the dykes and volcanics of the Coastal Complex are also regarded as being the product of this same spreading episode.

Gabbros and granodiorites of the Coastal Complex are older than the volcanics and were deformed prior to this spreading episode. They represent pre-existing crustal material probably of Grenvillian age which became incorporated with the oceanic rift environment.

Definition of the Coastal Complex and its separation from the Bay of Islands Complex removes major obstacles in the interpretation of both areas.

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PLATE I

a: Branching fluidized veinlets in quartz diorite; Little Neck.

b: Diabase dyke irregularly cutting quartz diorite at White Point. Note brecciated nature of quartz diorite (at arrow).

a: Tectonically banded ultramafics, near Grassy Gulch.

b: Augened ultramafic inclusions, Grassy Gulch. Note folding in inclusion on left.

PLATE III

a,b: Fluidized volcanic zone, separating brecciated volcanics on the right from brecciated gabbros on the left. Prehnitization pronounced in fluidized zone, resulting in lighter color. ~~Bottle~~ Bateau Cove.

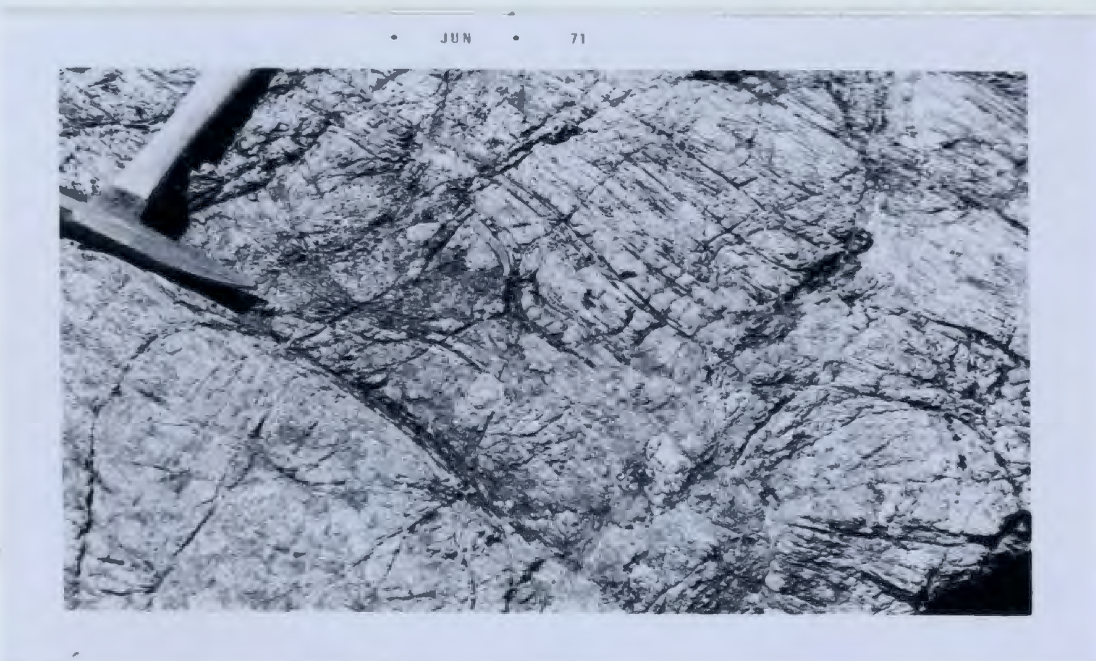
PLATE IV

a: Grassy Gulch fault; separating granodiorite on the left from amphibolitic mylonites on the right.

b. Trumpet Cove Mélange zone overlain by the Monkeyland slice. View north.

PLATE V

a: Typical amphibolitic mylonite. Grassy Gulch.



b: Two mylonitic inclusions augened by the host mylonitic fabric. 1400 Brook.

PLATE VI

a,b: Primary banding in ultramafic boulders in the Trumpet Cove mélange.

PLATE VII

a: Rubbly gabbro of the Virgin Mountain slice overlying a thin serpentinite zone at Fall Brook.

b: Serpentinite and diorite boulders forming the Trumpet Cove mélange zone. Trumpet Cove.

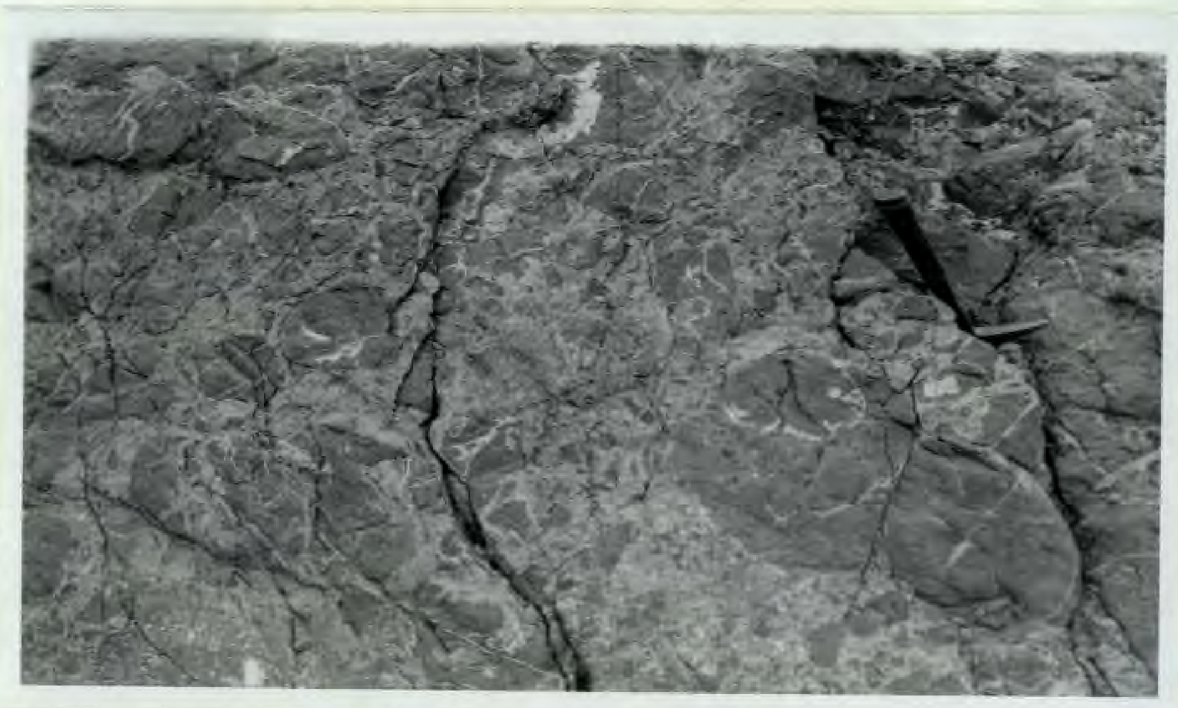
PLATE VIII

a: Quartz-rich sandstones and shales of the Bear Cove sediments at the mouth of Wild Cove Brook.

b. Limestone breccia from White Rocks. Oolite bed near the base.

PLATE IX

a: Pyroclastics at ~~Bottle~~ Cove
Batteau



Batteau
b: Pyroclastics at ~~Bottle~~ Cove. Prehnite and calcite abundant yielding lighter-color matrix.

PLATE X

a: High angle contact between volcanics on left and gabbros on right. Fluidized zone intervenes. In background, two conformable flows are present.

b. Gabbros of the O'Dwyer Mountain slice structurally above pillow lavas of the Lark Harbour slice.

PLATE XI

a: Raised shorelines at ~~Bottle~~ Cove.

Bottom

b: Pillow-basalts at base of ~~Bottle~~ Cove slice. Bottle Cove.

Bottom

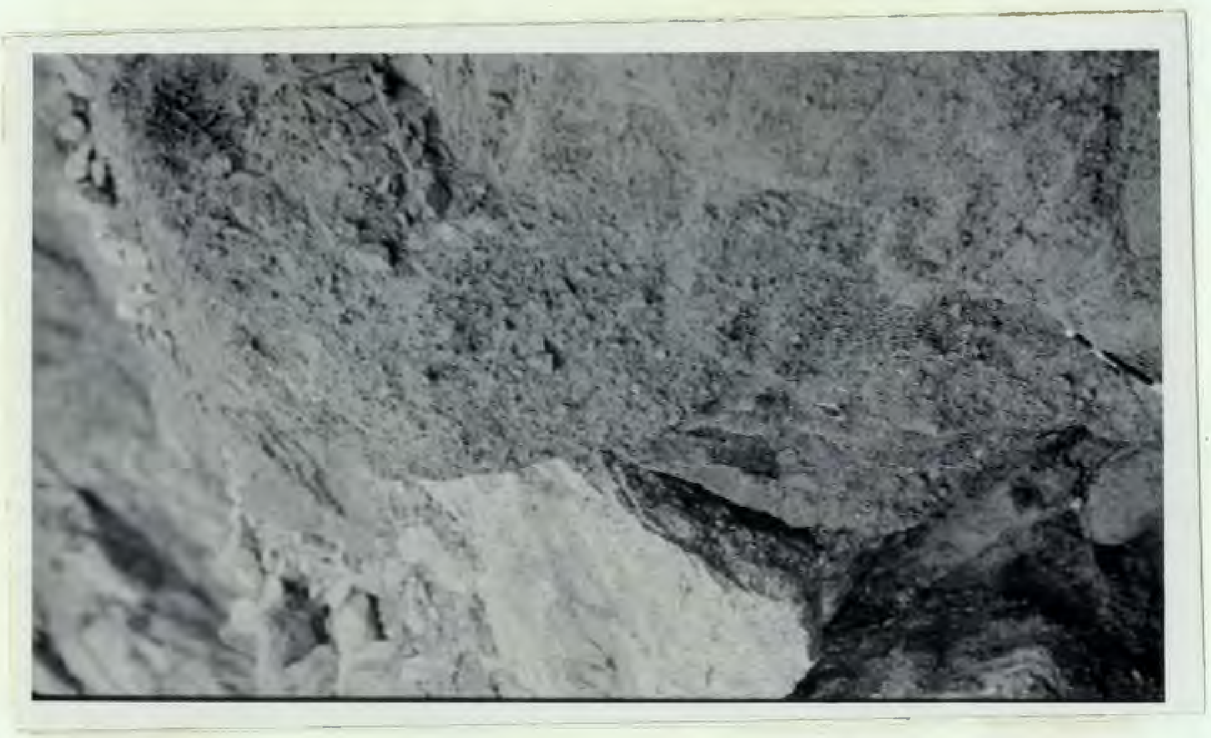
PLATE XII

a: Dyke swarms cutting granodiorite at South Head. Granodiorit
is surrounded by brecciated volcanics and dyke rock.

b: Base of Parker Beach slice. Shales can be seen protruding
from under the granodiorite scree.

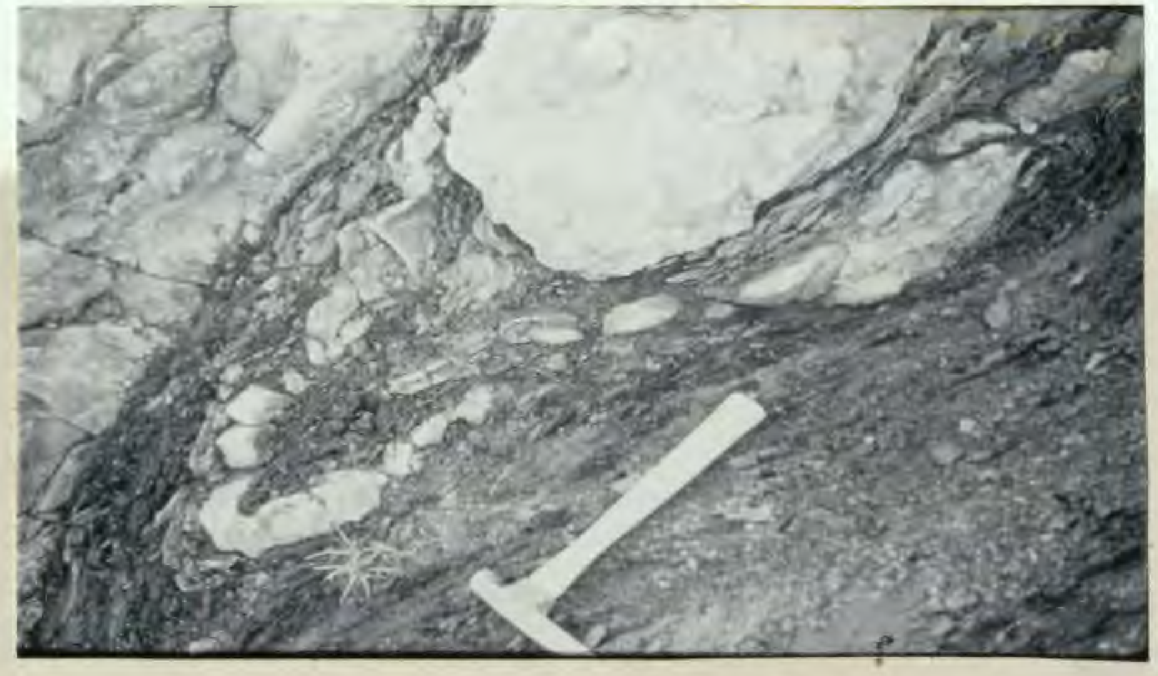
PLATE XIII

a: Banded gabbros at Bear Head.



b. Brecciated diabase dyke of the Monkeyland slice. Trumpet Cove.

PLATE XIV



a: Limestone boulders and lenses within a shale matrix; forming the mélange at Lark Harbour. Tight folding is common.

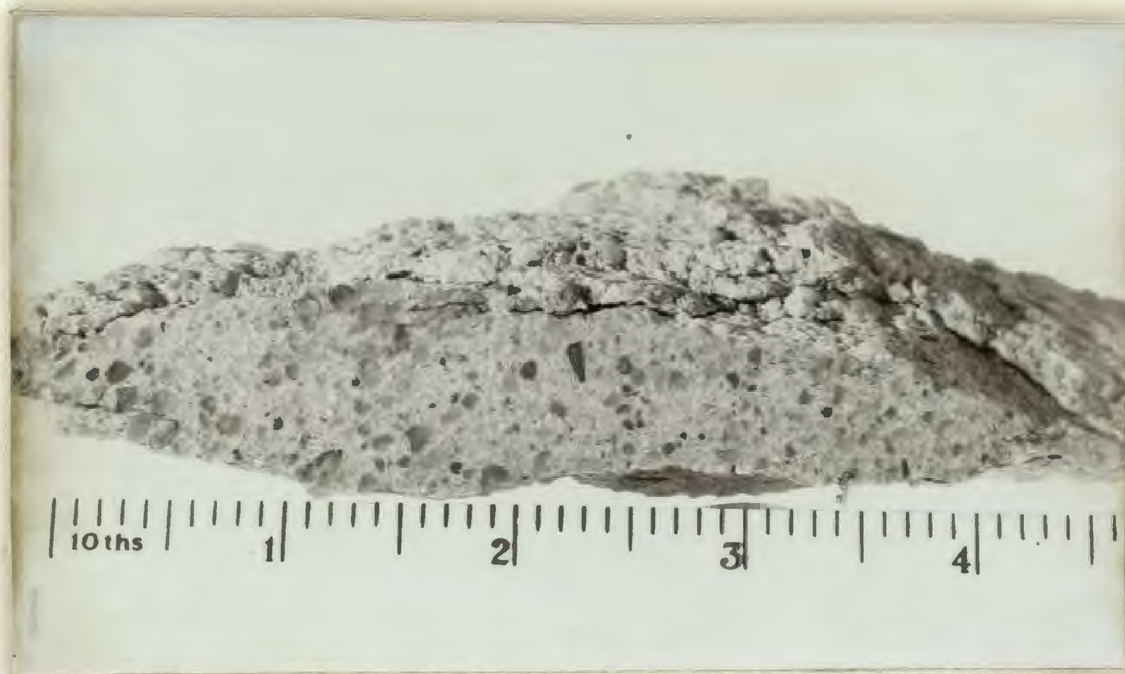
b: Basaltic mélange at Lark Harbour.

PLATE XV

a: Gritty conglomerate of the Blow Me Down Brook Formation. York Harbour.

b: Enlargment - note pitting and ultramafic frag. (arrow).

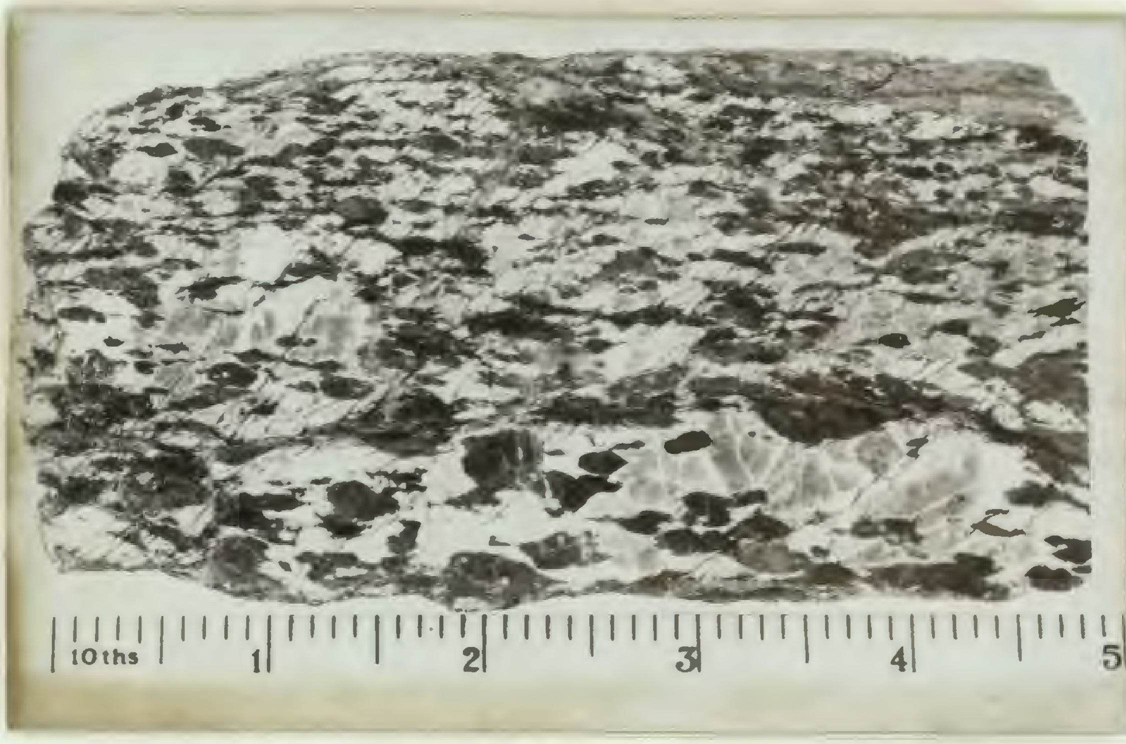
PLATE XVI



a: Quartz arenites from Bear Cove.

b: Enlargment - streaks were caused by cutting of sample.

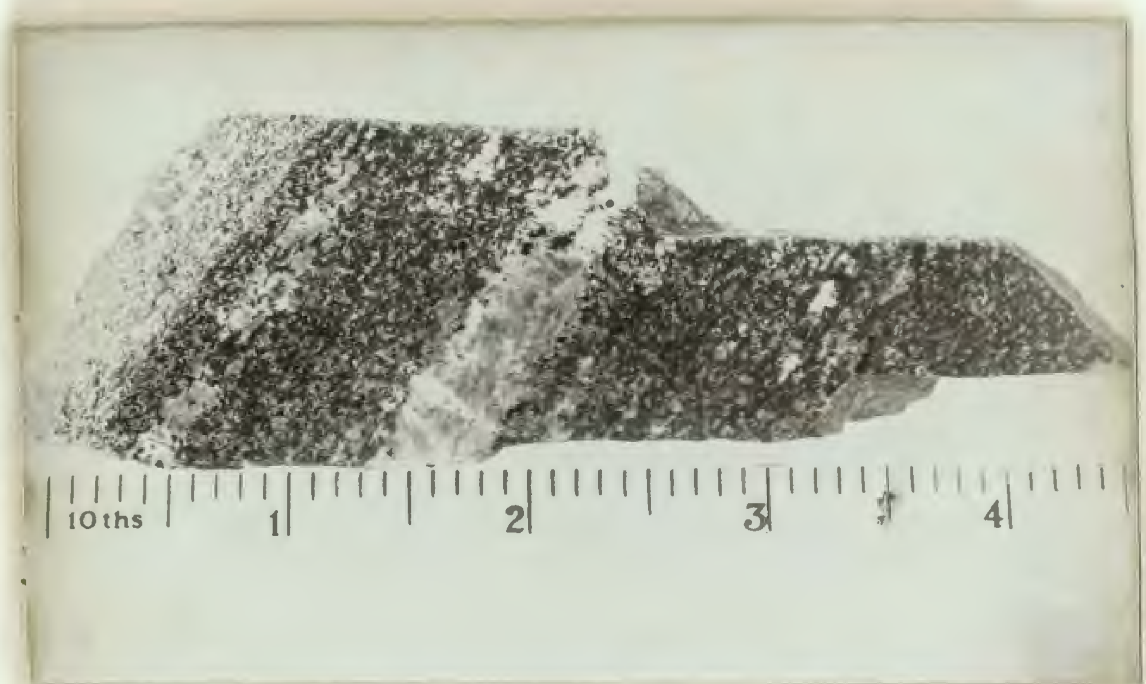
PLATE XVII



a: "Flaser gabbro" - Strong fabric in gabbro; elongation and augens of crystals - O'Dwyer Mountain slice. Note fractures in rock.

b: Enlargement.

PLATE XVIII



a: Banded gabbro with tectonic fabric parallel to banding.

b: Enlargment.

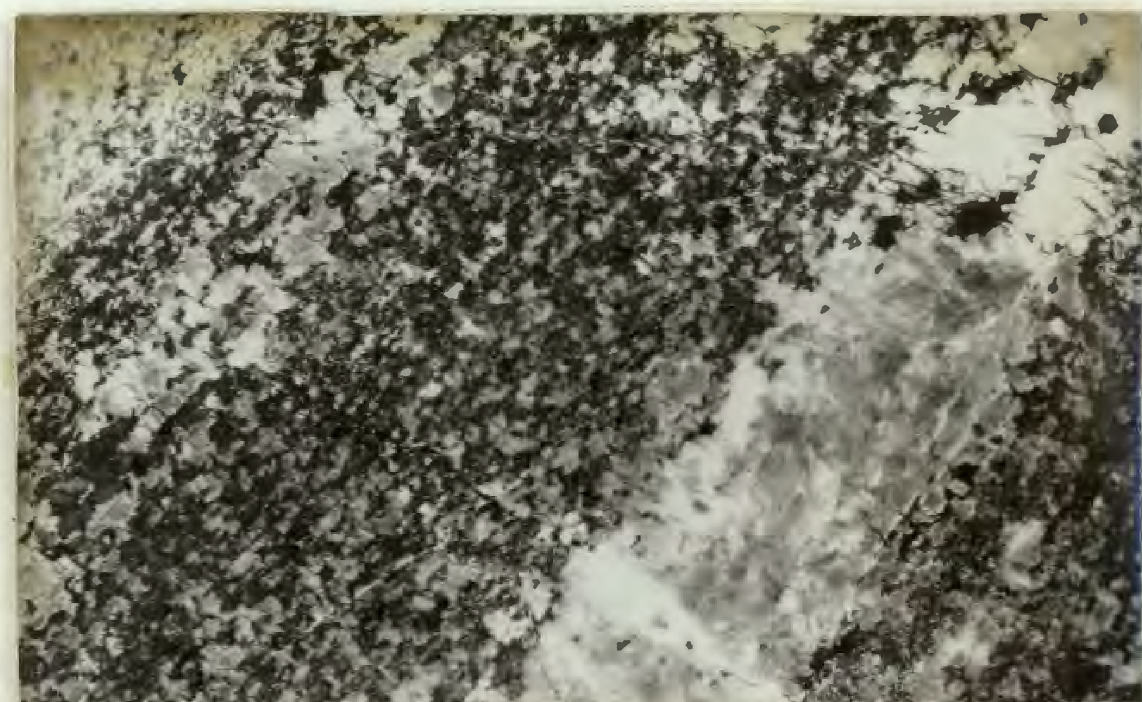
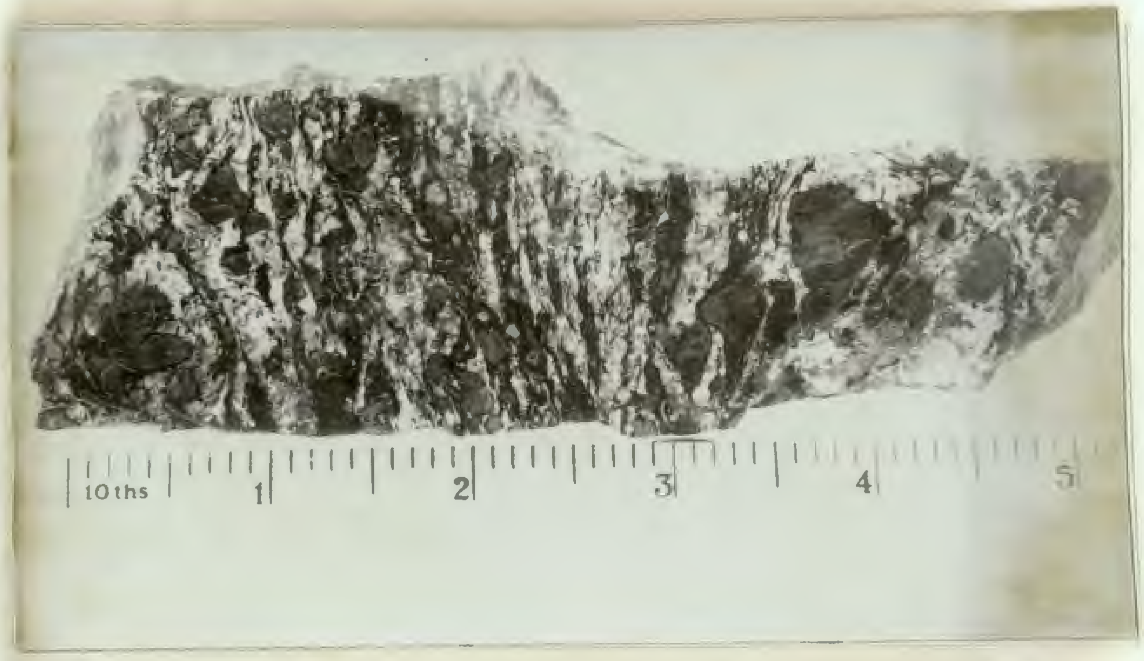


PLATE XIX

a: Amphibolitic mylonite from O'Dwyer Mountain slice. Note small fold in lower right corner.

b: Enlargement. Note discontinuity of light streaks and semi-circular blebs of feldspar.

PLATE XX



a: Gabbroic intrusions on O'Dwyer Mountain slice, displaying a good tectonic fabric.

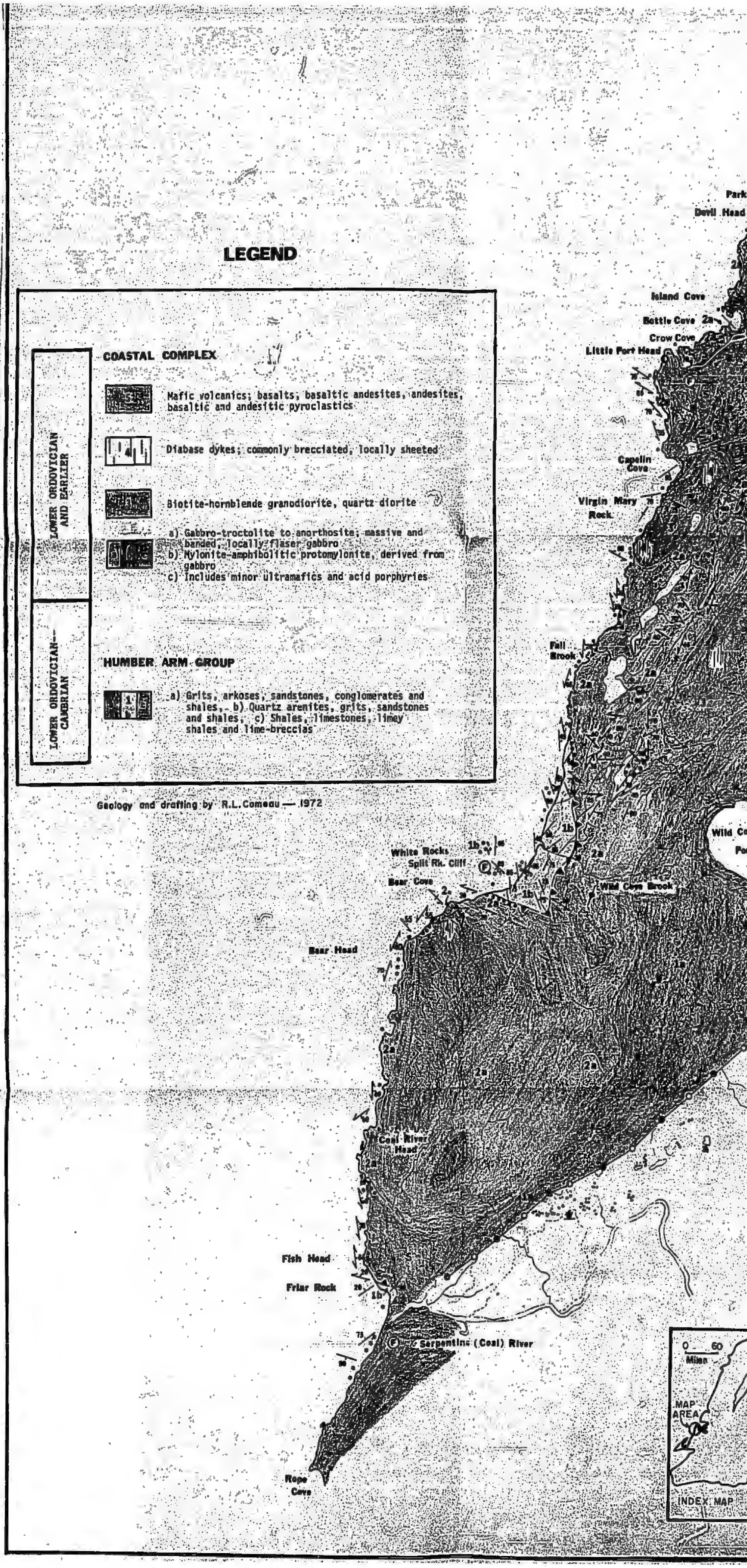
b: Enlargment. Note augens and stretched pyroxenes.

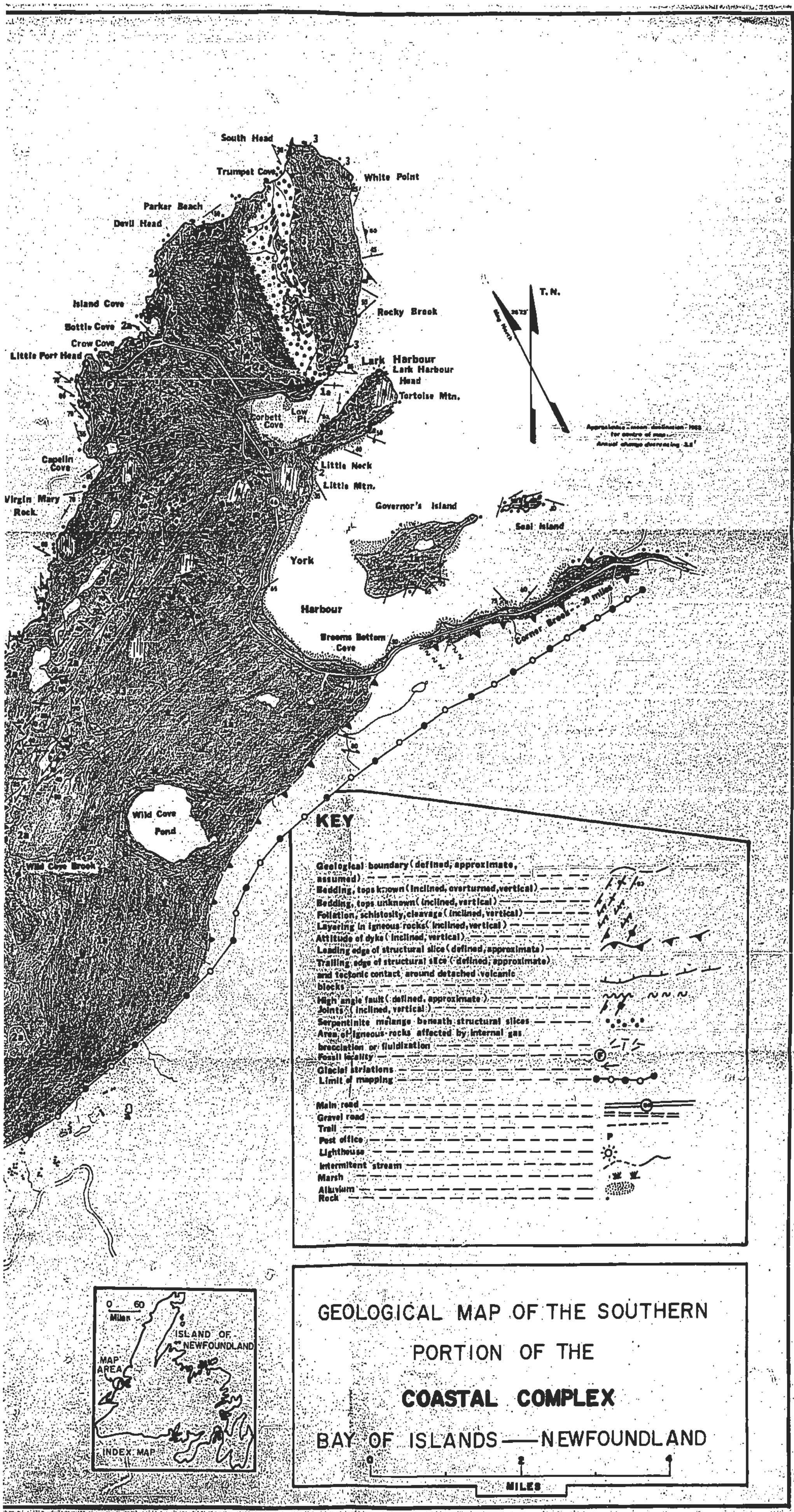
PLATE XXI

a: Pyroclastics from ~~Bottle~~ Battean Cove.

b: Enlargement.

1 of 1


LEGEND
COASTAL COMPLEX
LOWER ORDOVICIAN AND EARLIER
Mafic volcanics; basalts, basaltic andesites, andesites, basaltic and andesitic pyroclastics
Diabase dykes; commonly brecciated, locally sheeted
Biotite-hornblende granodiorite, quartz diorite
a) Gabbro-troctolite to anorthosite; massive and banded, locally flaser gabbro
b) Mylonite-amphibolitic protomylonite, derived from gabbro
c) Includes minor ultramafics and acid porphyries
HUMBER ARM GROUP
LOWER ORDOVICIAN-CAMBRIAN
a) Grits, arkoses, sandstones, conglomerates and shales, b) Quartz arenites, grits, sandstones and shales, c) Shales, limestones, limey shales and lime-breccias
Geology and drafting by R.L.Comeau — 1972
Parker
Devil Head
Island Cove
Bottle Cove
Crow Cove
Little Port Head
Capelin Cove
Virgin Mary Rock
Fall Brook
Wild Cove
White Rocks
Split Rk. Cliff
Bear Cove
Wild Cove Brook
Bear Head
Coal River Head
Fish Head
Friar Rock
Serpentine (Coal) River
Rope Cove
Miles
MAP AREA
INDEX MAP


South Head
Trumpet Cove
White Point
Parker Beach
Devil Head
Island Cove
Bottle Cove
Crow Cove
Little Port Head
Rocky Brook
Lark Harbour
Lark Harbour Head
Tortoise Mtn.
Corbett Cove
Low Pt.
T.N.
Capelin Cove
Little Neck
Little Mtn.
Virgin Mary Rock
Governor's Island
Seal Island
York
Harbour
Brooms Bottom Cove
Corner Brook
Wild Cove Pond
Wild Cove Brook
KEY
Geological boundary (defined, approximate, assumed)
Bedding, tops known (inclined, overturned, vertical)
Bedding, tops unknown (inclined, vertical)
Foliation, schistosity, cleavage (inclined, vertical)
Layering in igneous rocks (inclined, vertical)
Attitude of dyke (inclined, vertical)
Leading edge of structural slice (defined, approximate)
Trailing edge of structural slice (defined, approximate) and tectonic contact around detached volcanic blocks
High angle fault (defined, approximate)
Joints (inclined, vertical)
Serpentinite mélange beneath structural slices
Area of igneous rocks affected by internal gas brecciation or fluidization
Fossil locality
Glacial striations
Limit of mapping
Main road
Gravel road
Trail
Post office
Lighthouse
Intermittent stream
Marsh
Alluvium
Rock
0 60
Miles
ISLAND OF NEWFOUNDLAND
MAP AREA
INDEX MAP
GEOLOGICAL MAP OF THE SOUTHERN PORTION OF THE
COASTAL COMPLEX
BAY OF ISLANDS — NEWFOUNDLAND
0 2 4
MILES