THE VOLCANIC STRATIGRAPHY AND METALLOGENY OF NOTRE DAME BAY, NEWFOUNDLAND

PAUL L. DEAN

Thesis

THE VOLCANIC STRATIGRAPHY AND METALLOGENY OF NOTRE DAME BAY, NEWFOUNDLAND

A Thesis

Presented to

The Department of Geology

Memorial University of Newfoundland

In Partial Fulfillment

of the Requirements for the Degree

MASTER OF SCIENCE

---

by

Paul L. Dean

March, 1978

ABSTRACT

The geology of Notre Dame Bay can be considered to be essentially an Ordovician-Silurian volcanic island arc complex built upon Cambro-Ordovician oceanic crust and intruded by a variety of igneous rocks ranging in age from Ordovician to Jurassic. The stratigraphic evolution of this island arc complex may be divided into two distinct phases: (1) an Early to Middle Ordovician (pre-Caradocian) phase of extensive submarine volcanism recognizable throughout all of Notre Dame Bay, and (2) a Late Ordovician-Early Silurian (post-Caradocian) phase characterized by contrasting volcanic styles in three different belts. The two phases are separated in the southeastern portion of Notre Dame Bay by an extensive Caradocian argillite and overlying flysch sediments. In the northwestern portion, the post-Caradocian volcanic sequences rest uncomformably either on the Cambro-Ordovician oceanic crust or on the pre-Caradocian volcanic sequences. Intrusive igneous activity accompanied the separate phases of oceanic crust and island arc evolution but was most intense in the Late Devonian during the latest stages of the Acadian Orogeny.

The greatest percentage of insular Newfoundland's mineral wealth has come from the base metal sulphide deposits of Central Newfoundland, particularly from the copper deposits of Notre Dame Bay. Most of these base metal sulphide deposits are volcanogenic and stratabound and as such are integral elements of the stratigraphic sequence in which they occur. The Cambro-Ordovician ophiolitic rocks contain Cu-Zn massive sulphide deposits in mafic tholeiitic volcanic rocks. Mineral deposits of the pre-Caradocian island arc volcanic sequences are typically Cu-Zn (± Au)

massive sulphide deposits associated with felsic volcanism. Volcanogenic massive sulphide deposits in the Post-Caradocian volcanic rocks occur only in one belt, the Roberts Arm Belt of dominantly subaqueous volcanics. These are generally more polymetallic (Pb-Zn-Cu-Ag-Au-Ba) and are associated with areas of felsic volcanics in the upper part of the volcanic sequence. Several small vein-type deposits are associated with high level phases of igneous intrusions.

ADKNOWLEDGEMENTS

This study was supported by the Canadian Department of Energy, Mines and Resources Research Agreement 1135-D13-4-18/72 with Dr. D.F. Strong of Memorial University. The continuous support and inspiration by Dr. Strong are most gratefully acknowledged. Numerous discussions with R.K. Stevens, H.R. Peters, H. Williams, S. Swinden and J.P. Hibbard of Memorial University and with B.F. Kean of the Newfoundland and Labrador Department of Mines and Energy added much to the present concepts of Notre Dame Bay geology.

A special thanks to Noranda Exploration Company who permitted the free use of geological maps in the Notre Dame Bay area.

Initial drafting of the accompanying maps was done by Ken Andrews and supported by the Newfoundland and Labrador Department of Mines and Energy. Ken Byrne drafted the final version of the regional geological compilation map and Judy Dawe typed the final manuscript.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

1. INTRODUCTION

1.1. Location and Access

The area covered by the maps of this study lies north of the 49th parallel of latitude between 54° 00' and 56° 31' west longitude and is bounded to the north by the coastline of Notre Dame Bay and its numerous islands (Fig. 1.1.).

The Trans-Canada Highway, Route No. 1, crosses the south-western and south-central parts of the area. Various branch roads extend northward from the Trans-Canada Highway to reach the coast, peninsulas and islands of Notre Dame Bay. Regular ferry service is maintained between Long Island, Little Bay Island and St. Patricks in Green Bay; between Fogo Island and Carmanville on Hamilton Sound; and between Change Islands and Cobbs Arm on New World Island. All communities in the area are linked to the Newfoundland road system. The uninhabited areas of the coast and uninhabited islands are accessible by small boat from the active communities.

The interior portions of the area are generally accessible from the numerous logging roads which transect north central Newfoundland. Most rivers, except the Gander, are not navigable for long distances in canoe; however, the larger lakes, which are generally accessible by road, provide access by boat to large areas of the country.

1.2. Physiography

The major portion of the area comprises the northern part of the Newfoundland Central Lowlands, except the westernmost part which

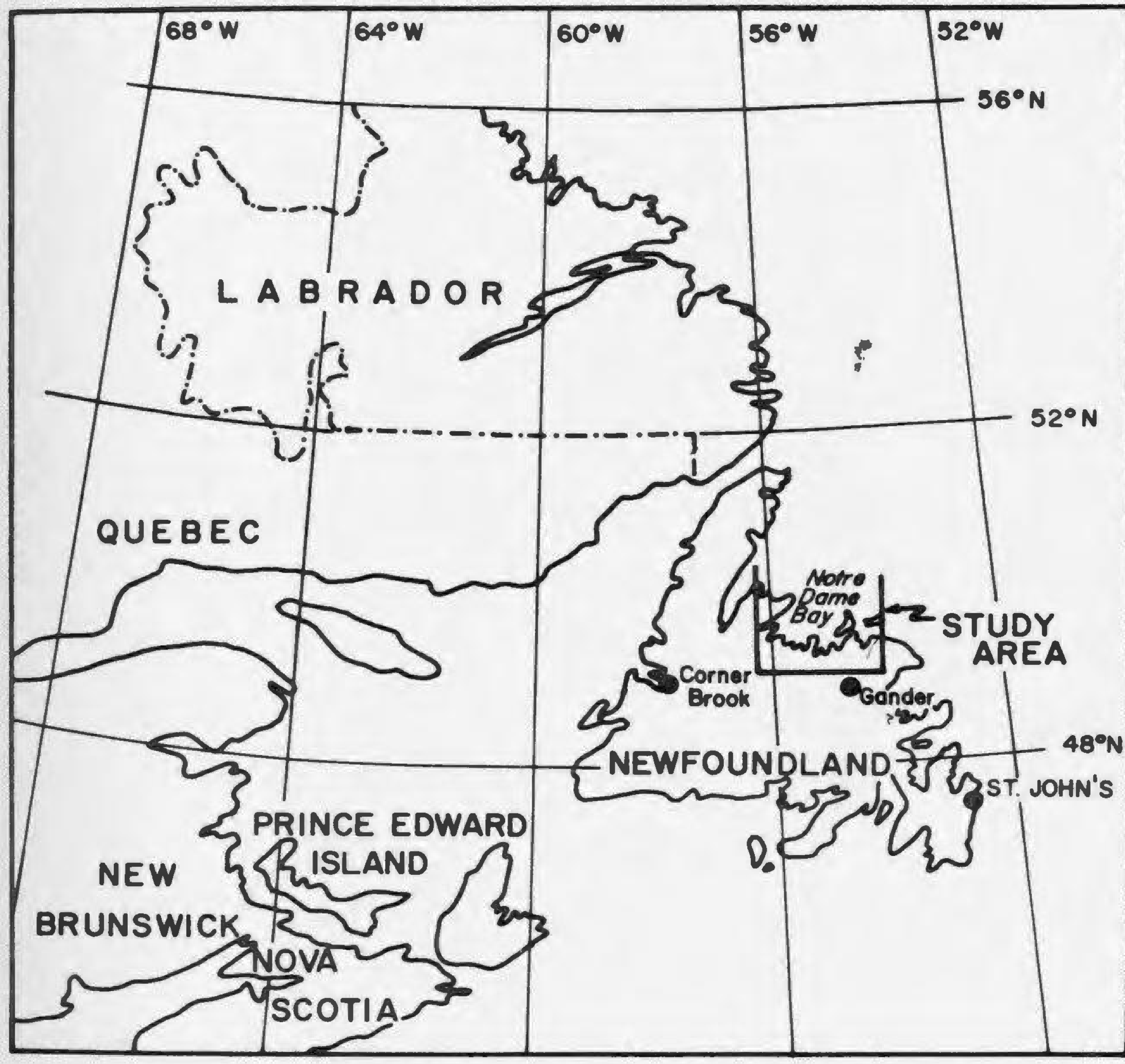


Figure 1.1. Location of Study Area

consists of the eastern extremities of the Newfoundland Highlands. (Bostock, 1969) (Fig. 1.2.)

In the Newfoundland Central Lowlands, elevations are generally less than 150 m.; ridges and gently rolling uplands up to 300 m. occur in the west central interior. The ridges are generally underlain by steeply dipping volcanic rocks while the gently rolling uplands are underlain by intrusive rocks.

The Newfoundland Highlands, in the map area, can be subdivided into the "Topsails Plateau" to the south of the Indian Pond Valley and the "Burlington Peninsula Uplands" to the north of this valley. The Topsails Plateau rises gradually upwards from 150 m. at the South Brook Valley to a distinct plateau with elevations greater than 300 m. This is the "High Central Plateau" of Twenhofel and MacClintock (1940). West of Kings Point, the Burlington Peninsula Uplands rise sharply above the Green Bay Fault scarp to an upland surface with elevations greater than 300 m. This upland surface is generally much more irregular on the western half of the peninsula. A lower upland surface, with elevations greater than 150 m. occupies a central trough extending from Baie Verte to Flatwater Pond and Mic Mac Lake.

Deep valleys are generally fault controlled and are glacially steepened.

Erosional monadnocks with elevations up to 600 m. are conspicuous topographic features in all three physiographic divisions. Hodges Hill and Skull Hill are the best examples in the Newfoundland Central Lowlands; Main Topsail and Fore Topsail on the Topsails Plateau; and Fire Tower Hill south of Flatwater Pond on the Burlington Peninsula Uplands. All of these monadnocks are composed of Devonian intrusive rocks.

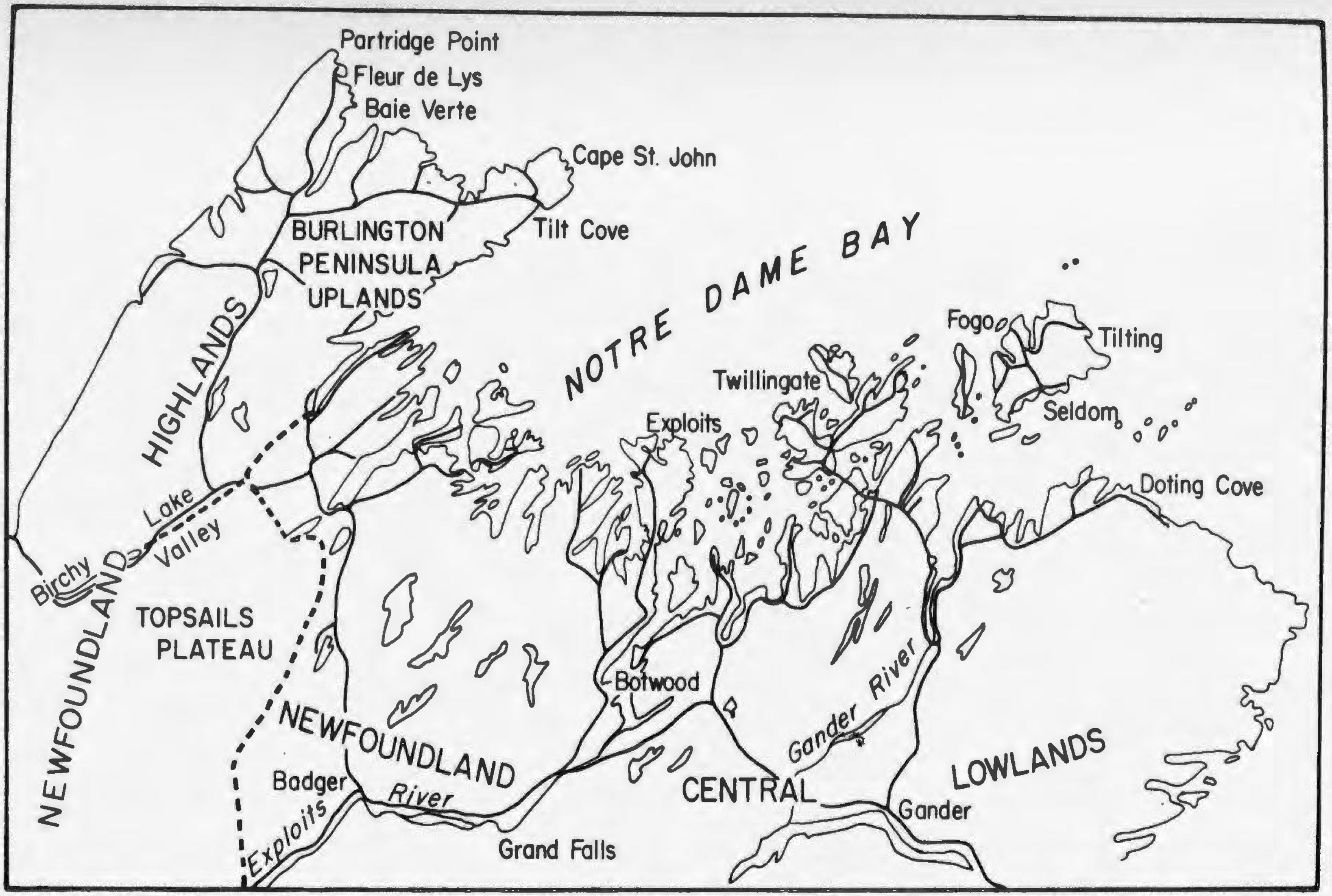


Figure 1.2. Physiographic subdivisions and major roads and towns of central Newfoundland.

The entire area was extensively glaciated during the Wisconsin phase of Pleistocene glaciation (Twenhofel, 1947). Ice movement was northward towards the coast although there are local indications of variation in direction of movement controlled by the local topography and bedrock. Most areas are covered by a thin discontinuous blanket of glacial till which is generally more continuous and thicker in areas underlain by sedimentary rocks. Raised glacial deltas are common near the heads of the larger bays, especially Halls Bay and the Bay of Exploits. Large inland valleys generally acted as glaciofluvial spillways during melting of the ice sheet and are filled with thick deposits of glacial outwash. The South Brook, Indian River and Exploits River Valleys are the most notable examples of these. Marine clay beds, often containing marine fossils, are present at the base of some of the glacial deltas and are also present as isolated occurrences up to 30 m. above the present shore line. The best perserved examples of these are at Clam Pond, between Halls Bay and Southwest Arm (Neale and Nash, 1963) and north of the Mine Pond on Pilleys Island.

Drainage in the area is almost entirely northward into Notre Dame Bay, with the exception of the Twin Lakes watershed in the west central part of the area which drains southward into the Exploits River and then eastward into the Bay of Exploits.

1.3. Geologic Setting

The north coast of Newfoundland marks the northeast termination of the Palaeozoic Appalachian Mountain System. Williams (1964) divided the Newfoundland Appalachians into the Western Platform, the Avalon

Platform and the Central Mobile Belt, based on their contrasting geological records in the Lower Palaeozoic. The Central Mobile Belt itself can be subdivided into three divisions: an eastern metasedimentary terrain underlain by gneissic basement; a western metasedimentary terrain underlain by a gneissic basement; and the main Central Volcanic Belt (Fig. 1.3.).

Wilson (1966) proposed that a "Proto-Atlantic Ocean" existed between the western and Avalon Platforms in the Lower Palaeozoic and that this ocean subsequently closed to form the orogenic Central Mobile Belt. With the gradual acceptance of Wilson's hypothesis and the advent of the plate tectonic theory, together with a flurry of geologic studies in Newfoundland, most geologists now accept the general idea that the Western Platform and the Eastern Platform were indeed parts of discrete continental plates separated by an ocean in the Early Palaeozoic. The eastern and western metasedimentary terrains represent continental margins of the respective plates which were deformed during the closing of the ocean. The Central Volcanic Belt then represents the remnants of the Proto-Atlantic Ocean and the orogenic products resulting from the closing process.

The Central Volcanic Belt is wider and better exposed in the Notre Dame Bay area than elsewhere in the Appalachian Mountain System. The general lack of large Devonian batholiths in the coastal areas and the well exposed stratigraphic sequences provide geologists with a rare opportunity to observe what has happened when an ocean closes and continents do not quite collide.

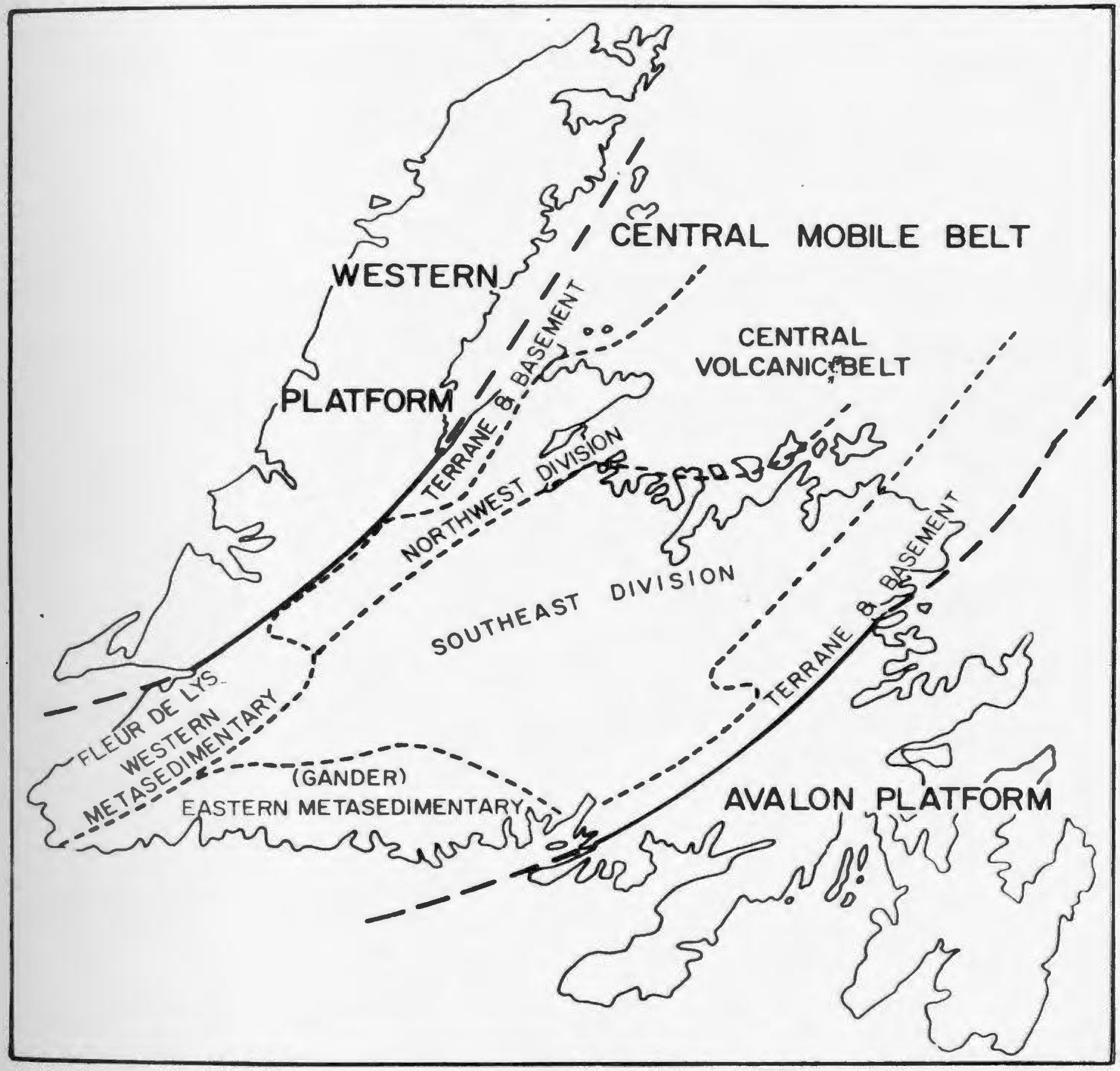


Figure 1.3. Major tectonic subdivisions of Newfoundland (modified from Williams, 1964).

1.4. Purpose of Present Study

By far the greatest percentage of insular Newfoundland's mineral wealth has come from the base metal deposits of the Central Volcanic Belt, particularly the copper deposits of the Notre Dame Bay area. These base metal sulphide deposits are volcanogenic and were formed contemporaneously with the volcanic rocks which enclose them, and as such are integral parts of the stratigraphic sequence in which they occur. The basic aim of the present study is to describe the total regional stratigraphy of Notre Dame Bay and the relative position of the numerous mineral deposits, prospects and showings in the stratigraphic sequence.

2. PREVIOUS WORK

The first geological observations in Notre Dame Bay were made by the earliest explorers and settlers who used conspicuous geological features to name the various coves, points and headlands. One finds such names as Marble Head and Doughball Cove where pillow lavas are well displayed; Red Rock Cove and Red Cliff in granitic areas; Limestone Island on rare occurrences of limestone; and Bumble Bee Bight, a community with black and yellow pyritized pillow lavas. These early settlers were also early discoverers of the mineral resources, for we find such names as Copper Island, Iron Point and Silverdale.

2.1. J.B. Jukes

The first geologist to describe the rocks of Notre Dame Bay was J.B. Jukes, the first "Geological Surveyor of Newfoundland". In 1840 he visited the eastern coast of Notre Dame Bay as far as the Bay of Exploits and travelled up the Exploits River as far as Bishops Falls. In his report and accompanying first geological map of Newfoundland, Jukes (1843) described the slates of Gander Bay and the Bay of Exploits as well as Change Islands, Indian Islands and New World Island. He assigned these rocks to the "lower slate division" of which the St. John's slates of the Avalon Peninsula were the type example.

Jukes also described the granites of Fogo and Toulinguet (Twillingate) Islands and the "micaceous trap rocks" (lamprophyres) which intrude the granites as dykes.

At the head of the Bay of Exploits he described the "amygdaloidal porphyritic rock overlain by brown and reddish gritstone and slate rocks" which continue up river to Bishops Falls. This relationship has since proven to be everywhere consistent within the Silurian Botwood Group (Williams, 1963).

2.2. Alexander Murray

The first systematic study of the geology and mineral deposits of Notre Dame Bay was initiated by Alexander Murray upon his appointment as director of the Newfoundland Geological Survey in 1864 and continued intermittently until his succession by James Howley in 1883.

Murray, in his survey of the northeast coast of Newfoundland in 1864, assigned the volcanic rocks, diorites and serpentinites at Baie Verte and Mings Bight to the Middle or Lower division of the Lower Silurian (now Ordovician) Quebec Group. The Quebec Group of eastern Quebec and of the west coast and Great Northern Peninsula of Newfoundland was well defined by Logan (1863) in his Geology of Canada. Murray himself had also mapped rocks of the Quebec Group in Gaspé.

He described the serpentinites at Tilt Cove and Round Harbour and also assigned these rocks, as well as the volcanic rocks at Halls Bay and Twillingate Islands, to the same division of the Quebec Group. He visited and described the Terra Nova Mine at Baie Verte and was quick to recognize similar copper occurrences in Quebec Group rocks at Mings Bight, Sunday Cove Island and Twillingate. He concluded, as Sterry Hunt (1861) and William Logan (1863) had done, that this division of the Quebec Group was the main metal-bearing rocks of Eastern Canada and Newfoundland.

In 1865, Murray visited Tilt Cove "to instruct myself as to the mode in which the copper ores of the country might be expected to occur" (Murray and Howley, 1881, p. 52). His astute observations and descriptions of these complex ores, which were just being developed, are uncredited by proponents of the syngenetic theory of mineral deposits so I shall quote from his report for 1865, p. 53:

> I may broadly state that the ore deposits of Tilt Cove occur under conditions strikingly similar to those known in Eastern Canada and to characteristic rocks of apparently contemporaneous origin.
>
> As from all I have hitherto seen, and from all the information I have been able to gather, the copper in this country will frequently be found to occur in a similar manner--that is to say, in beds rather than regular veins or lodes . . . . I think it right to call particular attention to the facts of this case, and to express a strong opinion for the benefit of adventurers and explorers, that the immediate neighborhood of the serpentinous rocks, wherever they may be found to exist, will be the most probable position for their labors being crowned with success.

In 1867, Murray mapped Tilt Cove in detail and studied the general area between Tilt Cove and Nippers Harbour. He concluded (p. 134) "that the presence of metallic ores are more or less indicated at many parts in nearly the same relative position to the serpentines as they are at Tilt Cove". On his map, he drew a line to show the probable position of the ore-bearing strata.

In 1871, Murray mapped much of the coastline of Notre Dame Bay and devised a regional stratigraphy for the area. He divided the rock units into two main divisions; a "lower formation" and "upper formations, trapdykes and overflows". Rocks included in the "lower formation" were generally those of the Quebec Group and its equivalents with abundant basaltic dykes and lavas with interbedded chert. These included most of the rocks of Halls Bay, Green Bay, Sunday Cove Island, Little Bay Island, Little Bay Head, Triton Island, Pilleys Island, Twillingate and northern New World Island, as well as the "ophiolitic" rocks associated with serpentine at Baie Verte, Snooks Arm - Tilt Cove, and on the Gander River.

The "upper formations" consisted largely of fossiliferous sedimentary rocks; conglomerates, sandstones, and slates, which unconformably overlie the "lower formation". Its area of outcrop extended along the coast from Ragged Harbour to New World Island and then southwestward to the Victoria River in an elongate trough occupying the Exploits and Gander River valleys. From the fossil content, Murray concluded that these rocks were Llandovery and younger. He described in detail the stratigraphy in several sections of the "upper formation", notably at Cobbs Arm, Goldson Sound, Indian Islands, Peters Arm, and along the Exploits River. Some sedimentary rocks within the volcanic units of Long Island, Little Bay Island, and at Halls Bay Head were erroneously assigned to the "upper formation".

Murray realized that some of the larger igneous bodies of the area were intrusive; however, foliated granitic rocks, such as the Fogo Batholith, were assigned to the Laurentian Gneisses and the "upper formations" were interpreted to unconformably overlie the "gneisses".

Murray's two-fold division of Notre Dame Bay stratigraphy was a very real and useful classification of the rock units for regional mapping purposes, and these two broad divisions, although somewhat subdivided are evident throughout the following chapters of this thesis. It was certainly very useful as an aide to mineral exploration since Murray continuously pointed out that rocks of the "lower formation" were much richer by far in minerals.

In 1875, Murray returned to Notre Dame Bay "to make a re-examination of certain parts of that bay in order to become acquainted with any new or previously undiscovered facts bearing upon the position of these mineral deposits, and to see conclusively how far my anticipations of former years were corroborated" (Murray and Howley, 1881, p. 411). He made a survey of the recently opened Betts Cove Mine and discovered that the mine was located almost exactly on the line he drew in 1867 to show the probable position of ore bearing strata. In his report for that year, Murray again re-emphasized the constant association of mineral-bearing strata with serpentine, chloritic slates and diorites.

Considering the conditions under which Murray worked and the state of the science of geology at the time, his contributions to the understanding of the geology and mineral deposits of Notre Dame Bay cannot be overestimated.

2.3 J.P. Howley

Alexander Murray's successor as Director of the Newfoundland Geological Survey, J.P. Howley, did very little field work in the Notre Dame Bay area and his main contribution was to compile Murray's data on his new geological map of Newfoundland (1907). Throughout his career, Howley kept an accurate historical record of the mining activities in central Newfoundland in his annual reports.

2.4 M.E. Wadsworth

In 1880, Dr. M.E. Wadsworth visited Notre Dame Bay and observed the rocks and mineral deposits along the coast between Betts Cove and Exploits Island. He published his observations in the American Journal of Science in 1884. His physical and petrographic descriptions of the rocks and ore deposits are very detailed and show him to be an expert petrologist, and his familiarity with recent volcanoes and volcanic areas of the world enabled him to interpret the volcanic origin of many of the features he observed.

In describing the volcanic forms we know so well as "pillow lavas", he says "these flows are seen to have rolled and tumbled over one another down the steep slopes in huge rounded botryoidal and link-like masses resembling in their irregular rocky structure a writhing mass of huge anacondas or a pile of Bologna sausages" (Wadsworth, 1884, p. 94). In his detailed petrographic descriptions, he concludes that "Excepting the secondary changes, this lava is in microscopic structure strikingly like that from the eruptions of Kilauea in 1872, the microscopic characters thus supporting the field conclusions" (op. cit., p. 95).

In addition to his excellent petrological work, Wadsworth also recognized the graptolitic shales at Lawrence Harbour and had some concept of the stratigraphy and geological history of Notre Dame Bay. "The whole region bordering on Notre Dame Bay has clearly been the theatre of tremendous volcanic activity which in part at least is of later date than the graptolite shales" (op. cit., p. 95).

He regarded the ore deposits as being:

> of secondary deposition. . . . having been brought up from below finely disseminated through the basaltic material and later concentrated by percolating thermal waters. . . . in the broken fissured altered portions of the rock (op. cit., p. 103).

He observed no serpentine in any of the areas he visited and stated that:

> the ores occur in diabase and schist hence the statements, so industriously circulated in almost every article relating to the Newfoundland copper deposits, regarding the relationship of the ores to serpentine are entirely incorrect in the districts seen by me (op. cit., p. 104).

2.5. A. F. Buddington, E. Sampson and W. Agar

Another phase of geological interest in Notre Dame Bay began in 1915 when the first of the Princeton University Geological Expeditions to Newfoundland visited that region, under the leadership of A. F. Buddington. He, along with W. Agar and Edward Sampson, surveyed much of the coastline between Fogo Island and Pilleys Island and made a brief visit to the Tilt Cove area. The results of this work were never published; however, many of their original field notes and rock collections are preserved in the Newfoundland Rock Collection at Memorial University of Newfoundland. In a detailed study of their field notes, the writer has found the geological observations to be very detailed and accurate and the rocks to be described as well as, if not better than they have been described since.

They also visited most of the abandoned and producing mines of the area and gave excellent descriptions of ore petrology and ore-host relationships. In addition, a valuable collection of the ores and host rocks was made.

Sampson returned to Notre Dame Bay in 1916 and again in 1919 to describe the mineral deposits and to study the cherts for his doctorate thesis at Princeton University. In a paper in 1923 summarizing his thesis work, Sampson outlined the regional geology and stratigraphy of Notre Dame Bay and also described the various cherts and their intimate relationship with the volcanics. He suggested that the oldest rocks, consisting largely of submarine pillow lavas, were Cambrian in age and were overlain by a series of Ordovician pillow lavas, tuffs and shales. Silurian rocks were dominantly sandstones and conglomerates with no known volcanics. No fossils were found within the supposed Cambrian volcanics but a large collection was gathered from the Ordovician and Silurian rocks.

Sampson correlated several of the stratigraphic sequences within the Ordovician rocks and was the first to note "a persistant black graptolitic shale. . . of Llandeilo age" (Sampson, 1923, p. 575). This shale is presently regarded as a major marker horizon in Central Newfoundland geology (see Chap. 3).

He concluded that the cherts were chemical sediments resulting from the precipitation of excess silica introduced into sea water by the extensive subaqueous extrusion of lava. He pointed out that some of the cherts of Notre Dame Bay are contemporaneous with those of Great Britain and "fossil types are so nearly identical. . . . as to imply a connection or some means of migration between the two regions" (op. cit., p.588).

2.6. A. K. Snelgrove

In the late 1920's, there was a tremendous revival in geological interest in central Newfoundland because of the exciting new ore discoveries being made at Buchans, and Newfoundland was once again in an exploration boom. In 1928, A. K. Snelgrove published his "Geology of the Central Mineral Belt of Newfoundland - A collation and contribution." This work was essentially a compilation of Murray's and Sampson's work on Notre Dame Bay, together with new information on the South Coast district and detailed descriptions of the Red Indian Lake district, with which Snelgrove was much more familiar at the time.

Snelgrove was obviously a student of the Lindgren school of thought regarding the formation of ore deposits. He felt that the base metal deposits of the Central Mineral Belt were replacements and veins which were ultimately structurally controlled and genetically related to small igneous intrusions. The copper deposits of Notre Dame Bay were related to diorite intrusions while the ores of the Red Indian Lake district were genetically related to stocks of quartz porphyry which were related to Devonian granites at depth.

Snelgrove (1931) published a synthesis of his doctorate thesis on the Geology and Ore Deposits of Betts Cove - Tilt Cove Area. He defined the pillow lavas and interbedded sedimentary rocks as the "Snooks Arm series" which was assigned to the Lower Ordovician on the basis of one graptolite locality. Rhyolitic pyroclastics exposed north of the Snooks Arm series were called the Goss Pond volcanics. These rocks appeared to conformably overlie the Snooks Arm series and to be conformably overlain by rhyolitic and dacitic lavas known as the Red Cliff volcanics, also of probable Ordovician age. All of these rocks were intruded by various Devonian igneous bodies ranging in composition from serpentinite to granite porphyry.

The serpentinites, gabbros and diorites which Murray (1865) had assigned to the Quebec Group, along with the pillow lavas and sedimentary rocks, were considered by Snelgrove to be intrusive into the lavas and sediments and to be much younger than the Snooks Arm series.

Snelgrove considered the copper deposits at Betts Cove and Tilt Cove to be replacements and veins genetically related to the quartz diorites. He acknowledged that the deposits occur only in one particular pillow lava unit of the Snooks Arm series and always in chlorite schist but considered this to be a function of distance from the quartz diorites, and the chlorite schist to be a wall rock alteration feature.

In 1934, Snelgrove was appointed Government Geologist for the reinaugurated Newfoundland Geological Survey. He immediately initiated a programme of geological mapping and evaluation of mineral resources of the whole of Newfoundland. Much of this work was done by students of his former professors, Buddington and Sampson. This phase of the Princeton Geological Expeditions added much new data on the geology and mineral resources of Newfoundland and Snelgrove himself continued to add to this data until his retirement from the post in 1943.

Although Snelgrove's scientific work in Newfoundland geology and mineral deposits appears slightly erroneous in terms of present day knowledge and even in terms of Murray's knowledge of Notre Dame Bay, one must remember that he was, as most geologists are, a victim of the dominating theories of the time in which he worked. During his ten years as Government Geologist, Snelgrove had gathered and published almost every available piece of information on the geology and mineral resources of Newfoundland.

2.7. G. R. Heyl

The first of the Pinceton University Expedition students to work in Notre Dame Bay after Snelgrove was G. R. Heyl. In 1936 he published a synthesis of his doctorate thesis on "The Geology and Mineral Deposits of the Bay of Exploits Area" as a bulletin of the Geological Section of the Newfoundland Department of Natural Resources, edited by A. K. Snelgrove.

Heyl assigned all stratified rocks in the area to the Exploits series which included nine formations, almost all of which were assigned to the Middle Ordovician. These rocks were intruded by two large granodiorite batholiths and related rocks of late Silurian or Devonian age. He considered most of the metal sulphide deposits of the area to be vein types and genetically related to the late intrusive rocks.

Heyl's stratigraphy of the Bay of Exploits region has been shown to be locally upside down and nondefinitive (Williams, 1963b; Helwig, 1967) and many of his shelly fossils were misidentified or assigned to the wrong age. Two of his formations are part of a complex mélange which had not been recognized as such until recently (Horne 1968). He also failed to recognize the major fault of the area and correlated units across it.

In spite of all his errors, Heyl had a very good idea of the geological environment in which the Exploits series formed. He drew parallels with the East Indian island arcs and made detailed correlations with the Ordovician of the British Isles. His ideas on the origin of the mineral deposits of the Bay of Exploits cannot be strongly criticized as many of them are in fact vein-like in form and probably in origin, although they are probably not all the same age.

In 1937, Heyl studied the geology and mineral deposits of the New Bay area and extended the stratigraphic errors of the Bay of Exploits westward to New Bay. He did, however, recognize that the coarse conglomerates of the area are of Silurian age and collected many fossils from this unit. Again he suggested that the mineral deposits were replacements and veins and genetically related to late igneous intrusive activity. The deposits of the New Bay area however, are completely different from those of the Bay of Exploits and are very unlike vein-type deposits and are clearly volcanogenic.

Heyl (1937a) described the detailed petrology of the lamprophyres of the Bay of Exploits and noted that these rocks represent the youngest phase of igneous activity in the region.

2.8. G. H. Espenshade

In 1937, G. H. Espenshade of Princeton University described "The Geology and Mineral Deposits of the Pilleys Island Area". He divided the rocks into two "series" separated by a major east-west break which he called the Lobster Cove Fault. North of this fault rocks were assigned to "The Pilleys Series" and south of it to "The Badger Bay Series".

The Pilleys Series was divided into a lower group of volcanic and sedimentary rocks, the Cutwell Group, and an upper group of dominantly basaltic volcanics, the Lushs Bight Group.

The Badger Bay Series was divided into nine units by Espenshade. The lowest unit, the Wild Bight Volcanics, was overlain by 9000 feet (2740 m.) of marine clastic sedimentary rocks, divided into four formations and two groups. This pile of sedimentary rocks was overlain conformably by another submarine volcanic unit, the Roberts Arm Volcanics, which was disconformably overlain by red micaceous sandstone of the Springdale

Formation. Espenshade considered the Badger Bay series to be a continuous north-facing sequence of unbroken stratigraphy up to the Lobster Cove Fault. Although he had no identifiable fossils, he assigned all stratified rocks of the Pilleys Island area to the Ordovician, except for the Springdale Formation which he considered to be probably Silurian.

Espenshade's mapping of the Pilleys Island area has been followed by all subsequent workers. The only major flaw in his stratigraphy results from his failure to realize that a major fault lies between Pilleys Island and Long Island where he defined the Cutwell and Lushs Bight Groups. The Lushs Bight Group rocks on Pilleys and Sunday Cove Islands are presently considered to be older than the Cutwell Group (Williams 1962; Kean and Strong 1975) and there are no Lushs Bight Group rocks on Long Island. His attempted correlation with Heyl's (1936) Exploits series stratigraphy was erroneous because of Heyl's erroneous stratigraphy and Espenshades lack of fossils.

Espenshade considered the Pilleys Island copper-pyrite deposit to be a replacement by hydrothermal solutions of sheared and shattered zones in rhyolites of the Roberts Arm volcanics. He noted that the deposit was unique in that it was the only deposit in the Notre Dame Bay region to occur in rhyolite and suggested that this was perhaps because no rhyolite occurred in the other areas. Other small deposits and occurrences in the area were similarly termed replacements and veins, variably structurally controlled.

2.9. W. H. Twenhofel and R. R. Shrock

In 1937, W. H. Twenhofel and R. R. Shrock of the University of

Wisconsin described the Silurian strata of Notre Dame Bay and the Exploits Valley. Although their study did not extend west of the Bay of Exploits, they made detailed stratigraphic studies of eastern New World Island, Indian Islands, Yellow Fox Island, Change Islands, Upper Black Island and the general area near Botwood. Extensive fossil collections were made from the Silurian and from some Ordovician rocks.

The Silurian rocks were divided into three lithological divisions assigned to the Notre Dame Series. The oldest and thickest consisted of thin bedded red sandstones designated Botwood Formation. This unit was overlain by coarse conglomerates of the Goldson Formation which was overlain in turn by shales and red sandstones of the Pike Arm Formation. A fourth unit, probably younger than the Pike Arm Formation was indicated by a fossiliferous Silurian limestone block in a flow breccia on Upper Black Island. They saw no contemporaneous volcanic rocks within the Silurian, in contrast to the Ordovician sequences.

Williams (1962, 1963b) showed that even though the lithologic units of Twenhofel and Shrock were extensive and mappable as defined, their stratigraphy was incorrect in that the Goldson Formation was older than the Botwood Formation and the two were separated by an extensive Silurian volcanic unit, previously unrecognized.

Twenhofel (1947), in his study of the Silurian rocks of eastern Newfoundland, described the rocks of Hamilton Sound and adjacent bays to the south, as well as the strata of Gander Lake and Gander River. Because of the lack of good fossil collections and Twenhofel's belief that there were no volcanic rocks in the Silurian of this area, much

Silurian strata were assigned to the Ordovician and vice versa.

The sequence of sedimentary rocks along the shores of Gander Lake was designated the Gander Lake Series and correlated with the Silurian rocks of the Indian Islands area. Strata along the Gander River below Glenwood and along the coast from Gander Bay to Rocky Bay were believed to be Ordovician in age and were not included in the Gander Lake Series.

Red sandstones and siltstones at the head of the Bay of Exploits which were previously assigned to the Silurian Botwood Formation (Twenhofel and Shrock, 1937) were reassigned to the Springdale Formation (Espenshade, 1937) and the name "Botwood" was dropped. A Devonian age was proposed for these rocks since the Silurian fossils at the head of the Bay of Exploits occur only as fragments in conglomerates and these fragments were lithified before incorporation in the conglomerate. Williams (1962) found indigenous fossils of Silurian age in these same rocks.

Twenhofel and MacClintock (1940) described the physiography of Notre Dame Bay and its relationship to the rest of Newfoundland.

2.10. G. V. Douglas, D. Williams and O. N. Rove

In 1938 and 1939, Douglas, Williams and Rove conducted an extensive evaluation of the copper deposits of Newfoundland for the Newfoundland Government, with a view to determining the possibility of resuscitating the copper mining industry, particularly in the Notre Dame Bay area. They studied most of the known deposits and prospects and gathered a wealth of detailed information on the larger prospects and previous producers.

Their report (Douglas, Williams and Rove, 1940) added very little new information to the regional geology of Notre Dame Bay. Most of the geology and ideas on ore genesis were taken from the previous work of Snelgrove, Heyl, Espenshade, Murray and private reports.

Two of the Princeton University students on the study, H. J. MacLean and K. deP. Watson, made detailed studies of the Little Bay and Baie Verte - Mings Bight areas respectively and published separately.

2.11. H. J. MacLean

H. J. MacLean's study of the Geology and Mineral Deposits of the Little Bay Area was published in 1947 as a bulletin of the Newfoundland Geological Survey. MacLean adopted Espenshade's (1937) nomenclature for all features which could be followed from the Pilleys Island area westwards across Halls Bay into the Little Bay map area. The Lushs Bight Group, which underlies the major part of the map area, was divided by MacLean into the Little Bay Head, Western Arm and Halls Bay Head Sections. He considered the Little Bay Head Section, consisting largely of meta pillow lavas, to be the oldest and the overlying Western Arm Section to be correlative with the Halls Bay Head Section because of lithological similarities. The Western Arm Section, which yielded the only fossil in the area, a Lower Ordovician brachiopod *Discotreta*, was further subdivided into four distinct volcanic and sedimentary formations.

MacLean expanded Espenshade's Silurian (?) Springdale Formation to the Springdale Group and included in this group thick basalt flows, quartz latite flows, agglomerate and chert as well as the red sandstones, conglomerates and shales previously assigned to the Springdale Formation. He extended the Lobster Cove Fault westwards and suggested that it was a thrust fault, the Lushs Bight metabasalts having been thrust southward over the Springdale Group.

MacLean considered the various intrusive rocks in the Little Bay map area to be Acadian in age except for the amphibolite, olivine pyroxenite and gabbro in the Stocking Harbour area and the dolerite dyke swarms in the Little Bay Head Section of the Lushs Bight Group. These rocks he thought were pre-Acadian but younger than the Ordovician volcanics which they intrude. He suggested a major unconformity between the Lushs Bight and Springdale Groups indicating a strong Taconic disturbance with which these older intrusive rocks were possibly associated.

From his very detailed observations and descriptions of the numerous copper prospects and mines in the area, MacLean concluded that they were all quartz-pyrite replacement deposits in chlorite schists, related to hydrothermal activity along the major faults with subsequent deposition along minor fault zones.

2.12. K. deP. Watson

Kenneth dePencier Watson's study of the Geology and Mineral Deposits of the Baie Verte - Mings Bight Area was published as a bulletin of the Newfoundland Geological Survey in 1947 but the field work had been completed in 1939 and Watson in 1943 had published a paper on the mafic and ultramafic rocks of the Baie Verte area.

He divided the stratified rocks of the area into three distinct informal packages:- (1) "The Rattling Brook Group" of Precambrian (?)

paragneisses which underlie the area west of Baie Verte; (2) The Baie Verte Formation, consisting predominantly of Ordovician (?) volcanics; and (3) The Mings Bight Formation of Ordovician (?) gneisses and schists which occur on the southeast side of Mings Bight and possibly underlie the Baie Verte Formation. No fossils were found in the map area. The Mings Bight metasediments differ from the gneisses of the Rattling Brook Group in being less highly metamorphosed and containing more chlorite. Watson postulated a major northeast trending fault lying west of Baie Verte and separating the Baie Verte Formation from the Rattling Brook Group.

The ultramafic and gabbroic rocks of the area were thought to be concordant intrusives and to have been intruded into the Baie Verte Formation before its deformation and before the intrusion of the large Devonian (?) quartz diorite body southeast of Baie Verte. He noted that pseudostratification in these rocks was always parallel to stratification within the Baie Verte Formation.

Watson considered the copper-pyrite-gold deposits within the Baie Verte Formation to be mesothermal replacements associated with shear zones in highly chloritized greenstones, but was puzzled by the lack of wall rock alteration in the abandoned Terra Nova Mine. He recognized the gold bearing quartz veins of the Goldenville Mine were confined within a thin ferruginous chert band but suggested that this was because the chert was more brittle and fractured than the surrounding greenstones and hence more easily penetrated by gold-bearing hydrothermal solutions.

2.13 D.M. Baird

David McCurdy Baird began his geological studies of Newfoundland on the Burlington Peninsula in 1944 as a geologist of the Newfoundland Geological Survey. He continued studying various parts of north central Newfoundland until 1954 and contributed new knowledge and interest in this area. In 1947, he completed a Ph.D. thesis on the Geology of the Burlington Peninsula: A synthesis of this work was published in 1951 as a Geological Survey of Canada Paper.

Baird (1951) incorporated the previous work of Snelgrove (1931), Fuller (1941) and Watson (1947) and adopted the basic outlines of the geology and the terminology they had used, with several new additions in previously unmapped areas. Gneisses and schists which Watson (1947) had designated the undivided Rattling Brook Group were assigned by Baird to the Fleur de Lys Group since Fuller (1941) had mapped six separate formations within these rocks in the Fleur de Lys area. Baird retained Fuller's stratigraphy and formational names.

Watson's Mings Bight Formation was mapped eastwards to Pacquet and was expanded to become the "Mings Bight Group" since these rocks were more varied and complex than originally suspected. Similarly, the Baie Verte Formation was expanded to group status.

Snelgrove's (1931) Snooks Arm Series was renamed the Snooks Arm Group and Baird proposed the name Nippers Harbour Group for a sequence of altered volcanic and sedimentary rocks lying to the southwest of the Snooks Arm Group and separated from them by a belt of serpentinized peridotite. He suggested that these rocks may, wholly or in part, be correlatives of the Snooks Arm Group although they are different in many minor respects.

He proposed the name Cape St. John Group "to include that sequence of lava flows, with interbedded sedimentary and pyroclastic rocks, that overlie the Snooks Arm Group". He reassigned Snelgrove's (1931) Goss Pond volcanics and Red Cliff volcanics to the Cape St. John Group since these rocks represented only a small part of this dominantly volcanic sequence. He assigned names to the larger distinctive intrusive bodies in the area: the Burlington granite, Cape Brule granite, and Dunamagon granite, all of which were genetically related and Devonian in age.

Baird tentatively correlated the Fleur de Lys and Mings Bight Groups and ascribed a Precambrian age. On the basis of lithologic similarities, he suggested that the Baie Verte Group is equivalent to the Lower Ordovician Snooks Arm Group and probably unconformably overlies the Mings Bight Group. The Cape St. John Group, which he considered to overlie both the Snooks Arm and Baie Verte Groups without apparent break, suggested to Baird a later Ordovician period of subaerial volcanic activity and shallow marine sedimentation. He felt that the concordant ultramafic rocks of the area could be Taconic in age by analogy with the similar geologic setting of the Eastern Townships of Quebec, but concluded, like Watson (1947), that they were post-Baie Verte and pre-Devonian.

Baird followed Snelgrove (1931) and Watson (1947) in stating that the copper deposits of the Burlington Peninsula are mesothermal replacement deposits within chlorite schist in shear zones in Ordovician altered lava flows. He felt that the Stocking Harbour Fault along the eastern coast of the peninsula was the ultimate structural control for all the copper deposits of that region since they all occurred on the Fault itself or on a subsiduary shear zone. He thought that the copper minerals were derived from emanations from the abundant granitic rocks of the region rather than from the diorites, as suggested by Snelgrove (1931).

From the Burlington Peninsula, Baird moved to the Fogo-Twillingate-New World Island area of Eastern Notre Dame Bay for the field season of 1946. In his report on the reconnaissance geology of part of the New World Island-Twillingate area, Baird (1953) outlined the main stratigraphy and structural elements of this area. He applied no stratigraphic names to the rock units except for the Twillingate granite which he felt was Devonian since it discordantly intruded volcanic rocks which were probably of Ordovician age. He thought that all the volcanic rocks were Ordovician since the Ordovician Cobbs Arm limestone and other limestone lenses were found with the volcanics. He also collected Silurian fossils from the coarse conglomerates of the area.

Baird realized that the area was structurally complex with much faulting, since the Silurian conglomerates and other stratified rocks continuously faced northward yet there was an obvious repetition of stratigraphy. His conclusions as a result of his few days of reconnaissance geology in this area are interesting in light of more recent intensive geological studies in the New World Island-Twillingate area:

> New World Island and adjacent areas present some of the most interesting geology in all of Newfoundland. This is a region of structural complexity which holds in its detailed stratigraphy the key to many of the problems of the geological succession of northeastern Newfoundland. The relations

> of the Ordovician and Silurian, long a puzzle, will probably be solved when New World Island, the islands of Dildo Run and islands to the south are mapped in detail. The structure of the area will be undoubtedly important to the study of the regional structure of northeastern Newfoundland and indeed, northeastern North America.
>
> (Baird, 1953, p. 19)

Baird spent most of the 1946 field season on Fogo Island and the surrounding islands. The resulting map was published as a G.S.C. paper in 1950. A more accurate base map was later provided and additional mapping and checking of boundaries was undertaken in 1955 and 1956. The new Fogo Island Map Area was published as a G.S.C. memoir in 1958.

He divided the stratified rocks of the area into the Ordovician (?) Fogo and Farewell Groups and the fossiliferous Silurian Indian Islands Group. The Fogo Group on the Port Albert peninsula were assigned to the Ordovician because they contained volcanic rocks and volcanics of other Palaeozoic ages which were unknown in Notre Dame Bay at this time. He divided the Fogo Group into four formations composed alternately of shallow water sandstones and subaerial volcanic rocks. These were the Fogo Harbour, Brimstone Head, South End and North End formations. The other groups were not divided although the stratigraphy was described. Williams (1963a) and Eastler (1969) showed Baird's Fogo Group stratigraphy to be erroneous and also discovered that these rocks were in fact Silurian in age.

Baird assigned a Devonian age to the Fogo batholith and subdivided it into an early diorite-gabbro complex and a later granite-alaskite intrusive phase. Other intrusive rocks in the area were also considered Devonian. He noted no significant mineral occurrences in the area.

Baird contributed new knowledge on the mineral deposits of central Newfoundland in 1953 when he revised Snelgrove's (1938) "Mines and Mineral Resources of Newfoundland". In 1954 he compiled all available geologic data on all of insular Newfoundland for a new geological map of the island.

2.14. J. J. Hayes

John Jesse Hayes mapped the Hodges Hill-Marks Lake area for his doctorate thesis at the University of Michigan (1951c). The total area covered is roughly the eastern quarters of the Springdale (12H/8) and Gull Pond (12H/1) map sheets and the west halves of the Roberts Arm (2E/5) and Hodges Hill (2E/4) sheets. The Hodges Hills and Marks Lake map sheets were published as preliminary G.S.C. maps (Hayes 1951a, 1951b), and more detailed descriptions are given in the thesis (Hayes 1951c).

The Marks Lake sheet included the Badger Bay portion of Espenshade's (1937) Pilleys Island area. Hayes, however, followed Heyl's (1936) stratigraphy for the Bay of Exploits and assigned all his stratified rocks to the Ordovician Exploits series. Most of Espenshade's (1937) various formations and groups of the Badger Bay series were included as members in the various formations of the Exploits series except for the Crescent Lake Formation which was retained and the Wild Bight volcanics which was renamed the Wild Bight Formation.

Hayes considered the Wild Bight Formation to be the base of the Exploits series and to be overlain by the Sansom, Sivier, Crescent Lake, Breakheart, and Moretons Formations, the latter two of which are also dominantly volcanic rocks (Espenshade's Roberts Arm volcanics). The statigraphic sequence remained essentially as Espenshade had outlined it, but the application of Heyl's (1936) Bay of Exploits stratigraphic names was erroneous since his stratigraphy was incorrect (see section 2.7.). Hayes did recognize that the Ordovician stratigraphy of Notre Dame Bay consisted of a basal volcanic sequence overlain by arenaceous and argillaceous sediments which are in turn overlain by another distinct volcanic sequence.

Hayes mapped most of the stratigraphic units from Badger Bay southwards to the main highway and outlined the structure of the area in some detail. He traced a thick gabbro sill, which separated the Wild Bight and Sansom Formations, from Badger Bay to Marks Lake and named it The Marks Lake Sill. He felt it was Ordovician in age and related to the volcanism of the Breakheart Formation. Other intrusive bodies were assigned to the Devonian period. The large batholith in the south-central part of the area was subdivided into an early diorite phase, the Twin Lakes diorite complex, and a later granitic phase, the Hodges Hill granite batholith. The small mineral prospects of the area, and the Gull Pond copper prospect, which Hayes visited, were considered to be late hydrothermal deposits ultimately related to igneous intrusives.

2.15. J. Kalliokoski

J. Kalliokoski (1953, 1954) made preliminary G.S.C. maps of the Gull Pond (12H/1) map sheet and the east half of the adjacent Springdale 12H/8) sheet to the north. He followed the work of Espenshade (1937) and MacLean (1947) and assigned all stratified rocks to the Ordovician

Badger Bay series and the Devonian Springdale Group. The lower sedimentary rocks of the Badger Bay series were not assigned to any particular formation, but the upper sedimentary and volcanic rocks were mapped as Crescent Lake Formation and Roberts Arm Formation. The dominantly volcanic Springdale Group was divided into eleven units with no formal status. Both the top and bottom of the group was supposedly characterized by red sandstones and conglomerate. He presumed that the Springdale Group unconformably overlies the Badger Bay series. Acidic and basic lavas immediately north of the Lobster Cove Fault near Indian Brook were assigned to the Roberts Arm Formation since they are more deformed than Springdale volcanics.

All intrusive rocks were considered to be Devonian but syenitic granitic pebbles were found in the red conglomerates which supposedly formed the base of the Springdale Group. These conglomerates are presently assigned to the Carboniferous period.

Kalliokoski described the copper deposit at Mineral Point, Gull Pond as "pyrite replacement lenses in cordierite rocks near a fault" (Kalliokoski, 1951).

2.16 T.O.H. Patrick

Patrick (1956) produced a G.S.C. preliminary map of the Comfort Cove map sheet (2E/7) which included part of the area mapped by Heyl (1937). Rocks which Heyl (1937) had assigned to the Ordovician Exploits series and similar rocks to the south and east were renamed the Exploits Group which Patrick subdivided into a greywacke division, a volcanic division and a black shale division. No stratigraphic significance was attached to these units.

He described shaley conglomerates of the black shale division as consisting of fragments of greywacke with local concentrations of volcanic rocks and other rock types in a black shaley matrix and suggested that this rock may be a slump breccia formed by the tectonic disturbance of newly deposited shale and greywacke beds. These rocks have since been mapped as part of the complex Dunnage Mélange and a similar origin has been proposed by Hibbard (1976).

The Farewell and Indian Islands Groups (Baird 1950, 1958) and their undivided equivalents were believed to be dominantly of Silurian age and Patrick felt that the Indian Islands Group conformably overlay the Farewell Group which unconformably overlay the Exploits Group. All contacts between these groups are presently thought to be faulted.

Red sandstones and minor volcanic and conglomeratic rocks which overlie shale of the Indian Islands Group were assigned to the Springdale Group of Silurian or Devonian age (Twenhofel, 1947). Intrusive rocks in the area were assigned to the Devonian period except for lamprophyre dykes which Patrick felt could be younger than Palaeozoic. He interpreted the major northeast trending faults, such as the Reach Fault, as thrust faults.

2.17. S. E. Jenness

Stuart E. Jenness mapped and studied the Gander River ultrabasic belt in 1952 and 1953. The results formed a Ph.D. thesis at Yale University (Jenness, 1954) and a summary was published as a report of the Newfoundland Geological Survey (Jenness, 1958). He also mapped the Gander Lake map sheet (2D, east half) as a link to a four mile G.S.C. map to the east (Jenness, 1957, 1963).

Jenness discovered mid-Ordovician fossils in rocks of Twenhofel's (1947) Gander Lake Series of supposed Silurian age. These rocks were renamed The Gander Lake Group and assigned to the Mid-Ordovician. The Gander Lake Group was extended along strike northeastwards to the coast and expanded to include sedimentary and volcanic rocks of the Gander River valley which Twenhofel (1947) had recognized as Ordovician.

The gabbroic and ultramafic rocks were described as intrusive sill-like bodies in the volcanic and sedimentary rocks of the Gander Lake Group. An upper Ordovician age was suggested for these bodies since they were deformed with the rocks they intrude.

Jenness (1963) subdivided the Gander Lake Group into a lower, middle and upper unit, all of mid-Ordovician age. The lower unit consists of greywackes and argillaceous sandstones, the middle unit mixed volcanic and sedimentary rocks, and the upper unit shale, slate and minor siltstone. Various metamorphosed equivalents of these units were mapped with regional metamorphism increasing eastwards and granitization being common in the easternmost (lowermost) exposures of the lower unit. He recognized the common occurrence of gabbro and ultramafic bodies in the middle unit and these rocks were mapped as most abundant where volcanic rocks were the dominant lithologies.

2.18. E. R. W. Neale

E. R. W. Neale made 1 inch : 1 mile G.S.C. preliminary maps of the Baie Verte (Neale (1958a), Nippers Harbour (Neale, 1958b), Fleur de Lys (Neale, 1959) and Kings Point (Neale, Nash and Innes, 1960) map sheets on the Burlington Peninsula and adjacent areas. He compiled the previous work of Fuller (1941), Watson (1947), MacLean (1947) and Baird

(1951) and followed the same terminology and stratigraphic sequence used by Baird (1951) with the exception of the assignment of a Devonian rather than Ordovician age for the Cape St. John Group (Neale, 1958b). The Cape St. John Group was found to contain fragments of Snooks Arm Group rocks and fragments of the ultrabasic rocks which intrude the Snooks Arm Group.

Neale and Nash (1963) compiled Kalliokoski's (1953, 1954) Gull Pond and Springdale map sheets together with the previously mapped Baie Verte and Kings Point sheets in a 1 inch : 4 mile map of the eastern half of the Sandy Lake map sheet (12/H). The most significant change in the stratigraphic sequence resulted from the discovery of an unconformity between the Burlington Granodiorite (Baird's (1951) 'Burlington granite'), and a sequence of subaerial volcanic and sedimentary rocks extending from Flatwater Pond southward to Sheffield Lake. These rocks, which later became known as the Mic Mac sequence (Neale and Kennedy, 1967a), were correlated with the Cape St. John Group and assigned to the Silurian while the Burlington Granodiorite was given an Ordovician age since it intruded the Ordovician Baie Verte Group. A similar pluton which intrudes the Lushs Bight Group on the east side of Southwest Arm was also assigned to the Ordovician.

Volcanic rocks north of Indian Brook and north of the Lobster Cove Fault, which Kalliokoski (1953) had assigned to the Roberts Arm Formation of the Badger Bay series, were found to contain Silurian fossils and were assigned to an unnamed Silurian unit. Kalliokoski's (1953, 1954) subdivisions of the Badger Bay series were retained as mapped but were assigned to the Exploits Group rather than Badger Bay, since the former had precedence.

A Silurian rather than Devonian age was suggested for the Springdale Group. The large bodies of quartz-feldspar porphyry in the area were postulated to be subvolcanic intrusives related to Springdale-Mic Mac- Cape St. John subaerial volcanic activity.

All of the sulphide deposits in the area were considered to be replacements in volcanic rocks.

Neale and Kennedy (1967a, 1967b) reconsidered the relative ages of various rock sequences on the Burlington Peninsula on the basis of structural styles and relative intensity of deformation. Metamorphosed mafic volcanic rocks extending from southeast of Baie Verte to Pacquet Harbour (Pacquet Harbour Group; Church, 1969), were removed from the Baie Verte Group and assigned a pre-Ordovician age. Similarly, the Burlington Granodiorite, which intrudes these rocks, was also assigned a pre-Ordovician age. The now restricted Baie Verte Group was believed to unconformably overlie these previously deformed rocks. Neale and Kennedy also suggested a Silurian age for the Baie Verte Group since they believed it to overlie the Silurian Mic Mac sequence of subaerial volcanic and sedimentary rocks. They also suggested that the Cape St. John Group, including the more intensely deformed parts of the sequence, rests unconformably on the older deformed volcanic sequence.

Neale, Kean and Upadhyay (1975) described an unconformable relationship between the Snooks Arm Group and the overlying Cape St. John Group, and again correlated the Springdale, Mic Mac and Cape St. John Groups.

2.19. H. Williams

Harold Williams began geological studies in Notre Dame Bay in 1956 when he mapped the igneous rocks of Tilting Harbour area on Fogo Island for a M.Sc. thesis at Memorial University (Williams, 1957a). The results of this study were published as a report of the Geological Survey of Newfoundland (Williams, 1957b) and were incorporated in Baird's (1958) G.S.C. memoir of the Fogo map area.

Williams returned to Notre Dame Bay in 1961 to begin work on a G.S.C. 1 inch to 4 mile map of the Botwood (2E) map area. In 1961 he compiled the previous work of Heyl (1936, 1937a), Espenshade (1937), Twenhofel and Schrock (1937), MacLean (1947), Hayes (1951a, 1951b), Baird (1958) and Neale (1958) and completed reconnaissance mapping of the west half of the Botwood map sheet (Williams, 1962). He followed the basic stratigraphic outline and terminology of previous workers but made several significant changes. The Nippers Harbour Group was eliminated and these rocks were assigned to the Lower Ordovician Lushs Bight Group. Williams found that Espenshade's (1937) Lushs Bight Group on Long Island, where it conformably overlies the Cutwell Group, was totally different from the remainder of the Lushs Bight Group as mapped by Espenshade (1937) and MacLean (1947). He included these rocks in the Cutwell Group and suggested that the Lushs Bight Group is older than the Cutwell Group since Mid-Ordovician fossils were collected from the Cutwell Group on Limestone Island near Little Bay Island.

Williams followed Hayes' (1951a, 1951b) rather than Heyl's (1936) stratigraphic sequence for the Exploits series and applied the name Exploits Group. No formational names were used but the Wild Bight volcanics defined the base of the group while the Roberts Arm volcanics and equivalents (Breakheart and Moreton's volcanics) were assigned to the top of the sequence. A mid-Ordovician age was assigned to the entire group.

A previously unrecognized extensive volcanic unit was found to underlie sandstones of the Silurian Botwood Formation (Twenhofel and Shrock, 1937). The Silurian volcanic and sedimentary rocks were grouped together as the Botwood Group. Red sandstones on Sunday Cove, Pilleys and Triton Islands which were assigned to the Springdale Group (MacLean 1947) were correlated with sandstones at the top of the Botwood Group and assigned a Silurian age.

In 1962, Williams mapped the Twillingate (2E/10) map area on a 1 inch to 1 mile scale and discovered that Heyl's (1936) stratigraphy of the Exploits series was in error and needed much revision. Heyl had assigned volcanic rocks north of the Lukes Arm Fault to the Breakheart basalt and Moreton's volcanics and these units supposedly formed the top of the Exploits series. Williams believed that these were the oldest rocks in the area and correlated them with the Snooks Arm and/or Lushs Bight Groups. South of the Lukes Arm Fault, Williams found a continuous north-facing sequence consisting of Ordovician volcanic rocks, mid-Ordovician limestone and limey shale, graptolitic black slate and argillite, Upper Ordovician to Lower Silurian greywacke which coarsened upwards into Lower Silurian conglomerate (Goldson Formation). This was the first good fossiliferous stratigraphic sequence to be established for Notre Dame Bay. This sequence was unnamed by Williams.

In the southeast corner of the map area, on the Port Albert Peninsula, the Silurian Goldson conglomerates were found to be overlain by volcanic rocks and sandstones which Williams (1962) had assigned to the Botwood Group. He now included the Goldson conglomerates in the Botwood Group and defined the base of this formation as the base of the Botwood Group.

The Twillingate granite, which intrudes volcanic rocks north of the Lukes Arm Fault was assigned a Devonian (?) age.

Williams felt that some of the faults which separated north-facing Silurian strata from north-facing Ordovician strata, particularly the Cobbs Arm Fault, were thrust faults which were later tilted.

Armed with the stratigraphic sequence of the Twillingate map area, Williams (1963b) compiled the maps of Patrick (1956), Baird (1958) and Jenness (1958) and completed reconnaissance mapping of the Botwood map sheet, with some revisions being made to the west half. All Ordovician rocks north of the Lobster Cove and Lukes Arm faults were correlated and assigned to an unnamed unit, later called the Headlands Group (Williams, 1967a). Jenness's subdivisions of the Gander Lake Group were retained and the middle and upper units were correlated with a new restricted Exploits Group consisting of a lower dominantly volcanic assemblage and an upper dominantly sedimentary assemblage. The Wild Bight volcanics was removed from the Exploits Group and given group status. The Roberts Arm volcanics and the Crescent Lake Formation were grouped together as the Ordovician-Silurian Roberts Arm Group since the invalidation of Heyl's (1936) stratigraphy questioned the relationship of these rocks to the Exploits Group. Upper Ordovician to Silurian greywackes of the Twillingate map area were unnamed and were not shown as extending or having correlatives outside that map area. The three-fold division of the Botwood Group was retained and the Silurian Indian Islands Group was divided into three separate units outlined by Patrick (1956). The Silurian Cape St. John Group was subdivided into a volcanic unit with metamorphosed equivalents, a sedimentary unit and a unit consisting of quartz-feldspar porphyry (Cape Brule granite) and related pyroclastic rocks.

Williams (1972) later wrote more detailed descriptions of the sequences, proposed new stratigraphic names and listed faunal collections from the area in an unpublished manuscript. This unpublished manuscript has been most useful for the present study.

In the course of mapping the volcanic rocks and mineral deposits of Notre Dame Bay, Williams made a most significant rediscovery first made by Alexander Murray in 1865 but ignored for over 100 years. Williams (1963c) concluded that "the base metal mineral deposits and volcanic rocks are genetically related and the sulphides originated with the volcanism." This revived idea of volcanogenic sulphides shed much new light on the origin of and exploration for base metal despoits.

Williams (1967b) described the Silurian rocks of Notre Dame Bay and their relationships to other Palaeozoic rocks. The Silurian rocks were described in geographically separate belts termed the Cape St. John belt, the Springdale belt, the New Bay belt, the New World Island belt and the Botwood belt. The stratigraphic nomenclature and sequence were retained as previously outlined (Williams, 1963b). The Roberts Arm Group was assigned to the Ordovician although a Silurian age was not discounted. The volcanic rocks of the Buchans area, however, were assigned to the Silurian and included in the Springdale belt.

Williams, Kennedy and Neale (1972, 1974) outlined the structural and stratigraphic elements of Notre Dame Bay as viewed at that time, and divided the area into four zones with contrasting stratigraphy and structural styles. One major diversion from previous ideas was the implication that the Twillingate granite is older than most of the Lower Ordovician volcanic rocks of Notre Dame Bay since it is cut by numerous diabase dykes which cut across the foliation in the granite.

Williams and Payne (1975) described the Twillingate granite and surrounding volcanic rocks. They postulated that the granite and the volcanic rocks which it intrudes, which they named the Sleepy Cove Group, are older than and were deformed before the formation of surrounding Early Ordovician volcanic rocks of the Herring Neck Group. They felt that this older terrain represented a remnant island arc witn a more complex history than Lower Ordovician island arc sequences in central Newfoundland.

Williams and Hibbard (1976) described the Dunnage Mélange of the Bay of Exploits area and its relationship to surrounding rocks.

Williams et. al. (1977) summarized the geology along the Baie Verte ultramafic belt. They abandoned the name Baie Verte Group and separated the ophiolitic rocks of the belt into three different complexes. Coarse conglomerates and volcanic rocks south of Baie Verte were designated Flatwater Group and were said to lie unconformably on the ophiolitic rocks. The Flatwater Group was interpreted as having been deposited after the deformation and emplacement of the ophiolitic complexes against the metasedimentary rocks of the Fleur de Lys Supergroup.

2.20. M. Kay

Marshall Kay of Columbia University came to Newfoundland in 1961 to test the hypothesis that Newfoundland had drifted from Ireland. He concentrated on the northeast coast since it was the most promising region in which geology might resemble that of Ireland, and the Geological Survey of Canada was making new geologic maps of the area at that time (Williams 1962, 1963 a,b).

Kay and Williams (1963) described the Ordovician-Silurian relationships on New World Island and suggested that the various sequences of Ordovician and Silurian rocks were repeated along thrust faults which were later steepened. Kay (1967) described the various fault-bounded sequences and stated that the faults were not thrust but transcurrent faults. He applied various names to these sequences and the faults which separate them but the stratigraphic sequence and unit names were those of Williams (1963 a, b) except that Kay applied the name "Sansom greywacke" (Heyl, 1936) to the Upper Ordovician greywackes.

Kay and Eldredge (1968) described mid-Cambrian trilobites from the chaotic Dunnage Formation (Horne 1968). Kay (1969b) described the Silurian rocks of northeast Newfoundland with particular emphasis on the Silurian Goldson conglomerates of New World Island and their relationships to Ordovician rocks. He renamed the conglomerate unit the Goldson Group and described three separate formations, but these were not shown on a map. He also proposed several new formational names for the Ordovician strata of New World Island. The Lower and mid-Ordovician volcanic rocks were named the Summerford Formation and the overlying tuff, Cobbs Arm limestone and graptolitic argillite units were considered to be members of the Hillgrade formation.

Kay (1969b) described an unconformity between Silurian conglomerate and Summerford Formation pillow lava near Green Cove. Williams (1964a) mapped this volcanic unit as Silurian rather than Ordovician and if this is so, then there is no unconformity at this locality. Kay (1969b) first used the term Mic Mac Group for the sequence of Silurian (?) rocks at Mic Mac Lake on the Burlington Peninsula (Neale and Kennedy 1967).

Kay (1970) further described the flysch sequences of the Sansom greywacke and Goldson conglomerates of New World Island and described in more detail the bouldery mudstones of the Dunnage Mélange. He showed a fault, the Dildo Fault, separating the Dunnage Formation from Caradocian argillites to the north of Dildo Run. Horne (1968) had mapped these argillites as conformably overlying the Dunnage Formation. The Summerford Formation (Kay 1969b) was now referred to as the Summerford Group after Horne (1968).

Kay (1972) further described the Dunnage Mélange and its intrusions and commented upon its possible significance in terms of a Proto-Atlantic Ocean. He interpreted the mélange "as having formed in a trench above a northwest dipping subduction zone that evolved in the Cambrian and was terminated in about early Ordovician".

Bergström, Riva and Kay (1974) summarized all available data on the Ordovician faunas from north-central Newfoundland. The stratigraphic names of eastern New World Island were changed somewhat from Kay (1969b) in that the Hillgrade formation became the Hillgrade Group and the Cobbs Arm Limestone and the overlying argillite, which they named the Rodgers Cove Shale, were given formational status within the Hillgrade Group.

Kay (1975) described a sequence of strata, which he named the Campbellton sequence, lying south of the Dunnage Mélange and facing northwards. The Campbellton sequence comprises three units: The Loon Harbour volcanics, consisting of pillow lavas and submarine pyroclastic rocks; the Luscombe Formation or argillite with manganiferous chert members; and the Riding Island Greywacke. Kay suggested that the argillites and manganiferous chert beds of the Luscombe Formation are deep sea sediments above ophiolitic rocks of the Loon Harbour volcanics. Mafic rocks exposed within the outcrop area of Loon Bay volcanics, near Dildo Pond, were used as additional evidence for an ocean floor origin for this sequence. Kay interpreted this north-facing Campbellton sequence as Cambrian to early Ordovician oceanic crust descending beneath a subduction zone represented by the Dunnage Mélange to the north.

Kay (1976a) summarized the Ordovician stratigraphy of Newfoundland, but described only the New World Island-Bay of Exploits portion of Central Newfoundland. A summary and map of Kay's work in the Dunnage Mélange and the Ordovician-Silurian sequences of New World Island was published after his death in 1976 (Kay 1976b).

2.21. J. A. Helwig

James Helwig studied and mapped the rocks of the New Bay area and the Fortune Harbour peninsula for a Ph.D. study at Columbia University under the supervision of Marshall Kay. Helwig (1967, 1969) used the continuous coastal exposures of the New Bay area to redefine the ambiguous Exploits Group (Heyl, 1936, Williams, 1963b). He redefined the Exploits Group as:

> a grossly conformable sequence of lava, pyroclastic rocks, and sedimentary rocks which crop out in the New Bay and Bay of Exploits areas of central and eastern Notre Dame Bay; the lower limit is defined as the exposed base of the Tea Arm volcanics (probably pre-Llanvirnian), and the upper limit is defined as the base of the lowermost tongue of conglomerate of the Goldson Formation (Llandoverian).
>
> (Helwig 1969, p. 408)

Helwig divided the Exploits Group into seven formations, six of which were new. He retained Heyl's (1936) Lawrence Harbour shale but redefined it as a biostratigraphic unit and restricted it to those shales containing a distinctive lowermost Caradocian fauna. Younger Caradocian shales were referred to as "unnamed argillite". Greywackes overlying this argillite were named the Point Leamington Greywacke and correlated as a stratigraphic and facies equivalent of the Sansom greywacke to the east. Helwig found that some conglomerate units, which Williams (1963b) had mapped as Silurian Goldson Formation, were actual lentils within the Upper Ordovician Point Leamington Greywacke and that the Goldson Formation contained greywacke members interbedded with the conglomerates.

Helwig (1967) redefined the position of the Lukes Arm Fault through the Fortune Harbour Peninsula and assigned all rocks north of the fault to the Lushs Bight Group. The Lukes Arm Fault was placed arbitrarily at the base of the Boones Point Complex, a complex volcanic mélange with both tectonic and sedimentary components occurring along the Lukes Arm Fault Zone. This unit was included in the Lushs Bight

Group since it was conformably overlain by Lushs Bight sedimentary rocks, but Helwig recognized and mapped large slices and blocks of Silurian conglomerate within it.

The sedimentary rocks overlying the Boones Point Complex were referred to the lower Lushs Bight Group and the overlying volcanic rocks to the upper Lushs Bight Group. These rocks were separated from an intrusive-volcanic unit to the north by a large fault passing through Fortune Harbour.

Helwig (1967) retained the Wild Bight Group as mapped by Williams (1963b) and suggested it was a volcanic facies equivalent of the lower half of the Exploits Group, since it was conformably overlain by the unnamed argillite. The Sutter Lake (South Lake) pluton which intrudes the Wild Bight Group was believed to be Ordovician in age.

Helwig and Sarpi (1969) described the plutonic pebble conglomerates of the Goldson Group (Kay 1969b) on New World Island and suggested that these rocks represented fluxoturbidite deposits. Sedimentary structures indicated a source area to the north, probably north of the Lukes Arm Fault.

Helwig (1970) described the slump features of the Point Leamington Greywacke.

2.22. G. S. Horne

Gregory S. Horne studied the stratigraphy and structural geology of southwestern New World Island as a Ph.D. thesis at Columbia University under the supervision of Marshall Kay (Horne 1968). Syntheses of the stratigraphy were later published (Horne and Helwig, 1969, Horne 1970).

Horne (1968, 1970) assigned all rocks north of the Lukes Arm Fault to the Headlands Group (Williams 1967a) but he studied only a portion of these rocks between Lukes Arm and Bridgeport Harbour. He divided the Headlands Group into a lower volcanic unit, a sedimentary unit and an upper volcanic unit.

South of the Lukes Arm Fault, Horne followed the nomenclature of the three fault-bounded sequences outlined by Kay (1967) and gave new stratigraphic names to many units in each sequence. Within the southernmost Dildo sequence, Horne made the first detailed descriptions and map of part of the Dunnage Formation. He also distinguished a conformably overlying slaty argillite of Caradocian age which he named the Dark Hole Formation, thus putting an upper age limit on the Dunnage Formation. The Dark Hole Formation is overlain by the Sansom and Goldson Formations which are the uppermost units in all three sequences.

Within the Cobbs Arm sequence, north of the Cobbs Arm Fault, pre-Sansom rocks were assigned to the Summerford Group which Horne divided into six informal stratigraphic units designated Z, A, B, C, D, E. Units Z, B and D are volcanic rocks, unit A volcanogenic arkose, unit C Caradocian shale and unit E a chaotic sedimentary-volcanic unit. Equivalent units in the Toogood sequence, north of the Toogood Fault, were assigned to the Luke Arm Formation but were later included in the Summerford Group (Horne 1970).

Horne (1969) described in detail the internal features of the Dunnage Formation and suggested that it was primarily a sedimentary olistostrome that has been remobilized into a chaotic mélange.

Horne and Helwig (1969) correlated the stratigraphic successions of New World Island with those in the New Bay-Fortune Harbour area and extrapolated westward to Badger Bay and north of the Lobster Cove and Lukes Arm Faults to give a regional outline to the Ordovician stratigraphy of Notre Dame Bay. They correlated the Lobster Cove and Lukes Arm Faults and designated the area north of the "Lukes Arm Fault Zone" the Lushs Bight Terrane. They suggested that the Lushs Bight Group overlies the Cutwell Group (Espenshade, 1937) although Williams (1962) had shown the reverse to be true. The correlations with Espenshade's Badger Bay Series were in great error since the Sansom Greywacke equivalents in that area were shown as being Middle Ordovician in age.

2.23. W. R. Church

William R. Church began studying the metamorphic rocks of the Burlington Peninsula in 1964 to compare them with similar rocks of Ireland. Church (1969) assigned all the high-grade metamorphosed sedimentary and volcanic rocks of the Burlington Peninsula to the Fleur de Lys Supergroup, which consisted of a western and eastern division separated by the Baie Verte Group of low-grade volcanic rock and associated gabbroic and ultramafic rocks.

The western division consists of rocks which Neale and Nash (1963) assigned to the Fleur de Lys Group and Church subdivided these rocks into an older Rattling Brook Group (Watson 1947) and a younger White Bay Group (Betz 1948). The eastern division consisted of the Mings Bight Group (Baird 1951) and metamorphosed volcanic rocks previously considered to be parts of the Baie Verte and Cape St. John Groups (Neale and Nash 1963; Williams 1962). The metamorphosed mafic volcanics, previously part of the Baie Verte Group, were named the Pacquet Harbour Group and the metamorphosed silicic volcanics, previously part of the Cape St. John Group, were renamed Grand Cove Group. Church felt that all of these rocks were structurally coeval and were deformed and intruded by the Burlington granodiorite and Cape Brulé porphyry in pre-Mid-Ordovician times, and the low grade volcanic rocks of the Baie Verte, Snooks Arm and Cape St. John Groups (including the Mic Mac sequence) must all lie unconformably on this older metamorphosed terrain.

Church and Stevens (1971) first described the Newfoundland sequences of layered ultramafic rock, gabbros, sheeted dykes and pillow lava, particularly that at Betts Cove, as ophiolites representing ancient oceanic lithosphere of the central part of the Appalachian system. They suggested that the emplacement of the Bay of Islands and Hare Bay ophiolites "can be explained as the result of underthrusting of the western continental margin and a segment of the ancient oceanic crust beneath oceanic lithosphere now represented by the Betts Cove and Baie Verte ophiolites. Such movements may be related to early contraction of the Appalachian-Caledonian ocean basin along a southeasterly dipping Benioff zone" (Church and Stevens, 1971 p. 1465).

They alternatively suggested that the ophiolites may have been emplaced directly onto the Fleur de Lys rocks at the time of formation along a ridge in a small ocean basin or during an ocean closing phase while a ridge axis was positioned relatively close to the continental margin.

2.24. J. F. Dewey and J. M. Bird

During 1969, 1970 and 1971, John F. Dewey and John M. Bird presented plate-tectonic models for the evolution of the Appalachian orogen particularly in west and west-central Newfoundland. These models relied heavily on the interpretation of the age relationships between the various deformed and undeformed volcanic sequences on the Burlington Peninsula and north of the Lukes Arm Fault. Dewey (1969) suggested that the Lukes Arm Fault represents a Lower Ordovician plate boundary with oceanic crust subducting westwards and the Dunnage Complex forming in the accompanying deep oceanic trench. The Cape St. John Group was shown as a Lower Ordovician island arc complex while the Baie Verte and Tilt Cove serpentinites were thought to be Arenig intrusives.

Bird and Dewey (1970) reinterpreted Dewey's model of westward subduction underneath west-central Newfoundland. The Lushs Bight Group was shown as oceanic crust attached to the North American continent and was underthrust by another plate of oceanic crust in the Dunnage trench zone. They stated that the Lushs Bight Group was deformed prior to deposition of overlying island arc sequences of the Rambler (Pacquet Harbour), Cape St. John, Catchers Pond and Cutwell Groups. They listed a previously unreported unconformity between the lower and upper parts of the Wild Bight Group and also suggested that the Springdale Group was Late Devonian and post-Acadian in age.

Dewey and Bird (1971) further refined the earlier model of a northwest-dipping Dunnage subduction zone and now recognized the ophiolite sequences at the base of the Baie Verte and Snooks Arm Groups.

They followed Church's (1969) terminology and interpretation of the Fleur de Lys Supergroup and felt that the Snooks Arm and Baie Verte Groups were formed in small marginal basins after the deformation of the Cape St. John Group. The Nippers Harbour Group and mafic volcanics (Beaver Cove Group) underlying the Cape St. John Group were felt to be part of an oceanic foundation to the eastern part of the Fleur de Lys Supergroup.

The Lushs Bight Group was referred to as the Little Bay Head Group but was again said to be unconformably overlain by the Western Arm and Cutwell volcanic sequences. The Springdale Group was assigned to the Lower Devonian, but redbeds at Kings Point, included in the Springdale Group by Neale and Nash (1963), were assigned to the Carboniferous.

Bird, Dewey and Kidd (1971) briefly described Newfoundland ophiolites in terms of the opening and closing of a Proto-Atlantic Ocean. They believed that the main ocean closed in pre-Ordovician times and the preserved ophiolites at Betts Cove, Baie Verte and west Newfoundland formed in younger marginal basins.

2.25. M. J. Kennedy

Michael J. Kennedy's work in Newfoundland has dealt mainly with the structural and metamorphic history of the metasedimentary terrains bordering the central volcanic belt on the west and east. His work with Neale (Neale and Kennedy, 1967a, b) is discussed in Section 2.18.

Kennedy and McGonigal (1972) subdivided Jenness' Gander Lake Group into three distinct divisions referred to as the "Gneissic, metasedimentary, and sedimentary and volcanic terranes" (sic). They considered the gneissic terrain to be unconformably overlain by the metasedimentary terrain which in turn is overlain by, or separated by a mélange zone from the sedimentary and volcanic terrain. They referred to the metasedimentary terrane as the Gander Lake Group and the Mid-Ordovician sedimentary and volcanic terrane as the Davidsville Group. Their Gander Lake Group was later renamed the Gander Group (McGonigal, 1973) and the gneissic terrane has been called the Bonavista Bay Gneiss Complex (Blackwood and Kennedy, 1975).

Kennedy and DeGrace (1972) described the structural setting of some sulphide deposits in the Lushs Bight Group. They noted that the chlorite schist zones containing the sulphides have an earlier foliation than that in the surrounding pillow lavas and suggested that the sulphide deposits themselves were zones of mechanical weakness along which early shear belts developed.

Kennedy, Neale and Phillips (1972) compared the Fleur de Lys Supergroup of the Burlington Peninsula with similar rocks of the Irish Caledonides. They used the same terminology as Dewey and Bird (1971) and included the Pacquet Harbour and Cape St. John Groups in the "Cambrian and older" Fleur de Lys Supergroup. The Burlington Granodiorite, Dunamagon Granite and Cape Brulé Porphyry were thought to have intruded the Fleur de Lys Supergroup prior to its deformation in pre-Ordovician time. Williams, Kennedy and Neale (1972, 1974) also followed this interpretation of Burlington Peninsula geology.

Kennedy (1973, 1975) suggested that there are two ages of ophiolite in the Baie Verte-Mings Bight area; one which is pre-Ordovician and deformed with the Fleur de Lys Supergroup and another of Early

Ordovician age. He also showed Nippers Harbour Group as oceanic crust predating the deposition of the island arc sequences of the Pacquet Harbour and Cape St. John Groups above a west dipping subduction zone, similar to the model of Dewey and Bird (1971).

2.26. H. D. Upadhyay

Hansa Datt Upadhyay studied the Gullbridge Mines copper deposit as a M.Sc. thesis at Memorial University in 1970. Upadhyay (1970) and Upadhyay and Smitheringale (1972) described the copper deposit as metamorphosed volcanogenic sulphides in a cordierite-anthophyllite alteration zone.

Upadhyay, Dewey and Neale (1971) described the Betts Cove Ophiolite in some detail and expanded the Snooks Arm Group to include the ultramafic rocks, gabbros and sheeted dykes as well as the overlying pillow lavas and sedimentary rocks. They suggested that the ophiolite formed in a marginal basin adjacent to an island arc lying to the southeast.

Upadhyay and Strong (1973) described the Betts Cove copper deposit and nearby copper showings as "Cyprus type volcanic exhalative mineralization produced at an ocean ridge during the earliest stage of Cambro-Ordovician sea floor spreading". They suggested that most volcanogenic sulphide deposits of this type occur near the contact between sheeted dykes and overlying pillow lava.

Upadhyay (1973) completed a Ph.D. thesis on the Betts Cove ophiolite and related rocks of the Snooks Arm Group. He proposed formational names for the various units within the Snooks Arm Group and these names are adopted in the present study. He followed Bird and Dewey (1971) in assigning the Cape St. John and Beaver Cove Groups to the pre-Lower Ordovician Fleur de Lys Supergroup, even though he noted a marked similarity between the rocks of the Beaver Cove and Snooks Arm Groups.

2.27. D. F. Strong

David F. Strong began field work in Notre Dame Bay in 1971 in the Pilleys Island area. In 1972, he described sheeted dykes within the Lushs Bight Group as indicative of Ordovician sea-floor spreading. He also described sheeted diabases in the Roberts Arm Group and suggested that there is no significant difference in nature or origin between the Lushs Bight, Cutwell and Roberts Arm Groups of volcanic rocks, and all were probably formed by sea-floor spreading.

Strong (1973a), following a chemical study of the volcanic rocks, postulated that the Lushs Bight Group and the associated Brighton gabbro complex had formed in an oceanic environment but the Roberts Arm Group represented a younger island arc complex and the two contrasting groups had later become juxtaposed along the Lobster Cove Fault.

Strong and Payne (1973) described the volcanic rocks north of the Lukes Arm Fault on northwestern New World Island and their relationships to the Twillingate granite. They divided the volcanic rocks into two groups, separated by a major structural discontinuity, the Chanceport Fault. The older volcanic rocks, to the north of the Fault, were named the Moretons Harbour Group which was subdivided into five formations. South of the Chanceport Fault, pillow lavas, bedded tuff and chert were assigned to the undivided Chanceport Group.

Strong and Payne showed that the Twillingate granite intruded the Moretons Harbour Group and therefore could not be an older crustal remnant, and that the metamorphism of the Moretons Harbour Group increases in intensity towards the contact with the granite.

Strong (1973b, 1974) summarized the plate tectonic and historical development of Newfoundland mineral deposits and suggested a Lower Palaeozoic east-dipping subduction zone underneath central and eastern Newfoundland to explain the observed pattern of zonation of metals. Strong et. al. (1974) presented geochemical evidence for an east-dipping subduction zone based on analysis of granitic rocks from eastern and east-central Newfoundland.

Kean and Strong (1975) described the geochemical and stratigraphic evolution of the Cutwell Group, which they showed to have strong affinities to modern island arc volcanism.

Norman and Strong (1975) described the petrology and geocnemistry of ophiolitic rocks between Mings Bight and Baie Verte.

Swinden and Strong (1976) described the plate tectonic setting of Newfoundland mineral deposits.

Strong (1977) summarized the tectonic setting of all volcanic rocks of Newfoundland. The sections of this paper dealing with the Notre Dame Bay area are based largely on the study represented by this thesis.

2.28. Graduate students of M.U.N.

By far the best and most detailed recent studies of the geology, stratigraphy, geochemistry and mineral deposits of Notre Dame Bay have been made by graduate students, mostly of the Memorial University of Newfoundland. The author has drawn freely from their theses and their contributions are acknowledged throughout the succeeding chapters.

2.29. Present study

The writer worked as a summer student with Noranda Exploration Co. Ltd. mapping various parts of the Central Volcanic Belt during the summers of 1969 and 1971. In 1972 he joined that company and spent 15 months on various exploration projects, dominantly conducting and supervising geological mapping and at the same time compiling all previous geological work in the west Notre Dame Bay Area. In the late summer of 1973, the writer joined Dr. D. F. Strong of Memorial University in a regional metallogenic study of Notre Dame Bay. That year the writer mapped in detail the northern half of the Fortune Harbour Peninsula which was a key area in deciphering the geology of Notre Dame Bay. In 1974, all previous work in the area was compiled on 1 inch : 1 mile map sheets in order to obtain a regional picture of the stratigraphy and metallogeny. With this regional picture in mind, key areas were rechecked in the summer of 1974 and unmapped areas were mapped in detail.

The results of this work are 13 1 inch to 1 mile geologic map sheets with brief descriptions of all mines, mineral prospects and occurrences. These 13 maps are included in the map folio of this thesis and will be referred to continuously in the succeeding chapters. Most of these map sheets are on open file with the Geological Survey of Canada as uncolored maps with marginal notes. They are all included in a Newfoundland Department of Mines and Energy report on the geology and metallogeny at Notre Dame Bay (Dean, 1977).

A regional geologic map on a scale of 1 = 250,000 (Plate 1), includes the geology of several areas for which there are no maps at 1 inch to 1 mile scale. This map was compiled by B.F. Kean of the Newfoundland Department of Mines and Energy using the authors maps as well as those of other workers, chiefly Kean. The rocks of some of these areas are described briefly in the thesis for sake of completion of the total regional picture of the geology of the Central Volcanic Belt.

This work presents a new five-fold division of the regional stratigraphy of Notre Dame Bay. This new division considers and incorporates all previous work and new detail is added in most of these areas. In addition, new areas have been mapped and new stratigraphic names are introduced. New fossil localities give more definite ages to several units and additional stratigraphic data and stratigraphic correlations suggest revised ages for other units.

The present study also classifies and describes the volcanogenic base metal deposits of Notre Dame Bay in relation to their position within the new five-fold regional stratigraphy.

3. REGIONAL STRATIGRAPHY

3.1. Introduction

Presently available stratigraphic and geochemical data suggest that the Central Volcanic Belt of Newfoundland is an Ordovician-Silurian island arc complex built upon Cambro-Ordovician oceanic crust. Island arc volcanism occurred in two distinct phases: (1) a Lower to Middle Ordovician (pre-Caradocian) phase of extensive submarine volcanism recognizable throughout the whole Central Volcanic Belt; and (2) an Upper Ordovician -Silurian (post-Caradocian) phase which is characterized by contrasting volcanic regimes in three distinct belts. The two phases are separated in the southeastern section of the Central Volcanic Belt by an extensive Caradocian argillite unit. This unit is not generally recognized in the northwestern section where the post-Caradocian volcanic sequences rest unconformably either on the oceanic crust, the pre-Caradocian island arc sequences or on a granodiorite body intruding those sequences. Post-Caradocian flysch sequences which directly overlie Caradocian argillites in the southeast were derived from an area to the northwest and are time-transgressive from west to east, indicating uplift in the northwest section in Mid-Ordovician time.

Intrusive rocks range in age from Late Cambrian to Late Devonian and are often comagmatic with the volcanic rocks.

Most of the base metal sulphide deposits are volcanogenic stratabound types and vary in characteristics with contrasting volcanic episodes and magma generation.

Figure 3.1. is a general correlation chart of various areas of

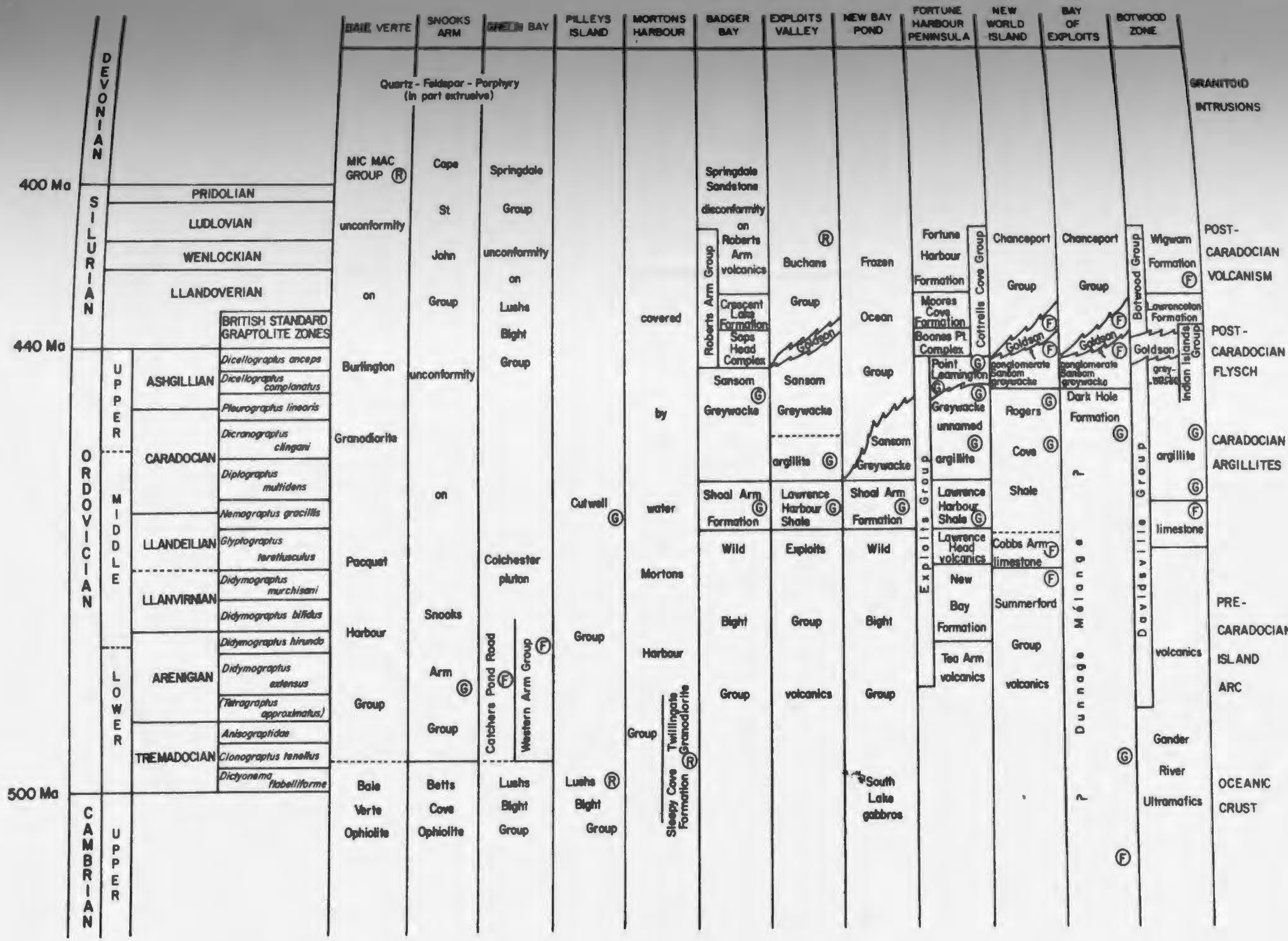


Figure 3.1 Correlation chart of Notre Dame Bay stratigraphy from west to east. R-radiometric date. F-shelly fossil. G-graptolite.

Notre Dame Bay and shows the separation of the various phases of stratigraphic evolution of the Central Volcanic Belt.

3.2. The Oceanic Basement

Present knowledge of the stratigraphy and geophysics of the Central Volcanic Belt indicates that it is entirely underlain by Cambro-Ordovician oceanic crust, although it is conceivable that this oceanic crust may be obducted onto continental crust near the margins of the belt.

A complete ophiolite suite, consisting of layered ultramafics, layered gabbros, sheeted diabase dykes, pillow lavas and overlying sediments is exposed at Betts Cove (Church and Stevens, 1971, Upadhyay et al., 1971) and a dismembered suite is exposed between Baie Verte and Mings Bight (Norman and Strong 1975). Fragmented ophiolites continue along strike in both these areas.

Pillow lavas, sheeted dykes and gabbros of the Lushs Bight Group of western Notre Dame Bay represent the upper portions of oceanic crust (Smitheringale, 1972; Strong 1972, 1973a). Pillow lavas of the Sleepy Cove Formation of North Twillingate Island are comparable to Lushs Bight lavas and are thought to have an oceanic origin.

At South Lake, layered gabbros and sheeted dykes are upfaulted within the Wild Bight Group and perhaps represent an oceanic basement to that group. Layered gabbros and ultramafics and possibly volcanic rocks of the Gander River ultramafic belt at the eastern margin of the Central Volcanic Belt are perhaps remnants of a fragmented, discontinuous ophiolite belt.

Stratigraphic, palaeontological and radiometric dates indicate a Late Cambrian to earlymost Ordovician age for the ophiolitic rocks of Central Newfoundland.

3.3. The Pre-Caradocian (Early) Island Arc

Volcanic rock groups assigned to the pre-Caradocian or early phase of island arc evolution conformably overlie ophiolitic rocks in the Snooks Arm and Western Arm areas. Elsewhere contacts are either faulted or unexposed or structural patterns do not expose the basement to these sequences. These other early arc sequences, represented by the Pacquet Harbour, Catchers Pond, Cutwell, Moretons Harbour, Wild Bight, and lower parts of the Exploits, Summerford, and Davidsville Groups, are inferred to overlie oceanic crust because of stratigraphic and lithologic correlations with the Snooks Arm and Western Arm Groups and because of regional stratigraphic and geophysical considerations.

The internal stratigraphy of the early phase of island arc evolution consists grossly of alternating mafic pillow lava units and submarine volcaniclastic-sedimentary units. The Wild Bight Group, which has the thickest and most complete stratigraphy of the pre-Caradocian volcanic groups, consists of three pairs of such units. Maximum exposed stratigraphic thickness of the early arc, represented by the Wild Bight Group, is approximately ten kilometers. Island arc volcanism was almost entirely submarine and is dated palaeontologically as Arenigian to lowermost Caradocian.

3.4. The Caradocian Interval

Island arc volcanism ceased abruptly in the late Llandeilian and early arc volcanic sequences in eastern Notre Dame Bay are overlain by ubiquitous Caradocian graptolitic shales exemplified by the Shoal Arm Formation, the Lawrence Harbour Shale, the Rodgers Cove Shale, the Dark Hole Formation and unnamed Caradocian argillites of the Exploits and Davidsville Groups.

Caradocian shales have been observed only in the Cutwell Group in northwestern Notre Dame Bay; and in other groups, pre-Silurian unconformities on the earlier sequences record either the erosion of this unit or its non-deposition.

Shale deposition continued throughout the entire Caradocian in easternmost Notre Dame Bay while to the west overlying flysch sedimentation progressed eastwards in Late Caradocian.

The Caradocian shales are remarkably argillaceous and commonly have a cherty base, indicating fairly deep water, even abyssal environments of deposition, yet they commonly overlie shallow-water limestone, volcanics indicative of fairly shallow water depths and even cross-bedded sandstones. This, together with the great thickness of overlying flysch-turbidite deposits in the southeastern section of the Central Volcanic Belt, indicates that this portion of the island arc sank to abyssal depths in the early Caradocian.

[redacted] Post-Caradocian Flysch

Caradocian argillites are generally overlain by variable thicknesses of Late Ordovician to Early Silurian well-bedded greywacke sequences exhibiting most features characteristic of turbidite deposits. These rocks are found throughout the southeastern portion of the Central Volcanic Belt and are known as the Sansom Greywacke and the Point Leamington Greywacke. More argillaceous facies equivalents occur in the slates of the Davidsville and Indian Islands Groups further east.

The greywacke-turbidite sequences are overlain by variable thicknesses of Lower Silurian polymictic conglomerates known as the Goldson Formation, which commonly exhibits features of proximal deposits. Contacts with the underlying greywackes are commonly gradational but are locally very abrupt.

Palaeocurrents, slump folds and other sedimentological features indicate transport of material from the northwest for both the greywacke and conglomerate sequences. Variable thicknesses, intense slumping and contemporaneous volcanism indicate considerable relief and instability in the basin of deposition. Thick beds, especially in the Sansom Greywacke, indicate rapid deposition.

3.6. Post-Caradocian Volcanism

Post-Caradocian or "late island arc" volcanic rocks can be grouped into three distinct belts with contrasting styles of volcanism. These are, from northwest to southeast, the Springdale Belt, the Roberts Arm Belt and the Botwood Belt. Volcanic rocks of the Springale Belt are confined to the northwestern portion of the Central Volcanic Belt and are represented by the Springdale, Mic Mac and Cape St. John Groups and the upper part of the Cutwell Group. Volcanism was dominantly subaerial but locally shallow marine conditions persisted.

Most late arc sequences in the Springdale Belt rest unconformably on pre-Silurian rocks except for the upper units of the Cutwell Group which rest conformably on Caradocian shales. Volcanic rocks in the Springdale Belt range in age from Late Caradocian to Early (?) Devonian.

The Roberts Arm Belt of post-Caradocian volcanism, represented by the Buchans, Roberts Arm, Cottrells Cove, Chanceport and Frozen Ocean Groups conformably overlies the Sansom Greywacke and equivalents, the Goldson Formation, or more rarely the Caradocian argillites. Volcanism is almost entirely submarine, with pillow lavas and interbedded cherty sediments being the most common rock types, and rhyolitic volcanics being confined to volcanic centres. The Roberts Arm Belt of late arc volcanism ranges in age from Late Caradocian to Middle (?) Silurian with volcanic activity being most intense in the Silurian.

The Botwood Belt of post-Caradocian volcanism occurs only in the Botwood Zone of Williams, Kennedy and Neale (1974) in the eastern section of the Central Volcanic Belt. It is represented by subaerial lava flows and pyroclastics of the Silurian Lawrenceton Formation and thin volcanic members of the overlying Wigwam Formation which consists dominantly of red sandstones. The Lawrenceton Formation disconformably (?) overlies Lower Silurian Goldson conglomerates.

The post-Caradocian volcanic sequences are referred to as the late phase of evolution of the Central Newfoundland island arc complex and will be referred to as "late-arc volcanics". Chemically these volcanics are a distinctly bimodal basalt-rhyolite assemblage with a marked lack of andesite, yet they are strongly calc-alkaline and resemble volcanics of modern island arcs. For this reason, they are referred to as "late-arc volcanics" although the Central Volcanic Belt did not necessarily have the configuration of an island arc at the time these rocks formed.

3.7. Intrusive Rocks

Pre-Devonian intrusive rocks of the Central Volcanic Belt are genetically related to the various different phases of evolution of the volcanic stratigraphy and are often comagmatic with volcanism.

Concordant to slightly discordant intrusive bodies in the upper sections of the ophiolitic rocks are generally gabbroic in composition and relatively small in size, and are most common in the Lushs Bight Group. Coarse hornblende gabbros of the Brighton Gabbro Complex which intrudes the Lushs Bight Group in the Pilleys Island area are also believed to be related to the Cambro-Ordovician oceanic crust.

Fine to coarse-grained gabbro sills are present throughout the pre-Caradocian island arc sequences and often intrude poorly consolidated strata indicating comtemporaneity with volcanism. Small tonalitic and granitic stocks sometimes occur near large extrusive masses of felsic volcanics. Several large bodies of soda-rich granodiorite intrude the ophiolitic and early arc sequences and are more common in the northwestern section of the Central Volcanic Belt. These are best represented by the Twillingate Granite, the Burlington Granodiorite and the Colchester Pluton. In the south-eastern section, similar rocks of the South Lake Igneous Complex intrude ophiolitic rocks and early arc rocks of the Wild Bight Group. Radiometric ages from these granodiorite bodies range from 510 to 440 Ma. These intrusions are generally believed to be the products of melting of subducted oceanic crust in an island arc environment (Payne 1974) but similar rocks also occur in ophiolite suites, e.g. the Little Port Complex in the Bay of Islands area.

Gabbro and diabase sills occur in both the post-Caradocian flysch and volcanic belts, being most common in the Roberts Arm Belt. Fine-grained granitic bodies are associated with large centres of acidic volcanism. In the Springdale Belt, quartz-feldspar porphyries which appear to be feeders for extensive acidic volcanism (DeGrace et al., 1976) are very common and can be quite large in areal extent, for example the Cape Brulé Porphyry.

Devonian intrusives post-date the main Acadian deformation and are generally discordant intrusive bodies of batholithic dimensions. They range in composition from gabbro to syenite and several large batholiths exhibit an early gabbroic phase intruded by a later granitic phase. Devonian intrusives in the northwestern section of the Central Volcanic Belt are generally richer in quartz and potash than those in the southeast. Microcline-megacrystic and garnetiferous granites, characteristic of the eastern and western metasedimentary terrains of the Central Mobile Belt, are absent in the Central Volcanic Belt.

Jurassic alkali gabbro stocks and lamprophyre dykes are probably related to the initial rifting of the Labrador Sea (Strong and Harris, 1974.)

4. THE OPHIOLITIC ROCKS

4.1 Introduction

The Geological Society of America 1972 Penrose Conference on ophiolites defined ophiolite as:

> a distinctive assemblage of mafic to ultramafic rocks. It should not be used as a rock name or a lithologic unit in mapping. In a completely developed ophiolite the rock types occur in the following sequence, starting from the bottom and working up: ultramafic complex, consisting of variable proportions of harzburgite, lherzolite, and dunite, usually with a metamorphic tectonite fabric (more or less serpentinized); gabbroic complex ordinarily with cumulus textures, commonly containing cumulus peridotites and pyroxenites and usually less deformed than the ultramafic complex; mafic sheeted dyke complex; and mafic volcanic complex, usually pillowed. Associated rock types include (1) an overlying sedimentary section typically including ribbon cherts, thin shale interbeds, and minor limestone; (2) podiform bodies of chromite generally associated with dunite; and (3) sodic felsic intrusive and extrusive rocks. Faulted contacts between mappable units are common. Whole sections may be missing. An ophiolite may be incomplete, dismembered or metamorphosed, in which case it should be called a partial, dismembered, or metamorphosed ophiolite.
>
> (Geotimes, v. 17, No. 12, p. 25)

According to the above definition, only the Betts Cove Ophiolite of the Central Volcanic Belt can be considered a complete ophiolite. The Baie Verte Ophiolite is a dismembered ophiolite and other ophiolitic rocks of the Central Volcanic Belt are partial ophiolites. The allochthonous Bay of Islands Igneous Complex is the best preserved ophiolite suite in Newfoundland and shows the entire ophiolite stratigraphy.

Figure 4.1 shows the stratigraphy of the various Newfoundland ophiolites and ophiolite remnants, all possibly formed at a mid-oceanic ridge during a single Cambrian phase of sea-floor spreading in the Proto-Atlantic Ocean.

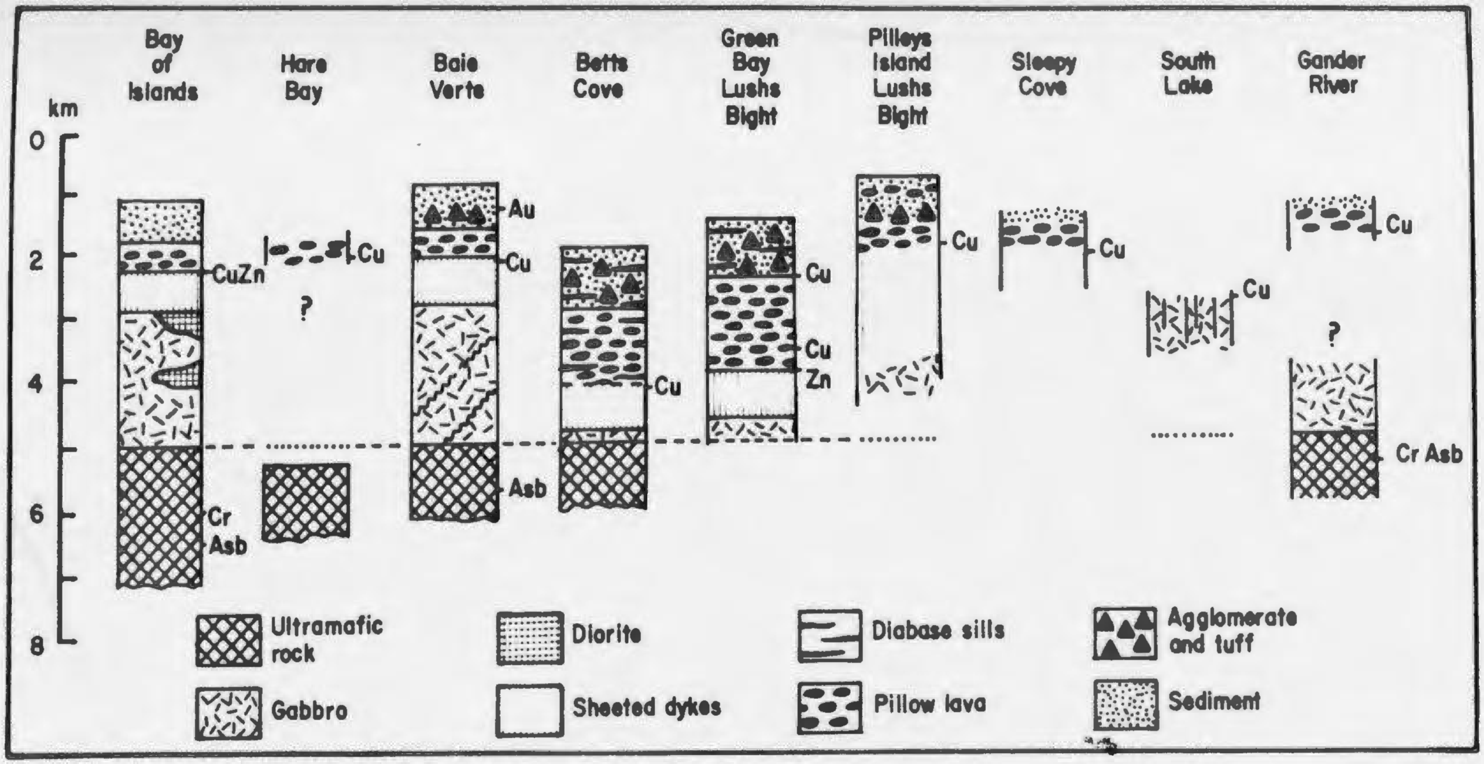


Figure 4.1. Stratigraphy and mineral deposits of ophiolites, partial and dismembered ophiolites of central and western Newfoundland. Dashed line is the approximate base of the Lower Paleozoic oceanic crust.

4.2. The Baie Verte Ophiolite (Plate 1 and 12H/9)

The Baie Verte Group of this thesis is considered to be almost entirely ophiolite and the terms Baie Verte Group and Baie Verte Ophiolite are used synonomously. The Baie Verte Group has been described as oceanic lithosphere by Church and Stevens (1971), Bird and Dewey (1971), Kidd (1974) and Norman and Strong (1975).

The Baie Verte Ophiolite marks the western boundary of the Central Volcanic Belt and probably also marks the "root zone" for the obducted Hare Bay and Bay of Islands Ophiolites (Malpas and Strong, 1974; Williams, et al., 1977). It is exposed on the Burlington Peninsula in a linear belt extending from Birchy Lake on the Trans-Canada Highway to Baie Verte and then swinging eastwards into Mings Bight, and extends north-eastwards offshore (Howarth, et al., 1976). The exposed base of the ophiolite is generally in fault contact with the polydeformed Fleur de Lys metasedimentary terrain to the west along a complex, presumably oversteepened thrust zone. This zone contains highly deformed amphibolitic schists, and serpentinized ultramafic rocks are locally remobilized along this zone.

The uppermost exposed section of the Baie Verte Group, consisting of mafic volcanics and volcanogenic sediment, is faulted to the east against both the Silurian-Devonian Mic Mac Group and the Burlington Granodiorite which underlies the Mic Mac Group. In the Mings Bight area, south-facing tuffs and pyroclastics at the top of the Baie Verte Ophiolite are in fault contact with the younger Pacquet Harbour Group of dominantly island arc volcanics to the south. However, ophiolitic rocks occur south of the supposed fault contact (Church, 1969) suggesting that the Baie Verte

Ophiolite may continue underneath the Pacquet Harbour Group.

The Baie Verte Ophiolite in the Mings Bight area has been described by Norman (1974) and Norman and Strong (1975) as a "schuppen zone" consisting of five fault-bounded structural blocks separated by serpentinized peridotite and/or talc carbonate. Various parts of the ophiolite stratigraphy are represented in each of the structural blocks but it is more complete in the two largest blocks which are consistently south facing and consist of (1) a basal peridotite-pyroxenite-gabbro unit, (2) a layered gabbro unit, (3) a sheeted diabase unit, and (4) a pillow lava unit overlain by agglomerate, tuff and cherty sediments.

Williams et al. (1977) have suggested that volcanic and sedimentary rocks of the Baie Verte Group in the Flatwater Pond-Mic Mac Lake area are considerably younger than the Baie Verte Ophiolite and have proposed the name "Flatwater Group" for these rocks.

4.3. The Betts Cove Ophiolite (Plate 1.)

The Betts Cove Ophiolite, as documented by Upadhyay et al. (1971) and Upadhyay (1973), is exposed along the east coast of the Burlington Peninsula from Tilt Cove in the north to Pittmans Bight in the south and forms the base of the east-facing Snooks Arm Group. Ophiolitic rocks south of Pittmans Bight extending to Stocking Harbour, were included in the Nippers Harbour Group by Upadhyay et al. (1971) and were believed to be part of an older ophiolite. Schroeter (1971) suggested that these rocks were part of the Betts Cove Ophiolite and DeGrace et al. (1976) confirmed this interpretation. These rocks are therefore included in the Betts Cove Ophiolite in the following discussion and the term "Nippers Harbour Group" is abandoned.

The western lowermost units of the Betts Cove Ophiolite are faulted against younger rocks of the Cape St. John Group and the Cape Brulé Porphyry. Contacts with the porphyry are intrusive in the Nippers Harbour area where giant rafts of ophiolitic rocks are completely surrounded by the porphyry (Schroeter, 1971; DeGrace et al., 1976). The southern end of the ophiolite is intruded by the Ordovician (?) Burlington Granodiorite at Stocking Harbour.

The ophiolitic rocks are overlain conformably by submarine volcanic and sedimentary rocks of the Snooks Arm Group which contains a single Lower Ordovician (Arenig) graptolite locality (Snelgrove, 1931). These rocks are assigned to the pre-Caradocian island arc of central Newfoundland. Subaerial volcanic and sedimentary rocks of the Cape St. John Group unconformably overlie the Betts Cove Ophiolite at Rogues Harbour.

The complete ophiolite stratigraphy is exemplified only in the Betts Cove area where a steeply-dipping, east-facing section is very well exposed. Elsewhere faults disrupt the sequence and the sheeted dyke horizon is generally missing. Upadhyay (1973) defined and mapped the ultramafic, gabbro, sheeted dyke and pillow lava members of the Betts Cove Ophiolite in the Betts Cove area. The stratigraphy is similar to the Baie Verte and Bay of Islands Ophiolites with the exception of the relative thinness (less than 300 m.) of the layered gabbro zone.

The pillow lava member of the Betts Cove Ophiolite is overlain by a sedimentary and pyroclastic unit known as the Bobby Cove Formation (Upadhyay, 1973) which, in this study, is considered to be the basal unit of the overlying island arc assemblage. Although part of this unit obviously represents layer one of the Lower Palaeozoic crust, a fine line cannot be drawn between the ophiolite and island arc sequences and the Bobby Cove Formation is included in the island arc sequence because of the predominance of andesitic agglomerate and tuff.

Mattinson (1975) has dated zircons from the Betts Cove Ophiolite near Nippers Harbour as 463 ± 6 Ma. This young age is untenable without major revisions to the Ordovician time scale since the ophiolite itself is conformably overlain by 2 km of pre-Arenig strata.

4.4. Lushs Bight Group (12H/9, 2E/12, 2E/11)

The Lushs Bight Group of ophiolitic rocks occurs north of the Lobster Cove Fault in western Notre Dame Bay. In the Green Bay area, it crops out between Southwest Arm and Halls Bay and in the Pilleys Island area on Sunday Cove Island, Pilleys Island and Triton Island. League Rock and Sculpin Island, two small islands east of Triton Island, are also composed of Lushs Bight Group rocks.

The Lushs Bight Group, as defined by Espenshade (1937) and as used by MacLean (1947), also included sedimentary and volcanic rocks which are now known to be of island arc affinity. These rocks have subsequently been placed in the Western Arm Group (Marten, 1971) and the Cutwell Group (Kean and Strong, 1975) and the Lushs Bight Group now includes only ophiolitic rocks. This reassignment means that there are no rocks of the Lushs Bight Group at or near the locality of Lushs Bight. The name "Lushs Bight" is retained but the type locality is moved to the eastern coast of Pilleys Island where it has recently been described by Strong (1973a). The terms Lushs Bight Terrane (sic) (Horne and Helwig, 1969) and Lushs Bight Supergroup (Strong and Payne, 1973) should not be used since it includes a wide variety of rocks of different origins with a wide age span.

The Lushs Bight Group is faulted against the Silurian-Devonian Springdale Group and the Ordovician-Silurian Roberts Arm Group to the south along the Lobster Cove Fault. It is conformably overlain by the Lower Ordovician Western Arm Group in the northwest and presumably by the Catchers Pond Group in the southwest, although contact relations have not been established in this area. A suggested fault (the Long Tickle Fault of Kean, 1973) between the Lushs Bight Group on Pilleys Island and the Cutwell Group on Long Island is exposed on the northeast coast of Sunday Cove Island in a 10 meter wide chloritic shear zone.

The Lushs Bight Group consists of mafic pillow lava, pillow breccia, aquagene tuff, sheeted diabase dykes, massive basalt flows, thin sills of gabbro and small bodies of ultramafic rocks. It is at least 4 km thick and the present large area of exposure is probably due to repetition of stratigraphy along major thrust faults (Kennedy and DeGrace, 1972; Dean and Strong, 1977). The sequence faces south in the Pilleys Island area and in the southern half of the Green Bay area. In the northern section of the Green Bay area, the stratigraphy faces north and is conformably overlain by north-facing strata of the Western Arm Group.

Marten (1971) recognized two facies of pillow lavas in the Lushs Bight Group which he named "the main facies" and "the black facies". He suggested correlations with the "Whalesback type" and "St. Patrick's type" pillow lavas divisions proposed by Papezik and Fleming (1967) for Lushs Bight Group rocks to the south. The main facies is characterized by epidotized pillow lavas and is overlain by the relatively fresh black facies characterized by chlorite alteration. More recent studies of metamorphism in ophiolites (Spooner and Fyfe, 1973) suggest that intense alteration and metamorphism of the lower pillow lava units is a common phenomenon and is a result of sub-sea floor hydrothermal metamorphism at active spreading ridges.

Sheeted dykes in the Lushs Bight Group (Strong, 1972) are more common than previously believed and are easily recognized in the southern half of the Springdale peninsula and at Pilleys Island. Gabbros are generally thin and are not commonly layered. Ultramafic rocks occur only as a few small bodies of serpentinized peridotite. Ferruginous chert beds and clastic sediments are locally well developed.

Geochemical studies of Lushs Bight lavas and dykes (Strong, 1973a; Smitheringale, 1972) show that these rocks are low-potash tholeiites with strong affinities with recent oceanic crust.

The Lushs Bight Group is overlain by the Lower Ordovician Western Arm Group and is intruded by the Brighton Gabbro Complex which gives a $\sim{}^{40}Ar/{}^{39}Ar$ radiometric age of 494 $\pm$ 5 Ma on hornblende (Stukas and Reynolds, 1974). Thus a Late Cambrian age is most likely for the Lushs Bight Group.

4.5. Brighton Gabbro Complex (2E/12)

The Brighton hornblende-gabbro complex intrudes pillow lavas and sheeted dykes of the Lushs Bight Group in the Pilleys Island area. It is exposed on Brighton Island and smaller surrounding islands and a small patch is exposed on the east coast of Pilleys Island. It is generally a very coarse-grained hornblende gabbro with a complex history of multiple intrusion with each intrusive phase being progressively less mafic. It is like some facies of the gabbros of other Newfoundland ophiolites, including its intrusive relationships to the pillow lavas and sheeted dykes, suggesting a similar origin. However, its slightly alkalic chemistry (E. Hussey, pers. comm.) suggests that it represents an off-axis igneous event away from the active ridge which produced the Lushs Bight Group.

4.6. Sleepy Cove Formation (2E/10)

The Sleepy Cove Formation, exposed on North Twillingate Island, forms the exposed base to the Moretons Harbour Group, a continuous steeply-dipping, west-facing sequence of dominantly island arc volcanics (Strong and Payne, 1973). The Sleepy Cove Formation consists dominantly of pillow lavas with numerous diabase dykes in several localities. Preliminary chemical analyses and lithologic similarity to the Lushs Bight Group volcanics suggest that these rocks are oceanic tholeiites.

The Sleepy Cove Formation is intruded by the Twillingate Granite, which has yielded a zircon radiometric U/Pb age of 510 $\pm$ 17 Ma. (Williams et al. 1976), suggesting a Cambrian age for the volcanic rocks.

Williams and Payne (1975) and Williams et al. (1976) have used the term "Sleepy Cove Group" for all the rocks which the Twillingate Granite intrudes and suggested that both the volcanic rocks and the granite were formed in an island arc environment. I see no evidence for Williams' and Payne's supposed fault contact between the Moretons Harbour and Sleepy Cove Groups at Tizzards Harbour, nor is there any lithological, chemical or structural contrast in this area. The Moretons Harbour Group is considered to be stratigraphically continuous in this area and is extended eastwards to include all the volcanic rocks north of the Chanceport Fault. The Sleepy Cove Formation is considered to be a remnant of an ophiolitic base to the Moretons Harbour Group.

4.7. South Lake Ophiolite (New) (2E/6)

The South Lake Ophiolite is but a small part of the South Lake Igneous Complex, exposed in a linear belt, approximately 45 km. long, northwest of Point Leamington. The South Lake Igneous Complex is generally fault bounded on its eastern and western margins but intrudes the Wild Bight Group of pre-Caradocian island arc volcanics on its north and south margins and is probably of Ordovician age.

Three different igneous phases are recognizable: (1) a layered gabbro-sheeted dyke complex, the South Lake Ophiolite; (2) a quartz-hornblende diorite phase; and (3) a granodiorite phase. The granodiorite phase intrudes the South Lake Ophiolite and also appears to be younger than the diorite phase. It is the only phase which definitely intrudes the Wild Bight Group.

The South Lake Ophiolite occurs on the north end of South Lake as a steeply-dipping, east-facing sequence of layered gabbros and sheeted dykes approximately 1 km thick. Mafic gabbros are common at the exposed base and grade upwards into interlayered mafic and leucocratic gabbro cut by diabase dykes perpendicular to igneous layering. The diabase dykes become more numerous eastwards and are intruded on the east by granodiorite with mafic inclusions. Similar granodiorite intrudes the gabbros to the west with more mafic inclusions and extensive development of intrusion breccia.

The South Lake Ophiolite is considered to be a remnant of the Cambro-Ordovician oceanic basement to the Central Volcanic Belt. The quartz-hornblende diorite may also have an oceanic origin. The granodiorite phase of the South Lake Igneous Complex is similar to the Twillingate Granite and may have formed during the early stages of island arc evolution.

4.8. Gander River Ultrabasic Belt (Plate 1.)

The Gander River Ultrabasic Belt (Jenness, 1954, 1958) extends from Gander Lake northeastwards towards Ragged Harbour and continues offshore and is exposed on Copper Island northeast of Ragged Harbour (Baird, 1958; Williams 1968). It marks the eastern boundary of the Central Volcanic Belt and is generally faulted (thrusted ?) against the Gander metasedimentary terrain to the east.

Nowhere is ophiolite stratigraphy exhibited in the Gander River Ultrabasic Belt but exposure is very poor compared to the Burlington Peninsula Highlands of Notre Dame Bay. The best exposures are on Copper Island where well-layered gabbros are cut by both granitic and mafic dykes. Jenness (1958) has pointed out the close spatial relationship between ultramafics, gabbros and volcanic rocks in this belt and all the components of an ophiolite, including small bodies of soda-rich granite, are present but are undoubtly dismembered and locally intensely metamorphosed.

Serpentinite, gabbro, and pillow lava blocks are incorporated in a mélange zone exposed to the east in the Carmanville-Aspen Cove area around the margins of several Devonian plutons. This mélange zone was certainly more extensive before the intrusion and its position relative to the ultrabasic belt and at the margin of the Central Volcanic Belt is certainly most significant. Jenness (1958) has described contacts between gabbro and slate, gabbro and tuff, gabbro and granite and serpentinite with limestone and slate with little or no thermal effects. This perhaps suggests that other parts of the Gander River Ultrabasic Belt have the character of a mélange and the whole belt could possibly be a mélange incorporating disrupted oceanic crust at the eastern edge of the Central Volcanic Belt.

Uzuakpunwa (1974) has suggested that the ultramafic belt formed part of the Gander Zone and was deformed with the Gander Group (Kennedy and McGonigal, 1972) before the Mid-Ordovician. He has also shown that the Davidsville Group volcanic rocks and the Carmanville mélange were thrust, in a nappe-like fashion over the Gander Group. If the ultramafic rocks were either in a mélange or at the base of the Davidsville Group volcanics, then surely the slippery serpentinites would behave as a lubricant and would become very deformed during any deformational episode.

The eastward thrusting of the ultramafics and gabbros as well as the Davidsville Group volcanics over the metasediments of the Gander Group explain the east-facing recumbent folds characterizing the Gander Group (Kennedy and McGonigal, 1972).

Much more detailed mapping is needed to define and delineate the boundaries and nature of the ophiolitic rocks of the Gander River Ultrabasic Belt and its significance as the eastern margin of the Central Volcanic Belt.

4.9. Mineral Deposits of the Ophiolitic Rocks

The most common type of economic mineral occurrence associated with the Newfoundland ophiolites is "Cyprus type" base metal sulphide deposits with relatively simple mineralogy (pyrite with chalcopyrite $\pm$ sphalerite). Some of these deposits such as Betts Cove Mine occur near the contact zone between the sheeted dyke complex and the overlying pillow lava unit (Upadhyay and Strong, 1973), suggesting that they were formed at the site of active spreading which formed the ophiolites. Others such as York Harbour Mine (Duke and Hutchinson, 1974) and the Rendell Jackman Mine (Kennedy and DeGrace, 1972) occur well above the sheeted dyke horizon in mafic pillow lavas and aquagene tuffs, but could also have formed near an active mid-oceanic ridge.

By far the greatest number of massive sulphide deposits of the "Cyprus type" occur in the Lushs Bight Group which has more copper prospects per square kilometre than any other group of rocks in Newfoundland. The copper deposits and prospects occur almost exclusively in chlorite schist zones (Peters, 1967) which probably represent alteration zones originally underneath the massive sulphide ore but later flattened with the massive sulphide body parallel to local structural trends. Kennedy and DeGrace (1972) have shown that the chlorite schist zones have an earlier schistosity not present in surrounding rocks, suggesting that these zones were areas of structural weakness in the early deformational history of the Lushs Bight Group.

Several major gold prospects occur in quartz veins within a thin band of ferruginous chert and tuff at the top of the Baie Verte Ophiolite near Mings Bight.

Layered chromite occurrences in ultramafic rocks of the Bay of Islands Ophiolite are poorly represented in the ophiolitic rocks of Central Newfoundland but occurrences have been noted from the Baie Verte Ophiolite (Norman 1973) and the Gander River Ultrabasic Belt (Jenness, 1958).

Serpentinized ultramafic rocks of the Baie Verte Ophiolite host the large Advocate asbestos deposits and other large prospects south of Baie Verte. These deposits probably formed during collision of the Baie Verte Ophiolite with the Fleur de Lys metasedimentary terrain and subsequent metamorphism (Williams et al., 1977).

Table 4.1. Mines, past producers and major mineral prospects in Newfoundland ophiolites.

Ophiolite sequence	Deposit name
Bay of Islands	York Harbour - Cu, Zn Gregory River - Cu Lewis Brook - Asb. Bluff Head - Cr.
Baie Verte	Terra Nova - Cu, Zn Goldenville - Au Barry and Cunningham - Au Advocate - Asb.
Betts Cove	Tilt Cove - Cu Betts Cove - Cu, Zn Burtons Pond - Cu, Zn Stocking Harbour - Cu Rogues Harbour - Cu, Zn
Lushs Bight Group	Whalesback - Cu Little Deer - Cu, Zn Little Bay - Cu Colchester - Cu Rendell-Jackman - Cu Sterling - Cu, An Lady Pond - Cu Little Bay Head - Cu Miles Cove - Cu Old English - Cu
Sleepy Cove Formation	Sleepy Cove - Cu
South Lake Ophiolite	South Lake - Cu
Gander River Ultrabasic Belt	Shoal Pond - Cr Gander River - Asb. Great Burnt Lake - Cu, Cr.

5. THE PRE-CARADOCIAN ISLAND ARC SEQUENCES

5.1. Introduction

The concept of an ancient island arc in the Central Volcanic Belt of Newfoundland is not a new one. Heyl (1936) felt that the "Exploits Series" volcanic and sedimentary rocks were formed in an ancient island arc environment. Marshall Kay (1951) proposed that many geosynclinal volcanic rocks of the Appalachians were remnants of a Lower Palaeozoic island arc that once lay along the eastern margin of North America. More recently Strong (1973a, b), Strong and Payne (1973) and Kean and Strong (1975) have presented detailed geochemical and stratigraphic studies which firmly substantiate an island arc origin for lower Palaeozoic volcanic rocks in several areas of Notre Dame Bay.

The recognition, during the present study, of widespread Caradocian shales overlying these dominantly volcanic sequences indicates that the Early and Middle Ordovician evolution of the island arc ceased or at least paused in the Caradocian. Thus the pre-Caradocian dominantly volcanic sequences of the Central Volcanic Belt are a distinct package of rocks with correlative time and lithologic units. This package consists dominantly of submarine volcanic and sedimentary rocks with a maximum measurable thickness of about 10 km, and possible thicknesses up to 12 km.

The gross stratigraphy of the composite sequences is relatively simple, consisting of alternating thick volcaniclastic-sedimentary units and mafic pillow lava units. The most complete section is that of the

Wild Bight Group which has three volcaniclastic units and three pillow lava units. The thickness of units and total section thickness can be seen to increase from west to east and then thin rapidly to the east (Fig. 5.1.).

Volcanic and sedimentary rocks assigned to the pre-Caradocian island arc sequences include (1) all those rocks which conformably overlie ophiolitic pillow lavas (Western Arm, Snooks Arm and Moretons Harbour Groups); (2) correlative sequences conformably overlain by Caradocian argillites and inferred to be underlain by oceanic crust (Wild Bight Group, the pre-Caradocian sections of the Cutwell, Exploits, Summerford and Davidsville Groups, the Loon Harbour volcanics); (3) similar pre-Caradocian volcanic groups whose base and top are undefined but are presumed to be directly underlain by oceanic crust (Catchers Pond and Pacquet Harbour Groups); (4) the complex Dunnage Mélange which appears to have formed contemporaneously with the pre-Caradocian island arc sequences.

5.2 Snooks Arm Group (Plate 1)

That portion of the Snooks Arm Group assigned to the pre-Caradocian island arc conformably overlies the Betts Cove Ophiolite and is unconformably overlain by the Cape St. John Group. It extends from the north side of Betts Cove to Beaver Cove Head, north of Tilt Cove. This section of rocks consists of four units exemplifying the alternating volcaniclastic-sedimentary and mafic pillow lava units characteristic of the early arc sequences. The following descriptions are taken mostly from Upadhyay (1973) who first applied formational names to the Snooks Arm Group.

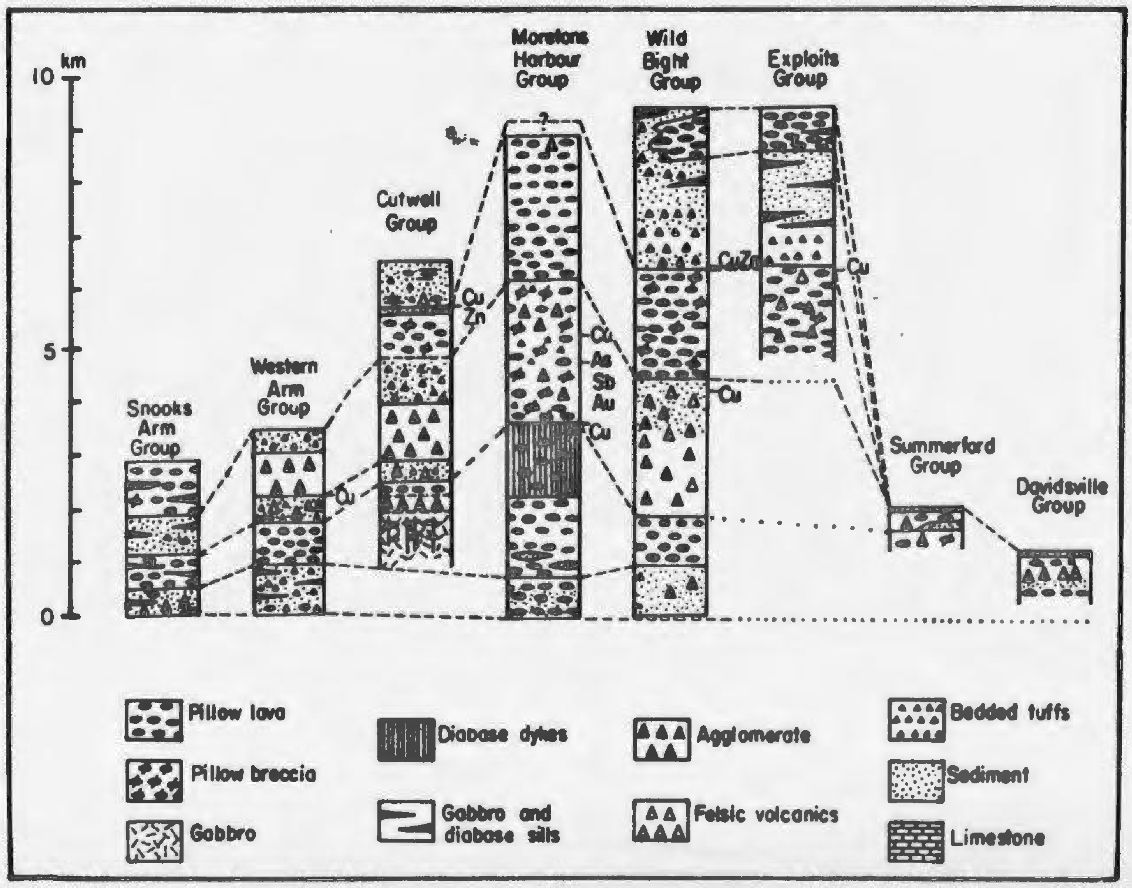


Figure 5.1. Stratigraphic sections for the various volcanic sequences of the pre-Caradocian Arc and the position of various mineral occurrences in the stratigraphy.

Dashed line at base of sections represents the top of the pillow lava unit of the ophiolites.

The Bobby Cove Formation is a volcaniclastic-sedimentary unit conformably overlying the pillow lava member of the Betts Cove ophiolite. It is approximately 500 m thick and is composed largely of andesitic agglomerate and tuff commonly exhibiting phenocrysts of clinopyroxene and plagioclase. Less common lithologies are andesitic flysch, greywacke, chert and argillite. Volcaniclastic rocks between Beaver Cove and Beaver Cove Head were previously assigned to the pre-Ordovician Beaver Cove Group by Dewey and Bird (1971) and Upadhyay (1973). These rocks are now included in the Bobby Cove Formation because of the strong lithologic and structural similarity with rocks south of Beaver Cove (DeGrace et al. 1976) and the term "Beaver Cove Group" is dropped.

The Venams Bight Basalt, overlying the Bobby Cove Formation, consists of about 500 m of pillow lava and minor pillow breccia. This unit is in turn overlain by the Balsam Bud Cove Formation, 750 m. of tuff, greywacke, agglomerate, chert and argillite. Large rhyolite clasts occur in coarser agglomerates, indicating nearby felsic volcanism, but no large rhyolite units have been described from the Snooks Arm Group. Snelgrove (1931) reported Lower Ordovician graptolites from this unit on the south side of Snooks Arm. Collections from this locality by the writer and Dr. David Skevington of Memorial University further substantiated an Arenig age for the Balsam Bud Cove Formation.

The uppermost unit of the Snooks Arm Group is the Round Harbour Basalt with an exposed thickness of 1000 m of dominantly pillow basalt. Possible units above the Round Harbour Basalt are not likely to occur under the waters of Notre Dame Bay to the east since a synclinal axis on the coast near Snooks Head apparently repeats the stratigraphy on an eastern limb.

All four units of the Snooks Arm Group are commonly intruded by diabase, porphyritic diabase, and fine-grained gabbro sills up to 200 m thick. Such sills are common throughout the pre-Caradocian volcanic sequences and are most likely comagmatic with the volcanism.

The Bobby Cove Formation is overlain unconformably by sedimentary rocks of the Silurian (?) Cape St. John Group at Pinnacle Point north of Beaver Cove (Neale et al., 1975). Felsic dykes, presumably related to the Cape Brulé Porphyry and Cape St. John Group volcanics, intrude the Snooks Arm Group and are particularly well exposed in the Tilt Cove area.

5.3. Pacquet Harbour Group. (Plate 1)

The Pacquet Harbour Group (Church, 1969) includes the package of dominantly meta-volcanic rocks south and west of Pacquet Harbour and southeast of Baie Verte. The rocks are intruded on the west and south by the Burlington Granodiorite, on the north by the Dunamagon Granite and on the east by the Cape Brulé Porphyry. The Pacquet Harbour Group is generally considered to be in fault contact with the Baie Verte Ophiolite south of Mings Bight (Church, 1969; Kennedy, 1975). However, since ophiolitic rocks are known from south of this supposed fault and other similar lithologies are known from both sides of the fault, the Pacquet Harbour Group probably overlies the Baie Verte Ophiolite and is in part a deformed equivalent to the non-ophiolitic portions of the Snooks Arm Group.

The Pacquet Harbour Group consists of mafic pillow lava, massive basalt flows or sills, mafic pyroclastics, bedded tuff, greywacke and chert. These rocks are intruded by numerous diabase, diorite and gabbro dykes and sills which appear to be contemporaneous with volcanism. Felsic pyroclastics and flows are present within the mafic pyroclastic and tuff units and are especially noteworthy in the immediate area of Consolidated Rambler Mines operations.

Internal stratigraphy and thickness of the Pacquet Harbour Group is unknown because of the poor exposure and complex structural history of these rocks. In the northwest, the rocks have been complexly polydeformed and metamorphosed to amphibolite facies. Deformation decreases southeastward and only greenschist metamorphism is evident in this area.

Rocks of the Pacquet Harbour Group were originally included in the Ordovician Baie Verte Group by Baird (1951) and Neale (1958) but were placed in the Fleur de Lys Supergroup by Church (1969) who considered the sequence to be pre-Baie Verte on the basis of its complex structural history. DeGrace et al.(1976) have shown that the deformation of the Pacquet Harbour Group is definitely post-Ordovician in age. Lead from the Ming Mine of Consolidated Rambler Mines Ltd. has been dated at 470 Ma (Sangster and Thorpe, 1975) suggesting an Early to Middle Ordovician age for the Pacquet Harbour Group.

The Pacquet Harbour Group appears to be in structural and stratigraphic conformity with metasedimentary rocks of the Mings Bight Group at Pelée Point on the north side of Pacquet Harbour. This presents a major geologic problem in central Newfoundland since the Mings Bight Group is generally considered to be part of the Fleur de Lys metasedimentary terrain whose eastern boundary with the Central Volcanic Belt is marked by a serpentinite belt or a major structural discontinuity.

There are several possible solutions.

(1) The sequence on the north side of Pacquet Harbour is separated from the main outcrop area of the Mings Bight Group by a fault at Bateaux Cove. Conceivably, the metasedimentary rocks in this section are not part of the Mings Bight Group but are meta-sediments within the Pacquet Harbour Group.

(2) The volcanic rocks in this section are part of the Mings Bight Group since similar meta-volcanic rocks are known from elsewhere in the Mings Bight Group, and in the main outcrop area of the Fleur de Lys Group.

(3) The contact between the two groups at Pelée Point is an early thrust fault later masked by the intense deformation and metamorphism in the area.

(4) The Mings Bight Group of metasedimentary rocks is part of the Central Volcanic Belt rather than the Fleur de Lys metasedimentary terrain.

The writer prefers the second hypothesis since the Baie Verte Lineament swings sharply to the east from Baie Verte (Norman, 1974) and was probably continuous from Mings Bight into Pacquet Harbour prior to the intrusion of the Dunamagon Granite. Thus the meta-volcanics at Pelée Point are analogous to the Birchy Schist of the Fleur de Lys terrain to the west (J. P. Hibbard, pers. comm. 1978).

5.4. Western Arm Group. (12 H/9, 2E/12)

The Western Arm Group (Marten, 1971) conformably overlies ophiolitic pillow lavas of the Lushs Bight Group on the northwest portion of the Springdale Peninsula. MacLean (1947) included these rocks in the "Western Arm Section" of the Lushs Bight Group but Marten (1971) applied formational names to the stratigraphy outlined by MacLean and raised the sequence to group status. The stratigraphy and lithologies can be readily correlated with the island arc portion of the Snooks Arm Group (Fig. 5.1. and 5.2.) and the Western Arm Group possibly represents the east limb of the syncline near Snooks Head, displaced by movements along the Green Bay Fault.

The lowest unit of the Western Arm Group, the Skeleton Pond Tuff, conformably overlies unaltered basalt of the Lushs Bight Group and is approximately 750 m thick. The lower half of this unit consists of two tuff members, each overlain by grey pillow basalt members. The upper half consists of a bedded tuff member with coarse breccia horizons at its top and base. The Skeleton Pond tuffs are mafic to intermediate in composition and are entirely waterlain. Thickly-bedded, coarse green crystal lithic tuffs are generally interbedded with green and red banded cherts and finer tuffs. Marten (1971) reported one thin horizon of silicified dacitic tuff near the middle of the upper tuff member.

MacLean (1947) reported a single specimen of the brachiopod *Discotreta* sp. from rocks now included in the Skeleton Pond Tuff. This fossil indicated an Early Ordovician, "probable late Canadian" (MacLean, 1947, p. 4.) age for the base of the Western Arm Group.

The Big Hill Basalt overlies the Skeleton Pond Tuff and consists of approximately 650 m. of dark grey pillow basalt with minor chert and argillite lenses.

<table>
<tr><th>Snooks Arm Group</th><th>Western Arm Group</th><th>Cutwell Group</th><th>Moretons Hr. Group</th><th>Wild Bight Group</th><th>Exploits Group</th></tr>
<tr><td rowspan="4">Round Harbour Basalt</td><td rowspan="4"></td><td>Caradocian Argillite</td><td rowspan="4">Western Head Formation</td><td>Caradocian Argillite</td><td>Caradocian Argillite</td></tr>
<tr><td>Parsons Point Formation</td><td rowspan="2">Penny's Brook Formation</td><td>Lawrence Head Volcanics</td></tr>
<tr><td rowspan="2">Burnt Head Formation</td><td>New Bay Formation</td></tr>
<tr><td>Side Harbour Formation</td><td rowspan="7">Tea Arm Volcanics</td></tr>
<tr><td rowspan="2">Balsam Bud Cove Formation</td><td>Western Head Agglomerate</td><td>Quinton Cove Formation</td><td rowspan="2">Little Harbour Formation</td><td rowspan="2">Seal Bay Brook Formation</td></tr>
<tr><td>Welsh Cove Tuff</td><td>Pigeon Head Formation</td></tr>
<tr><td rowspan="2">Venams Bight Basalt</td><td rowspan="2">Big Hill Basalt</td><td rowspan="2">Stag Island Formation</td><td>Beachy Cove Terrane</td><td rowspan="2">Sparrow Cove Formation</td></tr>
<tr><td>Webber Bight Formation</td></tr>
<tr><td>Bobby Cove Formation</td><td>Skeleton Pond Tuff</td><td rowspan="2"></td><td>Trump Island Formation</td><td rowspan="2">Omega Point Formation</td></tr>
<tr><td>Pillow lava member of Betts Cove ophiolite</td><td>Pillow lava of Lushs Bight Group</td><td>Sleepy Cove Formation (pillow lava)</td></tr>
</table>

Fig. 5.2. Correlation chart showing stratigraphic terminology and correlation for pre-Caradocian sequences with known internal stratigraphy.

The Welsh Cove Tuff overlies the Big Hill Basalt and is in turn overlain by the Western Head Agglomerate. These two units are undivided on the map sheets because of the small outcrop area of Welsh Cove Tuff. The Welsh Cove Tuff is approximately 250 m thick and is comprised dominantly of acidic crystal tuffs with interbedded chert, argillite and basic to intermediate tuffs. The Western Head Agglomerate has an exposed thickness of approximately 820 m of coarse, bedded mafic agglomerate with thin lenses of tuff, cherty tuff and pillow lava. Clinopyroxene phenocrysts characterize the mafic fragments within the coarse agglomerates. Diorite and gabbro clasts in the agglomerates were reported by Neale and Kennedy (1967a). The exposed top of the Western Head Agglomerate is the top of the Western Arm Group and younger stratified rocks are not seen in the Western Arm area.

The Western Arm Group is intruded by sills of porphyritic diabase and gabbro. These sills are especially prominent in the Welsh Cove Tuff and the Skeleton Pond Tuff. Like the sills of the Snooks Arm Group, these are also contemporaneous with volcanism since they intruded the tuff before consolidation, appear as fragments in the agglomerates, and were cleaved with the tuffs.

The Western Head Agglomerate is intruded by the Dollard Quartz Diorite, a small pluton which also appears to be comagmatic with volcanism.

5.5. Catchers Pond Group (12H/8, 12H/9)

The Catchers Pond Group (Dewey and Bird, 1971) out crops in a wedge-shaped area bounded by the Lobster Cove Fault to the south and the

Green Bay Fault to the northwest. This sequence of volcanic rocks is generally faulted against the Lushs Bight Group to the northeast along the Catchers Brook Fault, although Neale and Nash (1963) show a comformable contact in an area of limited exposure west of Catchers Pond. If this contact is conformable, then the Catchers Pond Group overlies the Lushs Bight Group since the Lushs Bight Group faces south in this area.

The Catchers Pond Group is faulted against the Silurian-Devonian Springdale Group to the east and south along the Lobster Cove Fault and against the Ordovician Burlington Granodiorite and Devonian porphyries to the northwest along the Green Bay Fault. A smaller area, south of Indian Pond, underlain by the Catchers Pond Group is separated from the main area of exposure by Devonian granite. This area is intruded by a small body of granodiorite very similar to the main Burlington Granodiorite.

The Catchers Pond Group consists of mafic pillow lava, mafic agglomerate, felsic agglomerate and tuff, felsic lava and thin beds of chert and limestone. Most rocks exhibit greenschist facies metamorphism, and tectonic cleavage is pronounced in mafic rock types. The internal stratigraphy and thickness is unknown because of the relatively poor exposure. The general lithologies are different from the Western Arm Group in that there is a greater abundance of felsic volcanic rocks. This possibly indicates that the Catchers Pond Group formed in proximity to a volcanic centre.

Trilobites from a single limestone bed in the sequence have been assigned an Early Ordovician (Arenig) age by Dean (1970). These fossils were previously thought to be Silurian in age and these rocks were included in the Springdale Group by Neale and Nash (1963).

The Catchers Pond Group is everywhere intruded by dykes, sills and small intrusive bodies of Devonian quartz-feldspar porphyry similar to the porphyry to the north and to fine grained phases of the Devonian granites. These porphyries are difficult to distinguish from the felsic flows of the Catchers Pond Group in the field but are chemically much more potassic (D. F. Strong, personal communication).

5.6. Cutwell Group (2E/12)

The Cutwell Group (Kean and Strong, 1975) is exposed on Long Island, Little Bay Island, Halls Bay Head and on several smaller islands in this general area. On Pilleys Island, the east coast of Sunday Cove Island and at Halls Bay Head, the Cutwell Group is faulted against the Lushs Bight Group. The Cutwell Group is inferred to overlie the Lushs Bight Group because of the strong lithological and stratigraphic similarities with the Western Arm Group (Fig. 5.2.)

The Cutwell Group on Long Island is the best studied sequence of Ordovician volcanic rocks in Notre Dame Bay and is well described in terms of island arc evolution by Kean (1973) and Kean and Strong (1975). The continuous south-facing sequence is greater than 5 km. thick and exhibits the effects of deposition in shallowing water depths upwards. Volcanic rocks change from island arc tholeiites to calc-alkaline, low-silica andesites with a corresponding increase in Al_2O_3 and K_2O and decrease in CaO and MgO upwards.

The Cutwell Group was divided by Kean (1973) into six formations and one "complex". Black shales at the top of the Parsons Point Formation, in the upper portion of the group, have recently yielded lower Caradocian graptolites. The Cutwell Group is the only sequence north of the Lobster Cove Fault to contain the Caradocian argillite unit so common in sequences south of this fault. This also means that the Cutwell Group includes both pre-Caradocian and post-Caradocian volcanic rocks as well as the Caradocian argillite unit. The following discussion will include only the pre-Caradocian portion of the Cutwell Group.

The lowest unit of the Cutwell Group, the Stag Island Formation, consists dominantly of basaltic pillow lava but also contains coarse explosive breccia and intrusive diabase members. Total exposed thickness is approximately 1200 m. although the base is not defined. The lithologies of the Stag Island Formation are typical of the lowest mafic volcanic unit of the pre-Caradocian arc sequences.

The Stag Island Formation is conformably overlain by approximately 500 m. of reworked pyroclastic and volcanogenic sedimentary rocks of the Pigeon Head Formation. These rocks are well-bedded and exhibit many sedimentary features indicating soft-sediment deformation. Grey, massive chert beds occur sporadically throughout the sequence and discontinuous arkose lenses are common.

The Pigeon Head Formation is conformably overlain by coarse agglomerates of the Quinton Cove Formation. This unit consists almost entirely of agglomerates except for a thin reworked tuff horizon in the middle of the formation. Fragments vary in size from microscopic to three feet across in a fine tuffaceous matrix. The Quinton Cove Formation thins rapidly to the southeast and is absent in the Southern Head area of Long Island where the Pigeon Head Formation is overlain by the Burnt Head Formation.

The Burnt Head Formation consists of a complex mixture of alternating and interdigitating pillowed andesite and pyroclastic members. Acidic pyroclastics, black cherty shale, chert and fine-grained tuffs occur as discontinuous units throughout the 1800 m. of stratigraphy of this formation. Complex and rapid volcanic facies changes reflect a complex environment of volcanism probably with much more volcanic relief present than at earlier times in the evolution of the volcanic sequence. Near the top of the Burnt Head Formation limestone blocks occur in tuffaceous rocks and the entire unit is overlain by shallow water limestones of the Parsons Point Formation. This formation is best exposed at Lushs Bight where the recrystallized limestone breccia is overlain by cross-bedded feldspathic greywacke which is in turn overlain by graptolitic Caradocian argillites. The entire formation has a maximum thickness of 75 m. The limestone unit contains abundant brachiopods, crinoid fragments, gastropods and trilobite fragments although no positive identifications have been made. This limestone unit occurs at the same stratigraphic position as the Cobbs Arm Limestone of New World Island and is most certainly time equivalent (Llandeilian).

The pre-Caradocian section of the Cutwell Group is intruded by cogenetic sills and stocks of granodiorite, gabbro and diabase and by felsic fine-grained intrusives (Seal Cove Complex) related to post-Caradocian volcanism of the Cutwell Group.

5.7. Moretons Harbour Group (2E/10, 2E/11, 2E/6)

The Moretons Harbour Group, redefined after Strong and Payne (1973), includes all those volcanic and sedimentary rocks north of the Chanceport Fault on Twillingate, New World, Black, and Exploits Islands and on the Fortune Harbour Peninsula and smaller surrounding islands. In the type area of Moretons Harbour-Twillingate, the group is a continuous southwest-facing sequence along the section B-A. (2E/10)

The base of the Moretons Harbour Group is represented by presumed ophiolitic volcanic rocks of the Sleepy Cove Formation described in Chapter 4. The Sleepy Cove Formation is presumably overlain by volcanic rocks of the Trump Island Formation east of Matthews Island in Friday Bay. To the east, the Twillingate Granite intrudes and separates the Sleepy Cove Formation in the north from the Trump Island Formation in the south. The Trump Island Formation borders the southern margin of the Twillingate Granite and consists of variably metamorphosed volcanic rocks, the dominant original lithologies being pillow lava, pillow breccia and bedded tuff. Original structures such as pillows are generally highly flattened and elongated. Where contacts are exposed, the Trump Island Formation is always faulted against younger rocks of the Moretons Harbour Group. Thickness of this unit is approximately 1 km.

Younger rocks of the Moretons Harbour Group are relatively little deformed or metamorphosed except for local areas of intense amphibolitization and are readily correlated with similar rocks of the Western Arm and Cutwell Groups, except for the greater abundance of diabase dykes in the Moretons Harbour Group.

The Webber Bight Formation consists of 1.5 km. of pillow lava characterized by abundant clinopyroxene phenocrysts and chlorite-blue-green hornblende amygdules. These lavas are intruded by numerous diabase dykes so that only small "screens" of lava still remain between the dykes. The number of dykes increases upwards to form the Beachy Cove, Herring Neck and Sweeny Island Terrains, all characterized by sheeted diabase dykes with minor screens of pillow lava and bedded fine-grained tuff. These sheeted dyke "terrains" are anomalous in the island arc volcanic sequences of Central Newfoundland since such rocks are generally restricted to ophiolitic sequences. These diabases, however, are island arc tholeiites, rather than oceanic tholeiites and their position near the base of the Moretons Harbour Group perhaps indicates the igneous roots of the early arc complex. Approximate thickness of this dyke terrain is 1.3 km.

The diabase dykes decrease in number upwards towards the base of the overlying Little Harbour Formation, which is characterized by abundant coarse pyroclastic rocks and bedded tuff. The Little Harbour Formation is approximately 2.5 km. thick and is overlain by 2.5 km. of black pillow lava of the Western Head Formation, which represents the exposed top of the Moretons Harbour Group. On the Fortune Harbour Peninsula and on Exploits Island, the Little Harbour Formation or equivalent pyroclastic rocks are absent and the Western Head Formation directly overlies the Sweeny Island sheeted dyke terrain.

The Moretons Harbour Group, as well as being intruded by numerous contemporaneous diabase dykes, is also intruded by cogenetic gabbro plugs, sills and dykes. Pink felsic dykes occur throughout the sequence but are especially prominent in the Little Harbour Formation where they are related to Au-As-Sb mineralization (Gibbons and Papezik, 1970). The age of these dykes relative to the volcanic rocks is unknown.

The absolute age of the Moretons Harbour Group is unknown. The Sleepy Cove and Trump Island Formations are presumably Cambrian in age since they are intruded by the Twillingate Granite which has given a U/Pb radiometric age of 510 ± 17 Ma on zircon (Williams et al., 1976). The younger formations correlate well with Lower Ordovician units of the Cutwell and Western Arm Groups.

Williams and Payne (1975) and Williams et al., 1976) included the Sleepy Cove Formation, the Trump Island Formation and part of the Webber Bight Formation in their "Sleepy Cove Group" and extended the fault contact with the Moretons Harbour Group at Sam Jeans Cove along the coast through Tizzards Harbour. The writer does not accept their proposed line of strong metamorphic contrast at Tizzards Harbour and all of the rocks at Tizzards Harbour are included in the Webber Bight Formation. Rocks which Williams et al. (1976) included in the Sleepy Cove Group are stratigraphically continuous into the Moretons Harbour Group and form the stratigraphic base to the Moretons Harbour Group. Hence, they are included in the Moretons Harbour Group and the term "Sleepy Cove Group" is not used in this study.

5.8 Wild Bight Group (2E/3, 2E/4, 2E/5, 2E/6)

The Wild Bight Group is exposed along the coastline and islands of Notre Dame Bay from Shoal Arm in Badger Bay to Osmonton Arm in New Bay and extends southwards to the Twin Lakes - New Bay Pond area where it is truncated by large Devonian batholiths. This sequence of rocks is approximately 10 km thick and is the thickest and most continuous stratigraphic sequence of pre-Caradocian island arc volcanic rocks. The section from the core of the Seal Bay Anticline, in the bottom of Seal Bay, to the base of the Shoal Arm Formation, in Shoal Arm of Badger Bay, is a continuous stratigraphic sequence and is the type section for the Wild Bight Group.

The lowest formation, exposed in the core of the Seal Bay Anticline, is the Omega Point formation (new). It consists of approximately 1 km. of well bedded tuff, chert, tuffaceous sandstone, and greywacke. This unit is overlain by approximately 500 m. of pillow lava known as the Sparrow Cove formation (new), which is in turn overlain by the Seal Bay Brook formation (new). The Seal Bay Brook formation is approximately 2.5 km. thick and consists dominantly of massive to poorly-bedded agglomerate and tuff, commonly containing clasts of green chert. Other less common lithologies of this formation are felsic flows and pyroclastics, bedded chert and greywacke, and mafic volcanic flows. The Seal Bay Brook formation is overlain by a unit of 1-2 km. of mafic pillow lavas and flows with thin felsic volcanic horizons called the Side Harbour formation (new). This unit is overlain by the Pennys Brook formation (new) which consists largely of bedded tuff but also contains thick units of mafic flows, pillow lavas, felsic flows and agglomerates, and thin units of chert, argillite and greywacke. Thickness of the Pennys Brook formation varies from 3-4 km. and rapid volcanic facies changes are characteristic of this formation.

The Wild Bight Group, like other pre-Caradocian volcanic groups, is intruded by gabbro and diabase sills which are contemporaneous with volcanism. The largest of these, the Marks Lake Sill (Hayes, 1951b) extends from Marks Lake to the coast of Badger Bay, where it exhibits features of early soft-sediment intrusion and later Acadian folding with the tuffs of the Wild Bight Group. The Marks Lake Sill was previously used to mark the top of the Wild Bight Group and stratigraphically higher tuffs and greywacke were included in the Beaver Bight Formation (Hayes, 1951b; Williams, 1963b.) This division is artificial since the rocks are identical above and below the sill and volcanic rocks continue up to the base of the Caradocian Shoal Arm Formation. Thus, the name 'Beaver Bight Formation' is dropped and these rocks are included in the Pennys Brook Formation of the Wild Bight Group.

The eastern exposures of the Wild Bight Group are intruded by the younger granodiorite phase of the Ordovician (?) South Lake Igneous Complex (Chap. 4).

Younger discordant intrusive bodies are Devonian to Jurassic in age.

The Wild Bight Group is everywhere overlain by Caradocian chert and argillite of the Shoal Arm Formation. Rocks within the group are undated but correlate well with Lower to Middle Ordovician rocks of the Cutwell and Western Arm Groups.

5.9. Summerford Group (2E/7, 2E/10)

The Summerford Group, redefined after Horne (1970), is exposed on southwestern New World Island and continues along strike northeastwards to Cobbs Arm and nearby offshore islands. This sequence of pre-Caradocian volcanic and sedimentary rocks is bounded to the south by the Cobbs Arm Fault and is overlain to the north by younger sedimentary rocks.

Horne (1969, 1970) divided the Summerford Group into six separate units. The lower half of the sequence consisted of two mafic volcanic units, Unit Z and Unit B separated by an arkosic unit referred to as Unit A. Unit B was overlain by Caradocian argillites of Unit C which was overlain by another mafic volcanic unit Unit D. This whole assemblage was overlain by a chaotic sedimentary unit referred to as Unit E, which was overlain by Upper Ordovician Sansom Greywacke, not part of the Summerford Group.

The present study has shown that Horne's (1970) interpretation of the stratigraphy is invalid. Unit Z and Unit B are indistinguishable in the field and Unit A is a discontinuous member occurring at the top of the volcanic sequence. Volcanics mapped as Unit D actually underlie the Caradocian argillites and are in fact the same as Unit B. Unit E consists of highly slumped Caradocian argillites and overlying Sansom Greywacke. Thus, the Summerford Group of this report consists of pre-Caradocian mafic volcanics with a discontinuous limy tuff and arkose unit near the top of the volcanic sequence. This sequence is overlain by Caradocian argillites, Unit C, which also include most of Horne's (1970) Unit E. The limy tuff and arkose unit, Unit A, appears to be a facies of the Cobbs Arm Limestone of the Hillgrade Group (Bergström et al., 1974) which overlies the volcanics of the Summerford Group between Hillgrade and Cobbs Arm.

The Summerford Group is dated palaeontologically as Late Arenigian to Caradocian (Neuman, 1976; Bergström et al., 1974). Tremadocian fossils have been reported from volcanics west of Village Cove (Kay, 1967) but these have never been confirmed.

The abundant limestone in the volcanic rocks, oxidized volcanics and eroded fossils indicate a turbulent, shallow-water environment of deposition for the top of the pre-Caradocian Summerford Group and the overlying Cobbs Arm Limestone. This possibly means that the Summerford Group volcanic sequence was much thicker than the 300-500 meters presently preserved north of the Cobbs Arm Fault. The present Summerford Group may be merely the top of this sequence thrust eastwards onto Silurian rocks along the Cobbs Arm Fault (Dean and Strong, 1977).

5.10. Exploits Group (2E/3, 2E/6)

The Exploits Group (Helwig, 1969) is exposed all around the arms of New Bay, on the west coast of the Bay of Exploits, on Thwart and Upper Black Islands, and on smaller islands in these three areas. The Exploits Group, as defined by Helwig (1969), can be divided into a pre-Caradocian volcanic and sedimentary division and a Caradocian and younger sedimentary division. The following discussion will include only the pre-Caradocian rocks.

The oldest rocks of the Exploits Group are the Tea Arm Volcanics, which consist dominantly of mafic pillow lavas, pillow breccia, and mafic flows similar to the lithologies of the Side Harbour Formation of the Wild Bight Group to the west. The Tea Arm Volcanics are exposed only in the core of the Strong Island Anticline and maximum exposed thickness is approximately 1.8 km.

The Tea Arm Volcanics are overlain by turbidites, tuffaceous sandstones, greywacke, conglomeratic turbidites and tuffs of the New Bay Formation. Tuff, argillite and chert at the base of this unit, previously named the Saunders Cove Formation (Helwig, 1969), are presently included in the New Bay Formation since similar lithologies occur at various stratigraphic levels in the New Bay Formation. Thus the Saunders Cove Formation is not lithologically distinct and the name is dropped.

The New Bay Formation is approximately 2.2 km. thick and is most likely a distal volcanic turbidite facies of the upper part of the Wild Bight Group. It is overlain by approximately 800 m. of mafic pillow lavas and flows of the Lawrence Head Volcanics which are conformably overlain by Lower Caradocian chert and argillite.

The New Bay Formation and Lawrence Head Volcanics are intruded by many large thick sills of gabbro and diabase which are again contemporaneous with the magmatic evolution of the pre-Caradocian sequences. These are more numerous and larger in the New Bay Formation than in any other part of the pre-Caradocian sequences.

5.11. Dunnage Mélange (2E/6, 2E/7, 2E/10)

The New Bay Formation of the Exploits Group grades transitionally eastwards into the chaotic Dunnage Mélange (Williams and Hibbard, 1976) which forms the Burnt Bay Peninsula north of Lewisporte, the islands of the eastern Bay of Exploits and Dildo Run, as well as a small part of southern New World Island.

The Dunnage Mélange consists of chaotic black and green argillite and pebbly mudstone with large blocks (or "knockers") of volcanic rocks, gabbro, greywacke, limestone, micaceous sandstone and granite. These apparently slid into the argillaceous sequence in a series of mass flow deposits and were further disturbed and tectonized. Hibbard (1976) has shown that the Dunnage Mélange, in its eastern part has a ghost stratigraphy which was originally continuous with the lower part of the

Exploits Group prior to disruption. The timing of this disruption of stratigraphy must have occurred in the Caradocian since the Lawrence Head Volcanics and the gabbro sills intruding the New Bay Formation occur as knockers in the mélange.

Dewey and Bird (1971), Kay (1972), and Williams and Payne (1975) have interpreted the Dunnage Mélange as an oceanic trench deposit associated with a west-dipping subduction zone east of the central Newfoundland island arc. Hibbard's (1976) work has shown that, at least in the southwestern portion, the mélange is formed entirely of rocks which were originally continuous with the pre-Caradocian Exploits Group stratigraphy prior to disruption in the Caradocian. This means that the mélange did not form until after pre-Caradocian island arc volcanism ceased and thus cannot be temporally linked to any subduction related to formation of that island arc. Thus the southwestern portion of the Dunnage Mélange is merely a disrupted, slumped portion of the pre-Caradocian island arc sequence and can be considered as stratigraphic equivalents of the New Bay Formation and Lawrence Head Volcanics of the Exploits Group.

The northeast portion of the Dunnage Mélange, as exposed on Coal All, Chapel and Dunnage Islands and on nearby smaller islands on the south side of Dildo Run, is significantly different and probably older than the southeastern and northwestern portions. The link and stratigraphic correlation with the Exploits Group or any other pre-Caradocian sequence is not at all apparent. These rocks contain Mid-Cambrian trilobites (Kay and Eldredge, 1968) in a limestone lens in a volcanic block in the argillaceous mélange. These are by far the oldest known fossils from the

Central Volcanic Belt and indicate mid-Cambrian volcanism in an area believed to be underlain by Upper Cambrian oceanic crust. One of the trilobites is of definite Atlantic provinciality (W. Dean, pers. comm., 1974). In 1976, the author, R. K. Stevens, D. Skevington and A. Poynter collected Tremadocian graptolites from the black shaley matrix of the Dunnage Mélange on a small island just north of Chapel Island on Route 340. These fossils indicate that the matrix of the mélange in this area is older than the initiation of island arc volcanism in the Arenigian in the rest of the Central Volcanic Belt.

The mélange in the Chapel Island area contains numerous clasts of micaceous sandstone. There are no known pre-Silurian rocks in the Central Volcanic Belt from which these clasts could have been derived. In this same area, the Dunnage Mélange is intruded by a series of stocks, sills and dykes with unique lithologies. Quartz-feldspar porphyry and diorite commonly contain mafic, ultramafic and amphibolitic inclusions. Granodiorite and syenite intrusions have been noted by Williams and Hibbard (1976). Rhyolite sills and dykes show strong flow layering and numerous features of soft-sediment intrusion. None of these intrusive bodies show any metamorphic effect on the mélange. For example, the graptolites were collected from within 150 m. of a diorite contact on the Curtis Causeway. Kay (1972) has reported conglomerates within the mélange containing clasts of the quartz-feldspar porphyry which intrudes the mélange. All these features indicate that these intrusives are a part of the unique geological environment in which this portion of the Dunnage Mélange formed and are part of that process of formation.

These rocks of the northeastern portion of the Dunnage Mélange are unique to the Central Volcanic Belt. Their older fossils with possible Atlantic provinciality, the micaceous sandstone clasts, and the contrast with the southwestern portion of the Dunnage terrane perhaps indicates the influence of an eastern continental margin to the Central Volcanic Belt. That is, these rocks were derived from an eastern continent and were mixed with the southwestern island arc terrain during the juxtaposition of both terrains in the Caradocian. This will be further discussed in Chapter 9.

5.12. Loon Harbour Volcanics (2E/7, 2E/3, Plate 1.)

The Loon Harbour Volcanics (Kay, 1975) are exposed in the core of an anticline in the Loon Harbour-Dildo Pond area, southeast of the Dunnage Mélange. The dominant lithologies are mafic pillow lavas, pillow breccia and tuff. These are identical to volcanic rocks of the Pennys Brook Formation of the Wild Bight Group and are conformably overlain by cherts and argillites which are identical to those of the Shoal Arm Formation, as exposed on Route 350 north of Northern Arm and on the south side of Lewis Lake. These argillites contain Caradocian graptolites on the east shore of Burnt Bay. Thus the Loon Harbour Volcanics represent the top of the pre-Caradocian island arc sequence, and these rocks do not bear any resemblance to Cambro-Ordovician oceanic crust as suggested by Kay (1975). The manganiferous cherts overlying the volcanics are widespread in the Caradocian in Notre Dame Bay and occur as far west as Badger Bay, where they overlie 10 km. of island arc volcanics of the Wild Bight Group. Although these cherts may indicate abyssal sedimentation, they are certainly not indicative of oceanic crust. Mafic gabbros out cropping south of Loon

Harbour and inferred to be further indicative of oceanic crust by Kay, (1975) are in fact micaceous alkali gabbros identical to the dated Jurassic Budgells Harbour Gabbro west of New Bay (Strong and Harris, 1974).

The present position of the Loon Harbour island arc volcanics southeast of the Dunnage Mélange is enigmatic if the Dunnage is either a subduction zone trench deposit or a "mixed zone" of island arc and eastern continental margin rocks. Either the Dunnage Mélange is an intra-arc feature or the Loon Bay Volcanics are allochthonous, having been thrust southeastward over the Dunnage prior to Acadian folding.

There is a remote possibility that the Loon Bay Volcanics and the overlying Caradocian rocks are a large block or series of blocks which form part of the Dunnage Terrain, that is a less disrupted stratigraphic portion of the Exploits or Wild Bight Groups.

5.11. Davidsville Group (Plate 1)

The Davidsville Group (Kennedy and McGonigal, 1972) extends from Gander Lake northeastward to the coast of Gander Bay and Hamilton Sound. It is separated from the Gander metasedimentary terrain to the east by the Gander River Ultrabasic Belt, a complex mélange, a major fault or an unconformity with relationships changing along strike.

The Davidsville Group includes a volcanic and a sedimentary division (Kennedy and McGonigal, 1972) which corresponds roughly to the middle and upper units of Jenness' (1957) Gander Lake Group. The volcanic division of the Davidsville Group is pre-Caradocian in age and is similar in most respects to the other pre-Caradocian island arc volcanics of Notre Dame Bay. The following discussion will apply only to the volcanic division.

Volcanic rocks of the Davidsville Group are best exposed in the Carmanville area near the coast of Hamilton Sound. Here they consist of submarine mafic agglomerates which commonly exhibit thick graded units with thin chert horizons near the tops. Chert fragments are locally abundant in the agglomerates. Some of these agglomerate units appear to be mafic pillow breccias rather than true pyroclastics.

Volcanic rocks exposed between Gander Lake and Ragged Harbour occur in thin discontinuous horizons in a tectonically complex zone. The volcanic rocks are entirely submarine and consist of mafic agglomerate, lapilli tuff, fine-grained tuff and highly altered mafic lava. Jenness (1958) described some of the mafic lavas as definite spilite. Conceivably, some of these volcanic rocks are ophiolitic and form an oceanic base to the Davidsville Group.

A thin limestone or calcareous siltstone unit occurs near or at the top of the volcanic division of the Davidsville Group. Brachiopods from this unit indicate a Middle Ordovician age for the youngest volcanic rocks of the Davidsville Group. This calcareous unit occupies a similar stratigraphic position to the Cobbs Arm Limestone of New World Island to the west. Recent identification of conodonts from this unit at Weirs Pond (S. Stouge pers. comm.) indicate an identical fauna to that at Cobbs Arm.

5.14. Intrusive Rocks of the Pre-Caradocian Sequences

The pre-Caradocian island arc sequences of the Central Volcanic Belt are intruded by a variety of intrusive bodies which are probably also of pre-Caradocian age. These intrusive rock types are relatively distinct and appear to be an integral part of the magmatic evolution of the island arc.

The most common type of intrusive body, characteristic of all pre-Caradocian groups, are gabbro and diabase sills. These sills vary in thickness from 0.5 m. to 300 m. and in strike length from 100 m. to 20 km. The most common lithology of the sills is medium to coarse-grained gabbro. Diabase sills are less common but are locally abundant. These are generally porphyritic with euhedral plagioclase being the common phenocryst.

The sills occur at all stratigraphic levels in the pre-Caradocian sequences and are contemporaneous with volcanism and sedimentation as evidenced by:

(1) the appearance of gabbro and diabase fragments in agglomerates;

(2) the occurrence of screens of gabbro and diabase between diabase dykes which feed overlying lavas;

(3) the lack of thermal metamorphism in rocks intruded by the sills;

(4) soft-sediment intrusion features.

Within some volcanic groups, gabbros occur as pod-like, slightly discordant bodies. These are more prominent in the Cutwell and Moretons Harbour Groups where there is a corresponding lack of sills.

Small granitoid stocks occur in most pre-Caradocian volcanic groups. These are often associated with felsic volcanic domes and appear to be sub-volcanic intrusive equivalents of the extrusive rocks.

Larger discordant intrusive bodies of pre-Caradocian age are:- the Burlington Granodiorite (12H/8, 9), the Colchester Plutons (12H/9), the Twillingate Granite (2E/10), the South Lake Igneous Complex (2E/5, 6), the Wellman's Cove Pluton (2E/12) and the Dollard Quartz Diorite (2E/12). These intrusions are characteristically granodiorites and quartz diorites, i.e. "plagiogranites". More detailed individual petrological descriptions are given in the map legends.

The Colchester and Wellman's Cove Plutons intrude only the Lushs Bight Group and may be part of the oceanic crustal sequences. However, the Wellman's Cove Pluton hornfelses the volcanic rocks of the Lushs Bight Group and contains abundant ultramafic inclusions.

The Twillingate Granite intrudes the base of the Moretons Harbour Group and is strongly metamorphosed along with the volcanic rocks along its southern margin. Williams and Payne (1975) suggested that the granite formed by partial melting of basalt in a subduction zone, while Payne and Strong (in press) suggest that it formed by partial melting at the base of the Moretons Harbour island arc volcanics. This will be discussed further in Chapter 9.

Only the granodiorite phase of the South Lake Igneous Complex intrudes the pre-Caradocian Wild Bight Group. Contacts between the older phases and the Wild Bight Group are faulted. Ophiolitic rocks are known from within the complex (the South Lake Ophiolite of section 4.7.) and conceivably a larger portion of the complex may have an oceanic origin.

The Burlington Granodiorite intrudes the Pacquet Harbour Group and is unconformably overlain by the Silurian-Devonian Mic Mac Group. A pre-Caradocian age is most likely although any pre-Devonian age is possible.

A major problem in dating such intrusives as the Twillingate Granite and the Burlington Granodiorite is the presently poorly defined absolute ages of the divisions of the Lower Palaeozoic time scale.

5.15. Mineral Deposits of the Pre-Caradocian Island Arc Sequences

The most important type of mineral deposit associated with the immature arc sequences are volcanogenic massive sulphide deposits. These are very similar to "Archean Type" massive sulphide deposits described by Sangster (1972) from the Superior Province of the Canadian Shield. They contrast markedly with the older Cyprus or Bett's Cove type and the younger Kuroko or Buchans Type deposits of the Central Volcanic Belt.

These deposits of the immature arc phase of Notre Dame Bay evolution are intimately associated with areas of felsic volcanism in thick submarine volcanic sequences. These felsic volcanic domes, presumably representing volcanic centres, generally occur at the top of a volcanic pile that begins with mafic pillow lavas which become more andesitic upwards.

The size of the area of felsic volcanism varies considerably and shows no apparent relationship to the size of the mineral deposit or whether a deposit formed at all. For example, the size of the felsic dome associated with the large Point Leamington Deposit in the Wild Bight Group (2E/5) is less than ten times larger than the sulphide deposit itself while that associated with the Indian Cove Prospect to the north is at least one thousand times the size of the sulphide body. Other felsic domes in the same area are apparently barren of sulphides.

The Point Leamington Deposit is the largest single sulphide body yet discovered in Newfoundland and best serves as the type deposit for the early arc volcanic sequences, because of its mineralogy and stratigraphic setting.

The mineralogy is relatively simple. It consists largely of massive pyrite, chalcopyrite and sphalerite with minor galena, arsenopyrite, gold and silver. Sphalerite (± gold) occurs in greater abundance at the stratigraphic top of the deposit which is often capped by a thin unit of cherty iron formation. Where a stockwork underneath the massive sulphide body is identifiable, it is enriched in chalcopyrite relative to pyrite and sphalerite is absent.

The Ming Mine of Consolidated Rambler Mines Ltd. in the Pacquet Harbour Group is a good example of a deformed Point Leamington type massive sulphide deposit.

Hydrothermal vein deposits of the Moretons Harbour area may be related to the Moretons Harbour volcanism or may be related to later igneous events. These deposits are characterized by disseminated to semi-massive sulphides in quartz veins associated with felsic dykes intruding agglomerates of the Little Harbour Formation. Mineralogy is complex and variable but arsenopyrite and pyrite are most common. Other minerals are stibnite, sphalerite, chalcopyrite, galena and gold.

The following table is a list of mines, past producers and major prospects within volcanic rocks of the pre-Caradocian island arc sequences.

Table 5.3

MINES, PAST PRODUCERS AND MAJOR PROSPECTS WITHIN VOLCANIC ROCKS OF THE PRE-CARADOCIAN ISLAND ARC SEQUENCES

Volcanic Sequence	Deposit Name
Pacquet Harbour Group	Rambler Mine - Cu, Zn, Au, Ag. East Mine - Cu. Big Rambler Pond - Cu. Ming Mine - Cu, Zn, Au, Ag.
Catchers Pond Group	Indian Pond - Cu.
Western Arm Group	Norris - Cu.
Moretons Harbour Group	Trump Island - Cu. Western Head - Cu. Taylors Room - Cu, Asp. Zn, Au. Stewarts Mine - Asp, Au, Sb, Cu. Frost Cove - Asp, Sb.
Wild Bight Group	Point Leamington - Cu, Zn, Au Indian Cove - Cu. Lockport - Cu, Zn.
Exploits Group	Saunders Cove - Cu, Zn. Tea Arm - Cu, Zn.
Summerford Group	Cobbs Arm - limestone.

6. THE CARADOCIAN ARGILLITES AND CHERTS

6.1. Introduction

All of the "early arc" volcanic sequences east of Halls Bay and south of the Lobster Cove Fault are overlain by black argillites (± cherts) of Caradocian age. These Caradocian argillites are the most extensive stratigraphic unit in the Central Volcanic Belt. Since they are also highly fossiliferous, they are a most useful "marker horizon" which aids considerably in outlining the stratigraphy and structural geology of central Newfoundland.

This period of quiet sedimentation and subsidence of the volcanic islands of the early arc marked a sudden major change in the evolutionary style of the Central Volcanic Belt. This is the basis for the pre-and post-Caradocian stratigraphic subdivisions of the area. The quiet sedimentation lasted throughout the entire Caradocian epoch in eastern Notre Dame Bay, while in the west greywackes flooded in from Taconic land masses to the west and gradually progressed eastwards. Thus the Caradocian argillites of western Notre Dame Bay contain only *Nemagraptus gracilis* Zone graptolites while in the east, argillites contain faunas of the *N. gracilis* Zone and the one, two or three succeeding zones of the Elles and Wood (1901-1918) British Standard Ordovician graptolite zonal sequence outlined in Figure 3.1.

For purpose of discussion in this thesis, the term "Caradocian argillites" refers to those argillites containing fauna of the Nemagraptus gracilis, Diplograptus multidens, Dicranograptus clingani or Pleurograptus linearis Zones, although the gracilis Zone could well be Llandeilian in age and the linearis Zone could similarly be Ashgillian.

6.2. Shoal Arm Formation (2E/3, 4, 5, 6.)

The Shoal Arm Formation is the most extensive horizon of Caradocian argillites and cherts in the Notre Dame Bay Area. It everywhere conformably overlies volcanic rocks of the Wild Bight Group and extends from North Twin Lake to Badger Bay, New Bay and around both sides of the Seal Bay Anticline in the New Bay Pond area for a total exposed strike length of 80 km.

Espenshade (1937) first defined the Shoal Arm Formation as part of his Badger Bay series of presumed Ordovician age. His Shoal Arm Formation consisted of a basal member of 100 m. of red and green cherty shales overlain by a black shale and argillaceous sandstone member with a total thickness of 350 m. In the present study, the sandstones have been placed in the overlying Sansom Formation and the top of the Shoal Arm Formation is redefined as the base of the first sandy bed overlying the black shale member.

Thus, the Shoal Arm Formation now consists of two distinct members; (1) a lower unit of banded red and green to black chert or cherty shale, and (2) an upper unit of black carbonaceous shale. The cherty member is generally rich in iron and/or manganese oxides. Radiolarians are locally very abundant, especially on Gull Island in Badger Bay (Sampson, 1923). The cherts bear many characteristics of modern deep oceanic sediments and are very similar to cherts from ophiolite suites.

The thickness of the Shoal Arm Formation varies from 120 m. in the Badger Bay area to 250 m. in the New Bay Pond area. Generally the chert member comprises 50 percent of the formation so that both members thicken and thin proportionately along the 80 km. of exposed strike length of the formation.

Graptolites occur only in the upper shaley member and can be readily collected where the formation is not badly folded. Fauna from the Badger Bay Area indicate a *Nemagraptus gracilis* zonal age for the black shale member in the western exposures of the Shoal Arm Formation. The probable southern extension of the Shoal Arm Formation, outcropping at Red Cliff and Leech Brook west of Grand Falls, also yields a *N. gracilis* Zone fauna (Bergström et al., 1974).

Graptolites from the New Bay Pond and New Bay Areas, on opposite sides of the Seal Bay Anticline, indicate a *Dicranograptus clingani* zonal age for the Shoal Arm Formation in these more easternly exposures. These fossil localities however are close to the top of the formation. It is most likely that the base of the Shoal Arm Formation is the same age everywhere but the top of the Formation is younger in the eastern sections. Further careful collecting of fauna from the base of the shaley member in the eastern localities should yield *N. gracilis* Zone graptolites.

Complete faunal lists for the various fossil localities within the Shoal Arm Formation are given in Appendix 1.

6.3. Lawrence Harbour Shale and Caradocian Argillites of the Exploits Group (2E/6)

The Lawrence Harbour Shale was originally defined by Heyl (1936) as part of his Ordovician Exploits Series. It consisted of 120 m. of grey chert, cherty shale and black shale containing numerous graptolites of Normanskill age. The formation was recognized only at

Lawrence Harbour and on Upper Black Island where it conformably overlay the Breakheart Basalt (now Lawrence Head Volcanics).

Helwig (1967, 1969) collected graptolites of various zones at Lawrence Harbour and concluded that there were two distinct units of different ages, probably separated by a fault. The name Lawrence Harbour Shale was applied to the older siliceous argillite bearing a *Nemagraptus gracilis* Zone graptolite assemblage. The younger shales, bearing *Dicranograptus clingani* and *Pleurograptus linearis* zonal assemblages, were referred to as "the unnamed argillite". Thus, the Lawrence Harbour Shale is a biostratigraphic unit of the Exploits Group which overlies the Lawrence Head Volcanics and has its top faulted. The "unnamed argillite" refers to those Late Caradocian shales conformably overlain by the Upper Ordovician Point Leamington Greywacke. In all localities the base of the unnamed argillite is faulted against older rocks.

Bergström et al. (1974) included Helwig's "unnamed argillite" in the Point Leamington Greywacke as a basal shale unit. They concluded that graptolites from these shales west and south of New Bay belong to the *Dicranograptus clingani* Zone while those from Lawrence Harbour to the east belong to the *Pleurograptus linearis* Zone and therefore the base of the Point Leamington Greywacke is diachronous, being younger in the east. Since the base of this shale is always faulted it seems that nothing can be said about the age of the base of the Point Leamington Greywacke with the shale included as a basal unit. If, however, the "unnamed argillite" is not included in the Point Leamington Greywacke, then the evidence of Bergstrom et al. (1974)

can be used to say that the base of the Point Leamington Greywacke is in fact diachronous, being younger in the east where argillaceous sedimentation continued through to the end of the *P. linearis* Zone.

It seems most likely that *N. gracilis* shales and cherts conformably underlay all these younger Caradocian argillites prior to faulting as appears to be the case for the easternmost exposures of the Shoal Arm Formation. Graptolites collected by H. Williams from the base of the unnamed argillite on the south shore of Cull Island (2E/11) appear to be a *N. gracilis* Zone fauna. Further collecting of graptolites from those shale sections with a cherty base may yield *N. gracilis* Zone graptolites.

Complete faunal lists for the "unnamed argillite" and the Lawrence Harbour shale are given in appendix 1.

6.4. Rodgers Cove Shale and Unit C of the Summerford Group (2E/10, 2E/8)

These two Caradocian argillite formations occur north of the Cobbs Arm Fault on New World Island and are in fact the same stratigraphic unit which has been given several different names by previous workers (Horne, 1969, 1970; Bergström et al., 1974). Both formations are the same age, yield the same graptolite fauna, are overlain by the Sansom Greywacke and are generally separated from the pre-Caradocian volcanic rocks of the Summerford Group by the Cobbs Arm Limestone or a facies-equivalent limy tuff and shale.

The Rodgers Cove Shale was introduced by Bergström et al. (1974) as the upper formation of the Hillgrade Group, which also includes the Cobbs Arm Limestone as its only other formation. It consists of dark siliceous shale with some beds of chert and fine-grained limestone. The average thickness is 30 m. and contacts with the Cobbs Arm Limestone are faulted where exposed. The Rodgers Cove Shale out crops discontinuously from Cobbs Arm westwards to Squid Cove. West of Virgin Arm, its place in the stratigraphy is taken by Unit C of the Summerford Group since the Cobbs Arm Limestone does not occur in this area except at Cottles Bay where the overlying shale is again, by definition, the Rodgers Cove Shale.

Graptolites collected from the Rodgers Cove Shale by Bergstrom et al. (1974) belong to the *Dicranograptus clingani* and *Pleurograptus linearis* Zones. Several localities, collected by Williams (1963) from shales now included in the Rodgers Cove Shale and Unit C, yielded graptolites identified by L. M. Cumming as *Orthograptus whitfieldi* indicating a *Nemagraptus gracilis* Zone age. This is perhaps a mis-identification of *Orthograptus quadrimucronatus* which is abundant in the Bergström et al. (1974) collections. *Orthograptus whitfieldi* is not known to occur in any other Caradocian argillites of Central Newfoundland.

Williams (1963) also collected graptolites from the western exposures of the Rodgers Cove Shale between Cottles Bay and Lukes Arm. This collection yielded *Dicellograptus divaricatus* var. salopiensisital (E & W), indicating an early Caradocian age. If the Rodgers Cove Shale does in fact conformably overlie the Cobbs Arm Limestone, then the base of the shale should yield *N. gracilis* Zone graptolites since the top of the Cobbs Arm Limestone is at youngest lower *N. gracilis* Zone (Bergström et al. 1974).

Unit C of the Summerford Group conformably overlies mafic volcanic rocks or limy tuffs and argillites also of the Summerford Group. It contains the same lithologies and is of the same thickness as the Rodgers Cove Shale, and is similarly conformably overlain by the Sansom Greywacke. It out crops in a structurally complex pattern on southwestern New World Island and on the north side of adjacent Farmers Island. It was originally defined and mapped by Horne (1969), whose stratigraphic interpretation of the Summerford Group is reviewed in Chapter 5.9. Unit "C" of this thesis also includes most of Horne's Unit "E" which contains the same age graptolites as C but is generally more highly slumped and tectonically disturbed. Unit F is entirely eliminated from the Summerford Group and the top of Unit C is the redefined top of the Group.

Unit C has yielded graptolites from the *D. clingani* and *P. linearis* Zones. Careful collecting from unfaulted sections should yield *N. gracilis* zone faunas from the base of this unit. Complete faunal lists for the Rodgers Cove Shale and Unit C are given in Appendix 1.

The Rodgers Cove Shale and Unit C best record the rapid and deep subsidence of the pre-Caradocian island arc during the Caradocian epoch. The underlying Llandeilian Cobbs Arm Limestone and volcanics of the Summerford Group were deposited in shallow marine conditions. The overlying 30 m of chert and shale, which probably represents the entire Caradocian epoch in this area, were obviously deposited in very deep water quite distant from any land source. When flysch deposition finally commenced in the Ashgill, at least 3 km of sediments were deposited before shallow marine conditions became once again dominant in the Middle Silurian.

6.5. Dark Hole Formation (2E/10, 2E/8)

The Dark Hole Formation (Horne, 1969) is exposed along the south coast of New World Island on the north shore of Dildo Run, and on the south coast of Farmers Island to the southwest. It is conformably overlain to the north by the Sansom Greywacke and appears to be faulted at its base against the Dunnage Mélange along the Dildo Fault (Kay, 1970), although this fault is difficult to define in the field.

The Formation varies in thickness from 150 to 300 m. It consists of tuffaceous dark chert at the base overlain by slaty argillite with minor thinly-bedded siltstone layers which increase in abundance upwards.

At Chenyville, in the southeasternmost exposures of the Dark Hole Formation, typical black chert and argillite conformably overlie 15 m. of coarse feldspathic arenite with lentils of coarse conglomerate containing rounded boulders of dacite porphyry and volcanic rocks. The boulders of dacite porphyry are very similar to the dacite porphyries which intrude the Dunnage Mélange to the south and appear to be derived from these intrusions. These Chenyville conglomerates (Kay 1976b) are best regarded as part of the Dunnage sequence rather than the Dark Hole Formation. Considering the difficulty of defining the trace of the Dildo Fault, one can reasonably assume that the Dark Hole Formation conformably overlies the Dunnage Mélange as Horne (1969) stated in defining the Dark Hole.

The Dark Hole Formation has yielded *D. clingani* Zone graptolites from a single locality at Joe Whites Arm near the top of the formation.

Considering the thickness of the formation and the cherty nature of its basal sediments, the Dark Hole Formation may contain rocks of the *N. gracilis* Zone.

6.6. Caradocian Cherts and Argillites south of the Bay of Exploits (2E/7, 2E/3, 2E/6)

A sequence of black to green chert, cherty argillite and shale conformably overlies the pre-Caradocian Loon Harbour Volcanics and extends from the southern end of Burnt Bay through Loon Bay to the area east of Birchy Bay where it is terminated by faults and the Devonian Loon Bay granodiorite. The sequence is at least 300 m. thick and is overlain to the north by the Sansom Greywacke.

These rocks were first described by Kay (1975) who assigned the name "Luscombe Formation" to the 300 m. section of chert, cherty argillite and manganiferous chert at Luscombe Point in Loon Harbour. Kay felt "intuitively" that these sedimentary rocks represented the upper part of Cambro-Ordovician oceanic crust. The abyssal character of the sediments cannot be disputed. However, the section at Luscombe Point is so identical to that of the chert member of the Shoal Arm Formation as exposed near New Bay Pond (2E/4) and on Route 350 north of Northern Arm (2E/3) that these cherts can also be no older than early Caradocian.

These cherts and argillites have not yielded any graptolites, probably because of the hornfelsing effect of the Loon Bay Batholith particularly in the well exposed areas. A search in the wooded areas away from the contact zone may be more fruitful.

A separate section of argillites, similar to and correlated with that previously described, is exposed on the east shore of Burnt Bay. The section faces north and is overlain by the Sansom Greywacke. Its base is faulted against the Silurian Goldson Formation and the section pinches out to the east against a series of faults. A single fossil locality south of Shoal Point in Burnt Bay has yielded late Caradocian graptolites. The faunal list is given in Appendix I.

6.7. Caradocian Rocks of the Davidsville Group (Plate 1)

The internal stratigraphy and structure of the Davidsville Group is poorly known but there is sufficient evidence to state that the sedimentary or slaty division overlies the volcanic division and is Caradocian and younger in age.

Anderson and Williams (1970) reported graptolites from the extension of the Davidsville Group in the Gander Lake Area to the south which are early Caradocian in age and possibly belong to the *Nemagraptus gracilis* Zone. Graptolites from the northwest shore of Weirs Pond, about 300 m. south of the Llandeilian "Cobbs Arm type" limestone, are middle Caradocian in age probably belonging to the *Diplograptus multidens* Zone.

Williams (1963b) collected Caradocian graptolites from several localities throughout the Davidsville Group. Those localities with positive specific faunal lists indicate either the *Dicranograptus clingani* or *Pleurograptus linearis* Zones. Bergström et al. (1974) recollected Williams' localities east of Gander Bay and also assigned a late Caradocian age.

Three of Williams' Caradocian graptolite localities from the westernmost exposures of the Davidsville Group on the Gander River lie very close to a supposed conformable contact with Mid-Silurian rocks of the Botwood Group. Either, there is a very condensed Upper Ordovician-Lower Silurian sequence in this area, implying that the Davidsville sediments are largely Caradocian in age, or the contact with the Silurian rocks is unconformable or is faulted as is the case to the north. In the latter case, the Davidsville argillites could still be dominantly of Caradocian age.

Complete faunal lists for the Davidsville Group as exposed in Plate 1 are given in Appendix 1.

6.8. Parsons Point Formation (2E/12)

The Cutwell Group on Long Island (Kean, 1973) is the only sequence of rocks north of the Lobster Cove-Chanceport Fault known to contain Caradocian graptolitic argillites. The Parsons Point Formation of the Cutwell Group is exposed in a small anticlinal structure in the village of Lushs Bight and on the nearby Oil Islands. It consists of a basal unit of recrystallized limestone and limestone breccia of Llandeilian age overlain by cross-bedded greywacke which is in turn overlain by 10 to 15 m. of black cherty argillite.

Graptolites collected by R. K. Stevens, D. Skevington and the writer from the south shore of Lushs Bight Harbour are a definite *Nemagraptus gracilis* Zone fauna.

These Caradocian argillites are apparently conformably overlain by submarine volcanic rocks of the Long Tickle Formation without any intervening greywacke sequence so characteristic of the Upper

Ordovician stratigraphy south of the Lobster Cove-Chanceport Fault. Nevertheless, the argillites of the Parsons Point Formation once again record a rapid subsidence of the pre-Caradocian island arc which had barely emerged above water during the deposition of the underlying limestone and cross-bedded greywacke.

7. POST-CARADOCIAN FLYSCH

7.1. Introduction

Caradocian argillites south of the Lobster Cove-Chanceport Fault are everywhere overlain by variable thicknesses of Late Ordovician and Early Silurian greywacke and conglomerate which exhibit all the features characteristic of flysch deposits. Greywackes, generally referred to as the Sansom Greywacke, or locally Point Leamington Greywacke, are dominant in the Late Ordovician, whereas conglomerates, generally assigned to the Goldson Formation, are dominant in the Early Silurian.

Neither the Ordovician-Silurian boundary nor the actual boundary between the Sansom and Goldson Formations is strictly defined in Central Newfoundland. The Sansom Greywacke generally coarsens upwards into conglomeratic beds which are assigned to the Goldson Formation. The Sansom locally contains lentils of Goldson-like conglomerate and the Goldson Formation has thick sections of greywacke. Llandoverian fossils have been collected from rocks mapped as Sansom and similarly rocks mapped as Goldson Formation locally contain an Ashgillian fauna.

Both the greywackes and conglomerates reflect the same style of flysch-turbidite sedimentation under gradually shallowing water depths and can thus be thought of as a coherent assemblage of sedimentary rocks. Perhaps a new group should be formed to include both these formations.

The variable thicknesses, local unconformities, abundant slump structures and mass slide features reflect instability and topographic relief in this basin formed during the Caradocian interval. Sedimentary structures indicate that most of the sediment was derived from lands to the north and northwest of the basin (Helwig, 1967, Helwig and Sarpi, 1969). The lack of any similar flysch deposits in the area north of the Lobster Cove Fault and the consistently unconformable relationship of Silurian-Devonian rocks on Pre-Caradocian rocks west of Halls Bay suggest that this area was uplifted in the Middle or Late Ordovician and was the source of the flysch deposited in the basin to the east.

Available palaeontological evidence indicates that flysch sedimentation gradually progressed from west to east through Late Caradocian times and possibly did not reach the eastern part of the basin until Llandoverian times.

7.2. Sansom Greywacke

The term "Sansom Greywacke" was first used by Heyl (1936) for the greywackes and quartzites of South Sansom Island in the Bay of Exploits. Williams (1963b) showed the extension of these rocks to the east on New World Island although he did not apply any formational names. Kay (1967) used the term "Sansom Greywacke" for the Upper Ordovician sedimentary rocks on New World Island. All subsequent workers (e.g. Horne and Helwig, 1969) have continued to use the term for these rocks on New World Island and in the Bay of Exploits area. McKerrow and Cocks (1977) have used "Sansom Group" in referring to these rocks. Until more detailed stratigraphic subdivisions of these strata are made, they are best referred to as the Sansom Greywacke.

In the present study, the term Sansom Greywacke applies to all Upper Ordovician flysch deposits overlying Caradocian argillites in central Newfoundland, with the exception of the Point Leamington Greywacke. This includes several new areas which previously had no names or obsolete names. Thus the present Sansom Greywacke occurs in four or more separate areas with various thicknesses and relationships to younger rocks. These areas or sections of the Sansom Greywacke will be discussed separately from west to east.

7.2.1 Badger Bay Section (2E/5)

The Sansom Greywacke in the Badger Bay Area includes strata assigned by Espenshade (1937) to the Gull Island Formation, the Julies Harbour Group and the Burtons Head Group of the Badger Bay Series. None of these names is in common use and the lithologies in any of these units are not significantly different from those of any other unit. The name Sansom Greywacke is applied to these strata because of the striking similarities in all aspects with the rocks of the type area of South Sansom Island and because of their same relative position in the stratigraphy of Notre Dame Bay.

The Sansom Greywacke conformably overlies black, lower Caradocian argillites of the Shoal Arm Formation on Gull Island and on the northwest shore of Shoal Arm. The sequence faces northward from Shoal Arm and is approximately 2 km. thick. The base of the Sansom is defined as the base of the first greywacke bed overlying the Shoal Arm argillites. The lower 100 m. consists of interbedded greywacke and argillite with beds averaging 30 cm. thick. Thick-bedded arenaceous greywackes are dominant in the next 500 - 800 m. Beds are generally from 0.5 to 2 m. thick.

Load casts and sole markings are characteristically abundant. The upper half of the section consists of fine-grained arenaceous greywacke with local argillaceous interbeds.

Poorly preserved graptolites have been collected from the upper portion of the Badger Bay section. They indicate a probable Late Ordovician age.

The Goldson Formation does not occur in the Badger Bay section. The top of the Sansom Greywacke is marked by melange of the overlying Sops Head Complex of the Roberts Arm Group. The Sops Head Complex includes lenses of Goldson-like conglomerate on the small islands in Duck Island Tickle and on Kay Island.

The Badger Bay Section of the Sansom Greywacke continues to the southwest, west of North Twin Lake where it is intruded by the Devonian Twin Lakes Diorite Complex. In the Badger-Exploits River area (2E/4, 12H/1), Sansom greywackes conformably overlie Caradocian argillites and contain Goldson-like conglomerate near Middleton Lake north of Badger.

7.2.2. New Bay Pond Section (2E/4)

The Sansom Greywacke conformably overlies Caradocian argillites of the Shoal Arm Formation on the northeast shores of New Bay Pond. The section is west facing and has a maximum exposed thickness of 1 km. The thickness appears to increase rapidly to the south but since it is intruded by Devonian granitoid rocks east of New Bay Pond, true thickness is unknown to the south.

The section consists largely of thickly-bedded coarse lithic greywacke which characteristically has a white weathered surface. Most of the lithic clasts are volcanic rock and chert fragments. These are generally very angular and unaltered. No fossils have been collected from the Sansom Greywacke in the New Bay Pond area. The Sansom is conformably overlain by volcanic rocks of the undated Frozen Ocean Group.

7.2.3. New World Island Area (2E/10, 2E/7)

The Sansom Greywacke crops out in several north-facing fault bounded sequences on New World Island and on the adjacent islands in the Bay of Exploits. These sequences have been variously named by Kay (1967) and revised names have been proposed by Kay in Bergström et al. (1974). They are now termed the Dildo, Cobbs Arm, Toogood and Virgin Arm sequences. The stratigraphic sections are similar in each of these "sequences" and the Sansom Greywacke can be considered to have been originally continuous prior to stratigraphic repetition along thrust faults (Dean and Strong, 1977).

In the Dildo sequence, between the north shore of Dildo Run and the Cobbs Arm Fault, the Sansom Greywacke conformably overlies Caradocian argillites of the Dark Hole Formation and is overlain to the north by the Goldson Formation. The thickness of the greywacke varies from 800 m. in the west between Dildo Run and Virgin Arm to 1500 m. in the east between Dildo Run and Milliners Arm.

In the Cobbs Arm Sequence, north of the Cobbs Arm Fault, the Sansom Greywacke conformably overlies the Rodgers Cove Shale and is again overlain to the north by conglomerates of the Goldson Formation. The average thickness is 900 m.

In the Virgin Arm Sequence, west of Virgin Arm, the Sansom Greywacke conformably overlies Caradocian argillites of Unit "C" of the

Summerford Group and is conformably overlain by the Goldson Formation in the core of a gently plunging, east-west trending syncline. Thickness varies from less than 100 m. to 650 m. although original thickness is difficult to determine because of the complex slumping of the beds in this area.

In the original type section, on the east shore of South Sansom Island, the Sansom Greywacke is a continuous north-facing sequence with a thickness of approximately 1 km. Volcanic rocks and shales of the Summerford Group on the south end of the island are separated from the greywackes by a minor fault, but these rocks are presumed to be the original base to the greywackes. The section is similar to that in the sequences of New World Island and is also very similar to the Badger Bay section.

The lower part of the South Sansom Island section consists of thickly-bedded coarse greywacke and interbedded slate. The slate beds decrease in number and thickness northwards up the section. The upper part of the section consists of thinly-bedded fine greywacke with considerably more argillaceous material than in the lower beds. Limey lenses up to several metres long are common. Intense slumping is characteristic of the upper part of the section on North Sansom Island and also in the Virgin Arm Sequence. Pebbly conglomerates occur in the uppermost beds on the northeast corner of South Sansom Island.

The greywackes consist largely of poorly sorted, angular plagioclase and quartz grains, chert and volcanic rock fragments and shale chips. Coarser thickly-bedded greywackes generally contain rounded plutonic pebbles. Graded bedding and sole markings and small scale cross-bedding are common throughout the section. Other sedimentological features indicating deposition by turbidity currents are scour channels, load casts, convolute bedding, slump breccias and intraformational breccias. Most features indicate transport of sediment from north to south.

Williams (1963a) has collected Lower Silurian fossils from the upper part of the Sansom Greywacke in the Cobbs Arm Sequence and the Dildo Sequence on New World Island. Thus, the Sansom Greywacke in this area is dominantly Ashgillian in age with its top being Lower Llandoverian.

7.2.4. Campbellton Section (2E/7)

The Campbellton Section of the Sansom Greywacke is exposed on both limbs of a major overturned syncline at Campbellton on the west shore of Indian Arm, Bay of Exploits. It conformably overlies Caradocian argillites on Indian Arm Brook and is apparently faulted against other strata in the area. The section is approximately 1 km. thick and the lithologies are the same as those in the New World Island area. Intraformational breccias are especially well displayed in the Campbellton Section. The greywackes are variably metamorphosed by the Devonian Loon Bay Batholith to the north and metamorphic biotite and garnet are common near the intrusive contact.

Kay (1975), called these rocks "Riding Island Greywacke" and felt "intuitively" they were probably of Early Ordovician or Cambrian age. Williams (1963b) had correlated these rocks with the Sansom of New World Island and from the striking lithologic and stratigraphic similarities, the name Sansom Greywacke best applies.

A separate block of Sansom Greywacke appears to overlie the fossiliferous Caradocian argillites along the east shore of Burnt Bay. These are well exposed in road cuts along Route 340.

7.3 Point Leamington Greywacke (2E/6)

Helwig (1967, 1969) proposed the name Point Leamington Greywacke for the Upper Ordovician flysch sequence in New Bay and on the Fortune Harbour Peninsula. Although this section of greywackes is obviously a correlative of the Sansom Formation in time, origin and style of sedimentation, the strata are slightly different in appearance and in most respects are similar only to the fine argillaceous greywackes in the upper portion of the Sansom.

The Point Leamington Greywacke is the uppermost formation of the Exploits Group. It conformably overlies Caradocian argillites and is overlain by the Goldson Formation. It has a maximum thickness of 3 km but locally thins to less than 1 km.

Helwig (1967) described the Point Leamington Greywacke as thin-bedded graded greywacke and silty argillite in rhythmic couplets. Other less common lithologies are pebbly and conglomeratic greywacke, pebbly mudstone and black argillite. Slump folds are the most common and characteristic sedimentary structures and graded bedding, cross lamination, convolute bedding, load casts, flute and groove casts are also well displayed. Sediment transport was dominantly from the north and northwest.

A conglomerate lentil with an average thickness of 600 m occurs in the lower part of the section near Point Leamington. This lentil consists largely of massive greywacke conglomerate. It was previously mapped as Silurian Goldson Formation by Williams (1963b) but it occurs much lower in the sequence than the Goldson and lacks the characteristic plutonic boulders and limestone clasts. However it does show that very coarse proximal turbidites were being deposited long before early Silurian time.

Late Caradocian graptolites and Ashgillian corals have been collected by Helwig (1967) from the Point Leamington Greywacke. Bergström et al. (1974) included the Caradocian argillites which underlie the greywacke sequence in the Point Leamington Greywacke. They showed that the graptolite faunas in the argillites in the west and south of the New Bay Area were slightly older than those on the Fortune Harbour Peninsula and thus concluded that the Point Leamington Greywacke, including the argillites was diachronous. Because the Caradocian argillites are so distinct and such an important stratigraphic marker, they should not, and are not herein, included in the Point Leamington Greywacke. However, the argument that the Point Leamington Greywacke is diachronous can still be made since greywacke sedimentation began in the New Bay area in Late Caradocian and did not advance eastwards to the Fortune Harbour Peninsula or New World Island areas until the Ashgillian, before which shale deposition continued throughout the entire Caradocian.

7.4. Goldson Formation

The Goldson Formation was originally defined by Twenhofel and Shrock (1937) at Goldson's Arm on New World Island but was not extended outside the type area. Similar conglomerates were mapped by Heyl (1936) in the Bay of Exploits as the Hornet Formation of the

Ordovician Exploits Series. Patrick (1956) and Williams (1962) also assigned these conglomerates to the Ordovician Exploits Group. Williams (1963a, b) mapped all of ~~the~~ coarse conglomerate units of eastern Notre Dame Bay as Silurian Goldson Formation and he assigned the formation to the Botwood Group. Kay (1969b) divided the Goldson conglomerates of northeastern New World Island into several formations of the "Goldson Group", thus effectively removing the Goldson from the Botwood Group. Although Kay's divisions of the Goldson Group are probably valid in the defined area, they cannot be extended outside that area and are not in common use.

In the present study, all of the Silurian coarse conglomeratic rocks which overlie the Sansom and Point Leamington Greywackes are referred to as Goldson Formation. It is still removed from the Botwood Group, since it contrasts so strongly with the overlying terrestrial and shallow marine formations of the Botwood Group and is so obviously part of the same sedimentary assemblage as the underlying greywacke units.

The Goldson Formation forms a significant part of the post-Caradocian flysch only in the eastern parts of Notre Dame Bay. West of New Bay its presence is suggested by coarse conglomeratic lenses in mélange overlying the Sansom Greywacke and by conglomeratic beds in the Sansom Greywacke near Middleton Lake north of Badger.

The three main areas of outcrop are: (1) New Bay, (2) New World Island, and (3) Lewisporte and Port Albert areas southeast of the Northern Arm - Reach Fault. The sections in these areas will be described separately.

7.4.1. New Bay Area (2E/6)

The Goldson Formation is exposed on the shorelines and islands of West Arm and Osmonton Arm in New Bay. It conformably overlies and intertongues with the Point Leamington Greywacke. It has an exposed thickness of approximately 600 m and the top of the section is faulted against older rocks. The formation consists almost entirely of light brownish-grey conglomerate with interbedded greywacke and minor shale near the base. The conglomerates are typically massive, very poorly bedded and several metres thick.

The conglomerates are polymictic with a dominance of sedimentary rock clasts which exhibit soft sediment deformation structures indicating that they were semi-consolidated prior to incorporation in the conglomerate. Rounded plutonic boulders and pebbles and coralline limestone boulders are also common and may form up to 20 percent of an outcrop. The limestones appear to have formed in relatively shallow water prior to incorporation in these mass flow deposits.

The limestone clasts in the Goldson Formation in New Bay have yielded abundant Llandoverian corals. Species of *Favosites* and *Halysites* are especially common. Brachiopods and trilobites indicative of a Llandoverian age have also been collected.

On the Fortune Harbour Peninsula, a large lens of Goldson-like conglomerate has been deposited within the Boones Point Complex, a complex mélange of probable Llandoverian age.

7.4.2. New World Island Area (2E/10, 2E/7)

On New World Island, the Goldson Formation generally conformably overlies the Sansom Greywacke in the north-facing Dildo, Cobbs Arm and Virgin Arm sequences. The northernmost conglomeratic sequence, the Toogood sequence (Kay, 1969) is fault bounded. The Toogood sequence contains the type area for the Goldson Formation and the area where Kay (1969b) defined the "Goldson Group".

In the Virgin Arm sequence, the Goldson Formation has a maximum thickness of 500 m. exposed at Intricate Harbour on the west shore of New World Island. Elsewhere thicknesses are less than 100 m. in the core of the syncline between Lukes Arm and Virgin Arm.

The conglomerates are very similar to the Goldson conglomerates in New Bay and again contain large coralline limestone boulders. Algae of Late Ordovician age have been reported from boulders in the base of the formation at Intricate Harbour (Horne and Johnson, 1970). Limestone clasts from the upper part of the formation contain clasts of Llandovery age.

In the Dildo sequence, the Goldson Formation gradationally overlies the Sansom Greywacke and its top is marked by the Cobbs Arm thrust fault (Dean and Strong, 1977). The section has a maximum thickness of 1500 m and is by far the thickest section of the Goldson Formation. It is entirely Early Silurian in age since the underlying Sansom Greywacke contains Llandoverian fossils. Llandoverian brachiopods have been collected from limestone clasts in this section (Helwig and Sarpi, 1969).

In the Cobbs Arm sequence, the Goldson Formation conformably overlies the Sansom Greywacke north of Hillgrade and south of Pikes Arm. This north-facing section of conglomerate has an exposed thickness of 750 m. The top 150 m is coralline shale, limy argillite and sandstone which was mapped by Twenhofel and Shrock (1937) as Pikes Arm Formation. These rocks are presently considered to be a member of the Goldson Formation in the Cobbs Arm Sequence. The argillites and shale beds of the Pikes Arm member are generally fossiliferous and numerous forms have been collected by Twenhofel and Shrock (1937). Some of these fossils may be as young as Middle Silurian although Kay (1976) says they are all Llandoverian.

Local unconformities of Goldson conglomerates on Sansom Greywacke (Kay, 1976a) are probably caused by the intense slumping commonly displayed in the upper part of the Sansom Greywacke or by channeling of the conglomerates into the unconsolidated greywacke. Unconformities between Goldson conglomerates and Cobbs Arm Limestone or Rodgers Cove Shale are anomalous and appear to be confined to the Cobbs Arm Fault Zone. These are perhaps related to the complex thrusting of the Cobbs Arm Sequence over the Goldson Formation.

The Toogood Sequence is fault bounded and consists entirely of Goldson Formation. It has an average exposed thickness of 1 km. Unconformities reported by Kay (1976a) between Goldson conglomerates and Ordovician Summerford Group volcanics are invalid. The volcanic units in the Toogood Sequence such as the one at Green Cove are large blocks which are underlain and overlain by Goldson conglomerates. Brachiopods, collected from one of these blocks on the Green Cove road, appear to be Silurian forms.

The Toogood Sequence is in several ways different from the other sections of the Goldson Formation. Dark coralline argillite and sandstone interbedded with the conglomerates are common and richly fossiliferous. The conglomerate clasts are very large in some portions of the section and beds with one dominant clast lithology are not uncommon. One bed near Pikes Arm contains a great abundance of diorite clasts while another nearby contains plagioclase-pyroxene porphyritic basalt. Red conglomerates are common near the top of the section, suggesting shallow water conditions.

Helwig and Sarpi (1969) described the conglomerates of the Toogood Sequence in detail and considered them to have formed by a combination of near-shore deposition, modified by gravity-induced transport downslope in submarine depressions in a structurally unstable region. These appear to be the most proximal turbidites of the New World Island sequences and were presumably derived from a land source which lay somewhere north of the Chanceport and Lukes Arm Faults in Early Silurian times. This land area which was subject to rapid erosion was apparently flanked by limestone reefs which were also rapidly eroded and redeposited as large clasts by turbidity currents pouring down a steep slope into submarine fan deposits.

7.4.3. Lewisporte and Port Albert Areas (2E/4, 2E/7, 2E/10)

Southeast of the Northern Arm - Reach Fault, in the Botwood Zone (Williams et al. 1972), the Goldson Formation is exposed in a linear belt that stretches from south and east of Lewisporte to the area immediately south of Birchy Bay where it disappears against the Reach(?) Fault. The strata appear again immediately east of the Reach Fault on the west side of the Port Albert Peninsula (2E/10)

A fault-bounded block within the Davidsville slates east of

Rocky Pond (2E/7) contains several hundred metres of coarse conglomerates which are included in the Goldson Formation.

In the Lewisporte area, the Goldson Formation has a maximum exposed thickness in excess of 1 km. The sequence generally faces southeast although several major fold structures are present south and east of Burnt Bay. Where exposed, the base of the Goldson Formation is faulted. However the contact with underlying argillites and greywackes may be conformable east of Burnt Bay on both limbs of a major anticlinal structure. Exposures in the Lewisporte area are generally massive conglomerates typical of the formation elsewhere, with characteristic plutonic and limestone boulder clasts. Indigenous Llandoverian corals have been collected by Williams (1972) from the shore of Rocky Pond east of Campbellton. Contacts with the overlying volcanic rocks of the Botwood Group are not exposed but a structurally conformable contact is suggested by the outcrop pattern of both units.

On the Port Albert Peninsula, the Goldson Formation conformably overlies 200 m. of siltstone and greywacke mapped by Williams (1963a) as Sansom Greywacke. No fossils have been collected from these rocks and they may in fact be finer sediments interbedded in the Goldson Formation. However, they are presently considered to be Sansom Greywacke after Williams.

The Goldson Formation is approximately 300 m thick in the section west of Port Albert. The lower 230 metres consist of typical conglomerate, and the upper 70 metres is thin-bedded greywacke with minor slatey beds (McCann, 1973). At Port Albert, the Goldson Formation is overlain by terrestrial volcanic rocks of the Wigwam Formation of the Botwood Group without any structural discordance. However, there is obviously a disconformity between the two formations since the entire Goldson Formation was deposited in marine conditions and must have been uplifted prior to deposition of the overlying volcanic rocks.

7.5. Indian Islands Group (2E/7, 2E/9)

The term Indian Islands Group was first used by Patrick (1956) for the Silurian strata on both sides of Horwood Bay, and Baird (1958) used the term for the continuation of the strata to the northeast on Dog Bay and Indian Islands. Williams (1963b) expanded the Indian Islands Group to include the strata on the west side of Gander Bay north of the fault at Rodgers Cove.

Williams (1963b) and Eastler (1969) showed the Indian Islands Group to be faulted (thrust?) against the Botwood Group on the west side of Horwood Bay. McCann (1973) felt that this contact was conformable and the Indian Islands Group was an eastern facies equivalent of the Botwood Group exposed on the opposite limb of the major syncline at Farewell Harbour. He proposed that the name Indian Islands Group be abandoned and these rocks be included in an expanded Botwood Group.

The writer concurs with Williams and Eastler (op. cit.) that the Botwood and Indian Islands Groups are separated by a major (thrust?) fault and the strata of the Indian Islands Group are more probably facies equivalents of the Sansom and Goldson Formation than the terrestrial rocks of the Botwood Group. The Indian Islands Group of this study is the same as that of Williams (1963b) but some of the formational names of McCann (1973) are retained and the descriptions and thickness of units are taken from his work.

The Indian Islands Group is a northwest facing sequence of Lower Silurian sedimentary rocks exposed on the west shore of Gander Bay, around Horwood Bay, on Dog Bay Islands and on Indian Islands. Exact thickness is unknown but is in the order of 2 km. Contacts with other rock groups are faulted. The strata are much more deformed than other Silurian sequences of Notre Dame Bay, with numerous small upright folds repeating beds in many coastal sections.

The lowest formation of the Indian Islands Group is the Tims Harbour Formation (new). It is exposed along the west shore of Gander Bay between Rodgers Cove and Dog Bay Point. Thickness of the formation is in the order of 1 km. It consists largely of cherty siltstone, sandstone and slate with minor limestone. Williams (1963b) collected *Favosites* from near Tims Harbour indicating Early Silurian or Late Ordovician age.

The Tims Harbour Formation is overlain by the Horwood Formation (Lower Formation of McCann). It is exposed on the east side of Horwood Bay where it consists of phyllite, slate and sheared siltstone with some limey shale with minor limestone. Total thickness is approximately 1 km. Corals of *Favosites* type have been collected from the limy shale beds of the Horwood Formation, and Berry and Boucot (1970) reported *Pentamerus* sp. indicating a Late Llandovery age.

The upper formation of the Indian Islands Group is the Stoneville Formation (McCann, 1973). The top and bottom of the section are faulted, but a thickness of 600 m is exposed. McCann (op. cit.) divided the formation into 3 members; a lower member, a diamict member and an upper member. The lower member consists of 350 m of interbedded grey slates and sandy siltstone with minor thin lenses of acidic pyroclastic rocks. The diamict member is 100 m thick and consists of pebbly mudstone and conglomerate with interbedded greywacke. It is very similar in all aspects to the Goldson Formation. The upper member consists of 140 m of greywacke with interbedded siltstone and slate.

McCann (op. cit.) suggested that the diamict member of the Stoneville Formation was deposited in a glaciomarine environment. However, many of the clast characteristics which he lists to suggest ice-rafted deposition are also found in turbidite deposits and may be observed in the Goldson Formation.

The Stoneville Formation contains the only strata of the Indian Islands Group which can be considered to be true flysch deposited by turbidity currents. Considering the generally diachronous nature of the post-Caradocian flysch deposits of Notre Dame Bay and the general lack of flysch in the Davidsville Group, it is conceivable that the flysch wedge of Notre Dame Bay did not advance into the easternmost areas of the Central Volcanic Belt until the Early Silurian. This eastern area, the Botwood Zone, appears to have been a stable basin of shale-siltstone deposition during Caradocian, Ashgillian and Early Llandoverian times.

8. POST-CARADOCIAN VOLCANISM

8.1. Introduction

Post-Caradocian volcanic sequences of the Notre Dame Bay area can be grouped into three distinct belts with contrasting styles and environment of volcanic activity and stratigraphy. They are, from northwest to southeast, the Springdale Belt, the Roberts Arm Belt, and the Botwood Belt (Fig. 8.1.). These volcanic sequences have been referred to by Dean and Strong (1975) and Strong (1977) as 'late arc volcanics' since they occur in the upper part of the Central Volcanic Belt stratigraphy and have chemical affinities with modern island arc volcanics. However, there is no direct evidence that this period of Late Ordovician to Early Devonian volcanism is related directly to subduction or that the Central Volcanic Belt constituted an island arc at that time. These rocks are here referred to as post-Caradocian volcanic sequences and the stratigraphy of the various groups in each belt will be described separately.

8.2. Roberts Arm Belt

The Roberts Arm Belt includes the Roberts Arm, Cottrells Cove, Chanceport and Frozen Ocean Groups. It continues south of the study area to include the Buchans Group (Kean et al., in press). Within the study area, it extends from the C. N. railway tracks at Lake Bond northward to Roberts Arm where a major change in strike occurs along the Crescent Lake Flexure. East of Crescent Lake, the Roberts Arm Belt strikes generally

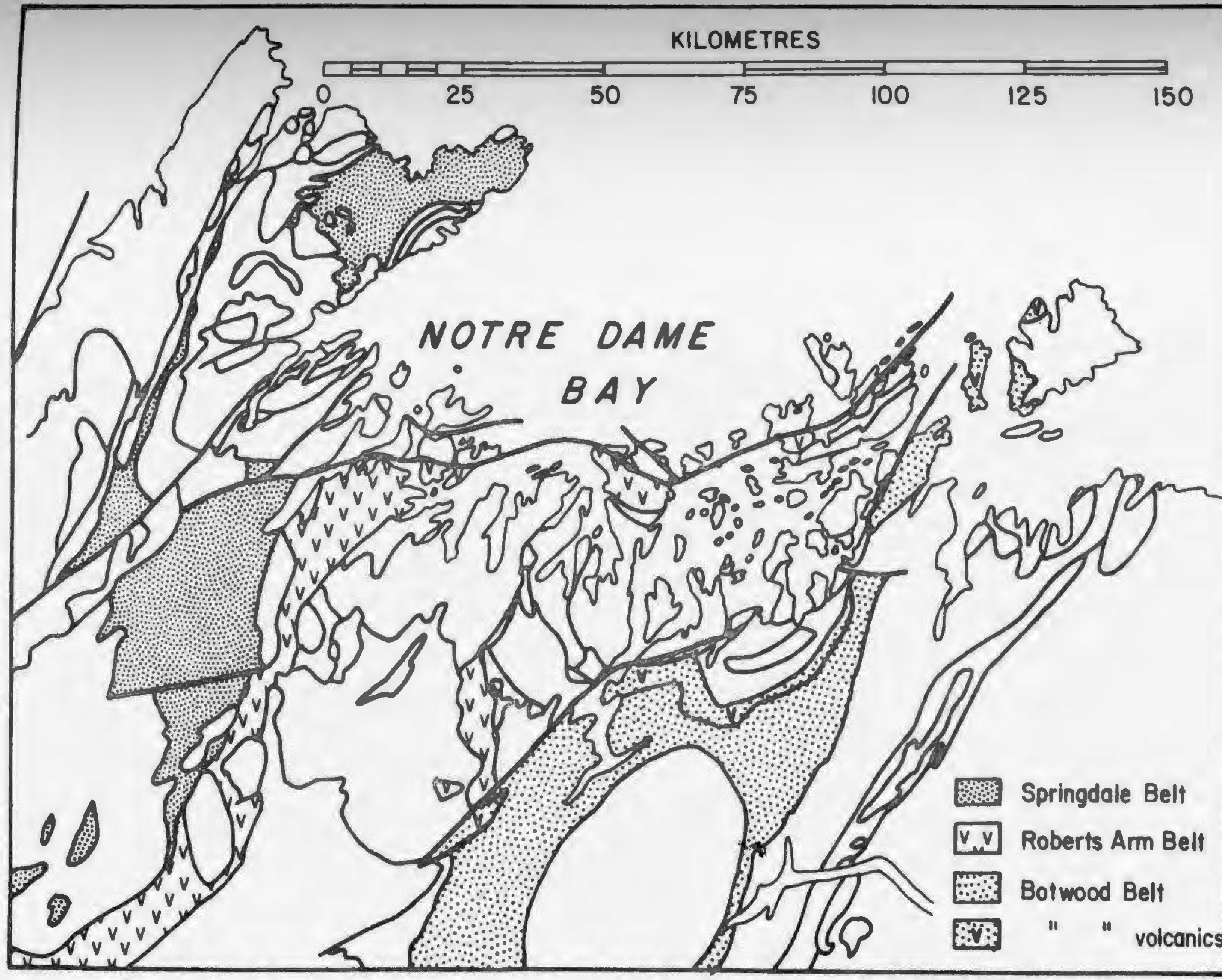


Figure 8.1. Distribution of Post-Caradocian volcanic rocks of the Springdale, Roberts Arm and Botwood Belts.

eastwards into the Fortune Harbour Peninsula and New World Island. The various volcanic sequences are underlain by post-Caradocian flysch and generally face west or north. The top of the belt is marked by either a thrust fault, an unconformity or Devonian intrusives.

In the Roberts Arm Belt, volcanism appears to have been almost entirely submarine. Pillow lavas and interbedded cherts are the most common rock type and felsic volcanic rocks are abundant only near volcanic centres. The volcanic rocks of this belt, like those of the Springdale and Botwood Belts, are a distinctly bimodal basalt-rhyolite assemblage with a marked lack of andesite. However, they are also calc-alkaline and have other chemical similarities to modern island arcs (Strong, 1977).

No fossils have been collected from the Roberts Arm Belt but stratigraphic relationships suggest a Late Ordovician or Early Silurian age.

Figure 8.2. shows the internal stratigraphy and correlation of units between the groups comprising the Roberts Arm Belt.

8.2.1. Roberts Arm Group (12H/1, 12H/8, 2E/5, 2E/12)

The Roberts Arm Group, which forms the main outcrop area of the Roberts Arm Belt of post-Caradocian volcanics, extends from Millertown Junction northward to Halls Bay and then swings eastward south of the Lobster Cove Fault on Sunday Cove, Pilleys and Triton Islands and in the Roberts Arm - Crescent Lake area. The Roberts Arm Group can be regarded essentially as a steeply dipping west to northwest facing sequence of dominantly submarine volcanic and volcanogenic sedimentary rocks.

In the type area of Sops Arm - Roberts Arm, the base of the Roberts Arm Group is represented by a complex volcanic olistostrome known

Post-Caradocian Island Arc Sequences

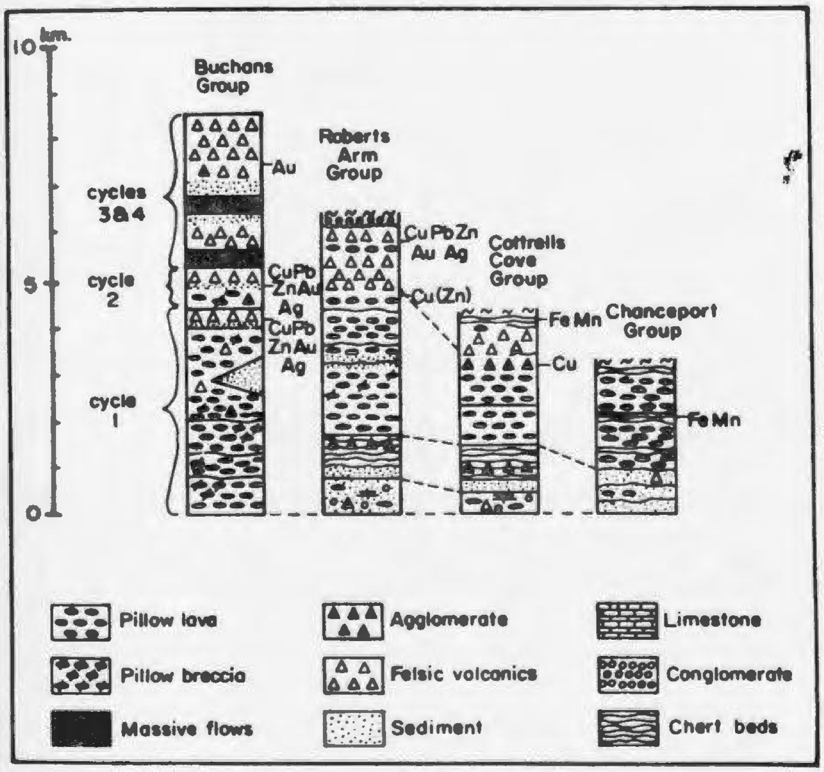


Figure 8.2. Correlation of volcanic rock units and stratigraphic distribution of mineral deposits in the groups comprising the Roberts Arm Belt.

as the Sops Head Complex (new). This unit consists of large blocks and lenses of volcanic rocks, limestone, conglomerate and greywacke in a matrix of chaotically slumped argillite. The conglomerate lenses are identical to Goldson conglomerates of eastern Notre Dame Bay and the limestone blocks are also similar to limestone clasts in the Goldson conglomerates. The Sops Head Complex is interpreted to be a giant slump deposit initiated by tectonic disturbances resulting from the initiation of Roberts Arm volcanism. It conformably overlies the Sansom Greywacke on the Burtons Harbour peninsula opposite Duck Island and is probably of Early Silurian or Late Ordovician age. The Sops Head Complex is not known to occur outside the Sops Arm area, and elsewhere volcanics of the Roberts Arm Group directly overlie the Sansom Greywacke.

The Sops Head Complex is apparently overlain by cherty and tuffaceous sedimentary rocks of the Crescent Lake Formation (Espenshade, 1937). To the south of the Tommy's Arm - Sops Arm Area a mafic volcanic unit, perhaps equivalent to the Sops Head Complex, underlies the Crescent Lake Formation. The Crescent Lake Formation is approximately 200 m thick and is conformably overlain by approximately 5 km of volcanic rocks with no formational status which are referred to as "volcanics of the Roberts Arm Group" or "Roberts Arm volcanics". This volcanic sequence consists grossly of a lower sequence of mafic pillow lavas with lenses of chert and cherty sediments and an upper sequence of mixed submarine volcanic rocks, including pillow lavas, mafic agglomerates, felsic lavas and pyroclastics, and interbedded volcanic greywacke, chert and tuff. Diabase sills intrude the mafic sequence and fine grained granitic stocks are spatially related to areas of felsic volcanics. Two of these plutons, the Woodfords Arm and Loon Pond Plutons are chemically similar to the felsic volcanics and are probably subvolcanic. The volcanics are disconformably overlain by red sandstone and conglomerate of the Springdale Group.

The Roberts Arm Group is intruded post-tectonically by Devonian granites and diorites.

8.2.2. Cottrells Cove Group (new) (2E/6, 2E/11)

The Cottrells Cove Group is exposed on the Fortune Harbour Peninsula between Southeast Arm and Fortune Harbour, on Green and Woody Islands north of Leading Tickles, on the southwest coast of Exploits Island and on the Duck Islands and Matthew Lane Island south of Exploits Island. The type section is the west coast of the Fortune Harbour Peninsula from Southeast Arm to Fleury Bight. These rocks were previously included in the Lushs Bight Group by Helwig (1967) because of the erroneous correlation of the Lukes Arm and Lobster Cove Faults. With the present correlation of the Lobster Cove Fault with the Chanceport Fault through Fortune Harbour (Dean and Strong, 1977), the Cottrells Cove Group forms a natural eastward extension of the Roberts Arm Group. Like the Roberts Arm Group to the west, it is generally a steeply-dipping north-facing sequence up to the Lobster Cove - Chanceport Fault.

The lowest unit of the Cottrells Cove Group is the Boones Point Complex (Helwig, 1969) which can best be described as an olistostrome. Typically, it consists of large blocks of pillow lava, dacite and limestone in a chaotic argillaceous matrix. Large lenses of coarse conglomerate, similar to the Goldson conglomerates, occur throughout the Complex. Volcanic blocks are often composed of variolitic pillow lavas.

Thickness of the Boones Point Complex varies from 0 to 450 metres.

The Boones Point Complex can be correlated with the Sops Head Complex of the Roberts Arm Group and is inferred to overlie the Point Leamington Greywacke although the contacts are faulted where exposed. It is overlain by the Moores Cove Formation, a 1 km. section of dominantly sedimentary rocks. These rocks include tuffaceous sandstones, slates, greywackes, cherts and thin lava flows. Red cherts at the top of the Formation are identical to cherts of the Crescent Lake Formation to the west.

Conformably overlying the Moores Cove Formation is the Fortune Harbour Formation, a dominantly volcanic sequence approximately 3 km. thick. This formation is divided into a lower pillow basalt member with thin chert beds and an upper felsic agglomerate and bedded tuff and chert member. The two members show interfingering relationships indicating contemporaneous mafic and felsic volcanism. The upper member exhibits rapid facies changes from coarse agglomerate in the west to tuff and agglomerate in the east and consists of onlv chert on the east coast of the Fortune Harbour Peninsula. One gabbro sill intrudes the Fortune Harbour Formation just immediately south of Fortune Harbour.

The age of the Cottrells Cove Group is unknown but is presumed to be Silurian because of Goldson type conglomerates in the Boones Point Complex.

8.2.3. Chanceport Group (2E/10, 2E/7)

The Chanceport Group (Strong and Payne, 1973) is exposed on New World Island in a wedge bounded by the Chanceport Fault on the north and the Lukes Arm Fault on the south. It is also exposed on North Sansom

Island, the southern tip of Black Island, the Duck Islands and other small islands in the Bay of Exploits. The Chanceport Group is best exposed in the steeply-dipping north-facing sequence between Carters Cove and Chanceport Harbour on New World Island.

The exposed base of the Chanceport Group at Carters Cove and on the south coast of North Sansom Island consists of pillow lava in a black chaotically slumped argillaceous matrix. On North Sansom Island, the pillow lavas are variolitic and this whole basal unit is similar to the Boones Point Complex of the Cottrells Cove Group. This is overlain by approximately 300 m of greywacke, tuffaceous greywacke, sandstone and chert similar to the Moores Cove Formation. This unit is in turn overlain by 2 km of mafic pillow lava with interbedded units of chert and tuff up to 100 m thick. Pebbly conglomerate and greywacke are abundant immediately south of the Chanceport Fault in Little Chanceport Harbour and on Black Island and the Duck Islands to the south. One thin sill of gabbro intrudes the Chanceport Group volcanics.

The age of the Chanceport Group is unknown but is presumably Late Ordovician or Silurian because of the correlation with the Cottrells Cove and Roberts Arm Groups.

8.2.4 Frozen Ocean Group (2E/4, 2F/5)

The Frozen Ocean Group (new), exposed in the Frozen Ocean - New Bay Pond area, is isolated from other groups of the Roberts Arm Belt which appear to form a single continuous structural feature from Buchans to New World Island. The Frozen Ocean Group, however, has many similarities to these other groups and is here described along with the Roberts Arm Belt.

The Frozen Ocean Group conformably overlies the Sansom Greywacke north of New Bay Pond and is apparently a continuous southwest facing sequence. The basal unit consists dominantly of mafic pillow lavas and pillow breccia. This unit is overlain by bedded tuff and agglomerate with interbeds of chert and sandstone. This bedded unit thins rapidly to the southeast. It is overlain by a mixed volcanic unit consisting of poorly-bedded agglomerate and tuff with minor lava flows. Lithologies and size of fragments in the agglomerates change rapidly along strike even on an outcrop scale, indicating considerable instability and relief in the submarine volcanic environment.

The southernmost outcrop area of the Frozen Ocean Group consists dominantly of felsic pyroclastics and flows. Locally, ignimbrite-like textures are apparent, indicating a subaerial environment of deposition. The relationship of these felsic volcanic rocks to the rest of the Frozen Ocean Group is unknown but they presumably represent the top of the sequence. Total thickness of the Frozen Ocean Group is estimated at 5 km.

The age of the Frozen Ocean Group is unknown but it is certainly Late Ordovician or Farly Silurian in the basal units because of the conformable relationship with the Upper Ordovician Sansom Greywacke.

The Frozen Ocean Group is intruded by large Devonian granitic and dioritic intrusions.

8.3. Botwood Belt (2E/3, 2E/4, 2E/6, 2E/7, 2E/9, 2E/10)

Except for thin pyroclastic lenses in the Stoneville Formation of the Indian Islands Group, post-Caradocian volcanic rocks in the Botwood Belt are confined to the Botwood Group. The Botwood Group (redefined after Williams, 1963b) is confined to the area south and east of the North Arm - Reach Fault. It extends from Fogo and Change Islands southwest along strike to Bishops Falls and continues southwest of the study area. The best exposures are at Change Islands, the head of the Bay of Exploits and on the Exploits River. The dominant lithologies of the Botwood Group are subaerial volcanics and red beds, contrasting markedly with the submarine lithologies of the Roberts Arm Belt.

The lower unit of the Botwood Group, the Lawrenceton Formation (new), disconformably (?) overlies conglomerate and greywacke of the Goldson Formation, which is removed from the Botwood Group for reasons given in Section 7.4. The Lawrenceton Formation consists of terrestrial mafic and felsic volcanic flows and pyroclastics with thin horizons of tuffaceous sandstone and conglomerate.. Felsic pyroclastic rocks are the dominant lithology of the Lawrenceton Formation but mafic flows, which are amygdaloidal and commonly coarsely porphyritic are locally dominant. Thickness is approximately 1.5 km. in the type area on the east side of the Bay of Exploits north of Lawrenceton but thin to the northeast and is only 210 m. at Port Albert. On Change Islands the formation thickens again to approximately 1 km.

Eastler (1969) collected Llandoverian corals from a conglomerate unit within the Lawrenceton Formation on Change Islands.

The Lawrenceton Formation is conformably overlain by the Wigwam Formation (new) which consists largely of red, micaceous sedimentary rocks, dominantly sandstones. These sandstones were originally named Botwood Formation by Twenhofel and Shrock (1937) who carefully mapped the section between Wigwam Point and Botwood at the head of the Bay of Exploits.

Patrick (1956) assigned the sandstones in the Comfort Cove map area to the Farewell Group and Baird (1958) assigned those of Fogo Island to the Fogo Group and those of Change Island to the South End Formation. Williams (1963b) included all those rocks in the Botwood Group and later (1972) proposed the name Wigwam Formation, with the type area being the section north of Wigwam Point, the same area as the original Botwood Formation of Twenhofel and Shrock (1937).

The sandstones of the Wigwam Formation are typically cross-bedded and commonly display ripple marks, mudcracks and other features indicative of deposition in shallow water. Thin volcanic units indicate continuation of Lawrenceton-type volcanism during sandstone deposition. The Brimstone Head member of Fogo Island is the best example and others are exposed near the mouth of the Exploits River and on the small islands north of Fogo Island.

The Wigwam Formation has yielded a shelly fauna of Late Llandovery - Early Wenlock age in the Bay of Exploits area. Berry and Boucot (1970) reported an Early Ludlovian *Monograptus* from Salmon Pond near Glenwood in the easternmost exposures of the Botwood Group.

The Wigwam Formation is at least 2 km. thick in the type area at the head of the Bay of Exploits and is 800 m. on Change Islands. The sequence generally faces eastwards and is faulted against the Indian Islands and Davidsville Groups. Williams (1963b) showed a conformable contact between the Botwood Group and slates of the Davidsville Group near Glenwood. However this contact is probably faulted since the Davidsville Group contains Caradocian graptolites immediately east of the contact, and the Ludlovian graptolite locality of Berry and Boucot (1970) occurs immediately west of the contact.

8.4. Springdale Belt

Post-Caradocian rocks of the Springdale Belt occur west of the South Brook valley and north and west of Halls Bay. The belt includes the Springdale, Mic Mac and Cape St. John Groups and the Long Tickle Formation of the Cutwell Group. There are no post-Caradocian flysch sequences in this area and the basal units in the Springdale Belt generally rest unconformably on Ordovician volcanic and intrusive rocks. Volcanic rocks are dominant and most lithologies and volcanic structures indicate a terrestrial environment of deposition. High-level porphyries appear to be subvolcanic intrusives. Sedimentary rocks appear to have been derived from the rapidly eroding volcanic terrane and deposited in shallow marine and lacustrine environments. Redbeds and fanglomerates form the upper units of the Springdale Group.

No fossils have been collected from the Springdale Belt but stratigraphic considerations and radiometric age dates indicate that volcanic rocks could range in age from Late Ordovician to early Devonian.

8.4.1. Springdale Group (12H/1, 12H/8, 12H/9, 2E/12)

The Springdale Group (MacLean, 1947) includes that large assemblage of volcanic and sedimentary rocks west of South Brook and south of the Lobster Cove Fault as well as two fault-bounded wedges of similar rocks north of the Lobster Cove Fault west of Springdale. A thin strip of Springdale Group red sandstones occurs immediately south of the Lobster Cove Fault on Sunday Cove and Pilleys Island and disconformably overlies volcanic rocks of the Roberts Arm Group. Elsewhere, contacts with older rocks are faulted. A possible unconformity on the Lushs Bight Group exists west of Davis Brook near Route 392. Pre-Springdale rocks are not exposed in the gently plunging Burnt Berry Syncline which extends from the Topsails Plateau northeastwards to Springdale. Approximately 3 km. of volcanic and sedimentary rocks are preserved in this syncline. The lower 2.5. km. of this sequence consists of alternating mafic and silicic volcanic units. Within each of these units, volcanic flows, agglomerates, breccias and pyroclastics may occur. These rocks show all of the features of subaerial volcanism and locally vent facies are quite prominent, such as at Goodyears Cove on Halls Bay. Minor lenses of red clastic sedimentary rocks are mappable within this lower volcanic sequence. Some of the silicic volcanics are high level intrusive porphyries and contain inclusions of chromite and serpentinite, presumably incorporated from underlying ophiolitic rocks.

The volcanic sequence of the Springdale Group is capped by 1-2 km. of red conglomerate and sandstone which seems to have been deposited in a series of deltaic fans off the eroding volcanic topography. Most clasts in the sediments are Springdale Group volcanics, although Lushs Bight type volcanics and granite clasts are not uncommon. A thin wedge of red sandstone and conglomerate, up to 100 m. thick, disconformably overlies the Roberts Arm Volcanics on Sunday Cove and Pilleys Island (2E/12).

The Springdale Group is undated. The volcanic rocks are intruded by the Upper (?) Devonian Topsails Granite and quartz-feldspar porphyry. An Early Devonian age is most likely.

Red sediments near the head of Southwest Arm, included in the Springdale Group by Neale and Nash (1963) are reassigned to the Carboniferous (Marten, 1971; Bird and Dewey, 1971).

8.4.2. Mic Mac Group (12H/8, 12H/9)

The Mic Mac Group (Dewey and Bird, 1971) is exposed in a narrow belt extending from Flatwater Pond southwards to the Green Bay Fault near the Trans-Canada Highway. It unconformably overlies the Ordovician Burlington Granodiorite to the east and is a west facing sequence. The Mic Mac - Flatwater Fault separates it from older rocks to the west.

The predominant lithologies of the Mic Mac Group are felsic pyroclastics. Mafic lavas, agglomerate and clastic sedimentary rocks are locally abundant. Coarse conglomerates are displayed in several localities where the base of the group rests unconformably on the Burlington Granodiorite. Maximum thickness of the Mic Mac Group is 2 km. The internal stratigraphy has been described in detail by Kidd (1974) but is not incorporated in the present study.

Volcanic rocks of the Mic Mac Group have a radiometrically determined age of 395 ± 5 Ma. (Neale and Kennedy, 1967b).

8.4.3. Cape St. John Group (Plate 1)

The Cape St. John Group (Baird, 1951) and related intrusive porphyries occupy the northeastern part of the Burlington Peninsula. It unconformably overlies volcanic and sedimentary rocks of the Snooks Arm Group north of Tilt Cove (Neale et al., 1975). South of Nippers Harbour, the Cape St. John Group lies unconformably on sheeted dykes and layered gabbros of the Betts Cove Ophiolite (Schroeter, 1971).

The main rock types of the Cape St. John Group are felsic pyroclastics, mafic flows and agglomerates, and interbedded sedimentary rocks, chiefly sandstones and conglomerates. The total thickness of the group is approximately 3.5 km. A detailed stratigraphic, lithological and geochemical study has been made by DeGrace et al. (1976) and the reader is referred to their work for more detailed information on these rocks.

The Cape St. John Group is the only group in the Springdale Belt which has had a detailed lithochemical study. Like the volcanic rocks of the Roberts Arm Belt, the Cape St. John Group is a distinctly bimodal calc-alkaline assemblage, suggesting a similar origin for the magmas which produced the volcanism in both belts although the rocks were deposited in a different environment.

The age of the Cape St. John Group is unknown and radiometric age dates have given ambiguous results (DeGrace et al., 1976). However, it is clearly post Mid-Ordovician and is most likely Late Ordovician or Silurian in age.

8.4.4. Long Tickle Formation (2E/12)

The Long Tickle Formation of the Cutwell Group (Kean, 1973) conformably overlies Caradocian argillites of the Parsons Point Formation at Lushs Bight on Long Island. It is the uppermost formation of the Cutwell Group and is generally a south-facing, south-dipping sequence in the type area on the south and west coasts of Long Island. Rocks assigned to the Long Tickle Formation also occur on the Oil Islands, Little Bay Islands, Halls Bay Head and on the west coast of Sunday Cove Island.

The formation has a maximum thickness of 1 km. and consists of interbedded and intertongued lava, agglomerate, tuff and limestone. The tuff beds are generally thick, graded and commonly reworked. Coarser pyroclastic rocks are characterized by fine-grained, creamy white angular volcanic fragments. Such felsic pyroclastic rocks conformably overlie the Parsons Point Formation on the Oil Islands west of Lushs Bight. Limestones occur as lenses within the flows and pyroclastic rocks and are locally fossiliferous. Nautiloid cephalopods collected by Strong and Kean (1972) were tentatively identified by Dr. R. H. Flower as indicating a Middle Ordovician age. However, a Late Ordovician age is more likely since the Long Tickle Formation overlies Caradocian rocks and the fossils were collected from the top of the formation.

All of the lithologies of the Long Tickle Formation indicate a marine environment of deposition with gradually decreasing water depths upwards. These are the only extensive thickness of volcanic rocks in the Springdale Belt to be deposited in such an environment.

The Seal Cove Complex, an intrusive-extrusive dome of felsic lava, plugs, dykes, sills and pyroclastics, intrudes the Pre-Caradocian and Caradocian rocks of the Cutwell Group and appears to have been the source of the felsic pyroclastic rocks in the Long Tickle Formation.

8.5. Mineral Deposits of the Post-Caradocian Volcanic Belts

The most important type of mineral deposit in the Post-Caradocian volcanic sequences are volcanogenic massive sulphides of the "Buchans Type". The name is taken from the well known Buchans deposits (Thurlow et al., 1975) which occur in the Buchans Group, a continuation of the Roberts Arm Group to the south.

The Buchans Type deposits are very similar to the Kuroko type deposits of Japan and also have many features of the Point Leamington Type of massive sulphide deposit. The Buchans Type deposits occur in mature calc-alkaline submarine volcanic environments, chiefly in areas of extensive felsic volcanism. They are generally polymetallic (lead-zinc-copper-gold-silver) but some are simple pyrite-chalcopyrite deposits and others are simply stockworks and hydrothermal alteration zones generally containing pyrite and chalcopyrite only. Barite occurs as a capping in some massive ores and in the case of the slumped and transported ores at Buchans, the barite occurs as fragments in brecciated ore. Cherty iron formation occurs in association with some deposits.

Buchans Type deposits occur almost entirely in the Roberts Arm Belt of post-Caradocian volcanics. The Botwood and Springdale Belts have very few base metal prospects of this type. This is presumably due to the lack of an aqueous environment for the precipitation of sulphides rather than any differences in magma composition or origin. In the Springdale Belt, the only base metal sulphide prospect of significance occurs in felsic volcanic rocks of the Long Tickle Formation where it conformably overlies Caradocian argillites of the Parsons Point Formation on the Oil Islands.

Iron-rich cherts occur within the Roberts Arm Belt but have no economic significance at this time.

Table 8.1 is a list of mines, past producing mines and major mineral prospects in the post-Caradocian volcanic sequences.

TABLE 8.1 Mines, past producing mines and major mineral prospects in the post-Caradocian volcanic sequences

Volcanic Sequence	Deposit Name
Buchans Group	Rothermere Zn, Pb, Cu, Ag, Au, Ba. MacLean Zn, Pb, Cu, Ag, Au, Ba. Lucky Strike, Zn, Pb, Cu, Ag, Au, Ba. Buchans River Zn, Pb, Cu, Ag, Au, Ba. Engine House Zn, Pb, Cu, Ag, Au, Ba. Oriental Zn, Pb, Cu, Ag, Au, Ba. Skidder Prospect - Cu, Zn.
Roberts Arm Group	Lake Bond - Cu, Zn. Starkes Pond - Cu, Zn. Southwest Shaft - Cu. Gullbridge - Cu. HandCamp - Au. Crescent Lake - Cu. Roberts Arm - Cu, Zn, Pb. Pilleys Island Old Mine - Cu, py. Bull Road - Cu, Pb, Zn, Ag, Au, Ba.
Cottrells Cove Group	Cooks Iron Mine - Fe, Mn. Sweeny's - Fe, Mn.
Long Tickle Formation	Oil Islands - Cu, Zn, Pb.

9. TECTONIC HISTORY

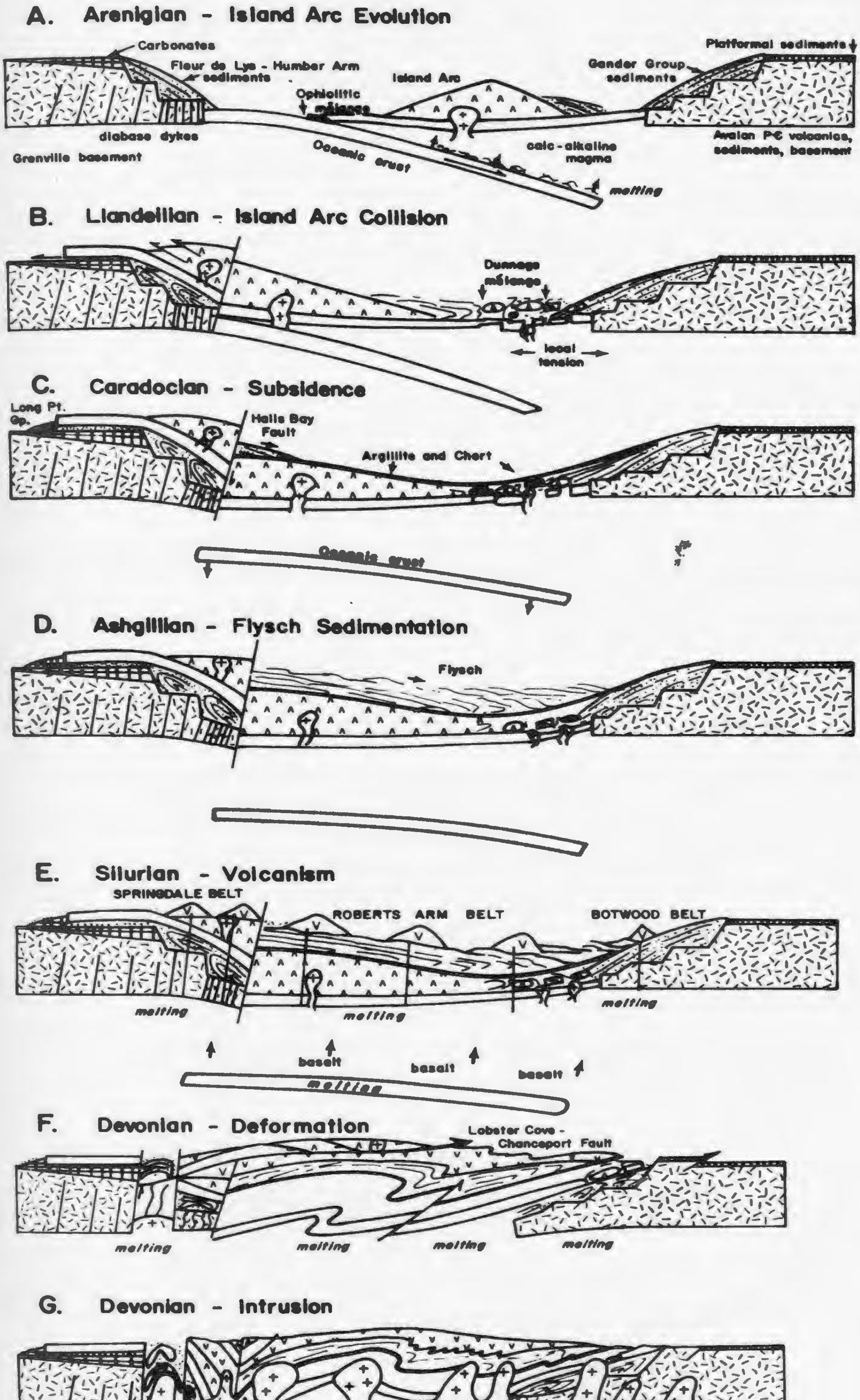
9.1. Introduction

The Tectonic evolution of the Central Volcanic Belt can be interpreted in terms of; (1) Ocean and Island Arc evolution, (2) Collision of the island arc with the North American Continent, (3) Caradocian crustal movements and subsequent volcanism and sedimentation, (4) Collision of the Avalon continent with the island arc, (5) Post-collision cratonization, and (6) Initial rifting of the present Atlantic Ocean. (Fig. 9.1).

The structures, metamorphism and intrusion accompanying each phase of evolution will be described separately. The diagrams of Figure 9.1 depicting the various phases of evolution are intended to exhibit concepts and are not meant to be accurate in scale or to conform with the actual geological cross-sections of the maps of this thesis.

9.2. Ocean and Island Arc Evolution--Pre-Taconic Metamorphism.

Williams *et al*. (1972, 1974), in summarizing the tectonic history of Newfoundland, emphasized a Late Cambrian orogeny which they felt to have much greater significance than the Taconic Orogeny in the development of the Appalachian system. The existence of this Late Cambrian orogeny was based on the structural interpretation of the western part of the Central Volcanic Belt on the Burlington Peninsula. Subsequent field work (DeGrace *et al*., 1976; Williams *et al*., 1977) and radiometric dating (Pringle, 1978; Bell and Blenkinsop, 1977) have shown that the supposed Pre-Lower Ordovician structures are better interpreted



9.1 Cartoons depicting the conceptual tectonic evolution of the Central Volcanic Belt.

as Devonian or younger, suggesting that there was no widespread Late Cambrian deformation in the Newfoundland Appalachians.

There are, however, areas of the Central Volcanic Belt in which Pre-Caradocian rocks have been metamorphosed in response to local igneous events during the magmatic and tectonic evolution of the island arc and its underlying oceanic crust. Widespread greenschist facies metamorphism in the ophiolitic volcanic rocks is an inherent feature in the formation of these rocks at a mid-ocean ridge (Gass and Smewing, 1973; Spooner and Fyfe, 1973). This metamorphism is essentially a hydrothermal metamorphism caused by sea water getting into the numerous fractures in the ridge system, being heated up by the high heat flow and metamorphosing and leaching the volcanic rocks. This metamorphism is generally confined to the lower part of the volcanics and the sheeted diabase dykes. The upper pillow lavas, eg. black facies of the Lushs Bight Group (Marten, 1971), appear to have been deposited after the greenschist facies metamorphism and generally exhibit zeolite facies metamorphism. The leaching accompanying the metamorphism of the lower pillow lavas results in hot metal-rich brines which may precipitate on the ocean floor as Cyprus type or Betts Cove type massive sulphide deposits. (Spooner and Fyfe, 1973)

The most intense pre-Taconic deformation and metamorphism occurs along the southern margin of the Twillingate Granite. The Sleepy Cove Formation, on the north margin of the granite, suffered very little metamorphism resulting from intrusion of the Twillingate Granite and no related fabrics are apparent. The Trump Island Formation, which is intruded by the southern margin of the Twillingate Granite, is metamorphosed to amphibolite facies and has a very strong vertical to sub-vertical fabric which parallels the margin of the granite. The granite itself has a strong parallel fabric along its southern margin and is cut by dykes and contains mafic inclusions which were also involved in the deformation.

The age and cause of this metamorphism is still an outstanding problem. Zircons from the Twillingate Granite give a U/Pb age of 510 $\pm$ 16-17 Ma while mafic inclusions and dykes cutting the granite give $^{40}Ar/^{39}Ar$ hornblende ages varying from 473$\pm$9 to 438$\pm$9 Ma (Williams et al., 1976). The age of 473$\pm$9 Ma was obtained on hornblende from an undeformed diabase dyke which cuts the granite post-tectonically, giving a minimum age for the deformation. Payne and Strong (in press) have postulated that the Twillingate Granite formed as a result of partial melting of the base of the 10-12 km of island arc volcanics of the Moretons Harbour Group. In several localities, notably at Sam Jean's Cove and on South Trump Island, textural relationships appear to indicate formation of granite by partial melting of the amphibolitized volcanic rocks. At these localities, the volcanics were certainly amphibolitized and had developed a fabric prior to or during the partial melting process.

The arguments of Payne and Strong for formation of the Twillingate Granite by partial melting of the base of the Moretons Harbour Group are theoretically convincing. Yet the Moretons Harbour Group is dominantly Lower Ordovician and the Twillingate Granite gives a Late Cambrian radiometric age. The Moretons Harbour Group probably did not have a thickness of 10-12 km in the Late Cambrian and according to this study could not have consisted of more than the Sleepy Cove and

Trump Island Formations at that time. Thus the 510±17 Ma zircon age for the granite is too old for the partial melting model. If the partial melting model is valid, then the zircon age may reflect the age of material melted rather than the age of the melt. However, if the minimum age of 473 Ma is considered for the granite, then the Moretons Harbour Group may have attained sufficient thickness by that time to produce the conditions necessary for partial melting of its base according to the Payne and Strong model. Alternatively, if the 510 Ma age is correct, then a higher geothermal gradient and shallower depths of melting would be required than those proposed by them.

Other pre-Caradocian granitoid intrusives had very little effect on the intruded rocks other than the formation of small thermal aureoles. The best example is the Wellmans Cove Pluton on Sunday Cove Island which metamorphosed volcanic rocks of the Lushs Bight Group to upper greenschist facies.

The New Bay Formation of the Exploits Group has undergone prehnite-pumpellyite facies metamorphism (Franks, 1974). This metamorphism appears to be related to the sudden increase in heat caused by the intrusion of large numbers of gabbro sills rather than to any burial process. Presumably, other portions of the pre-Caradocian island arc sequences intruded by similar gabbro sills may have suffered a similar metamorphism. This metamorphism may be preserved in those sequences which have not been further metamorphosed to greenschist facies.

9.3. Island Arc Collision--The Taconic Orogeny

The Mid-Ordovician Taconic Orogeny can be considered to be the result of the collision of the pre-Caradocian island arc with the ancient continental margin of North America. This effectively destroyed the long-lived stable continental margin and caused island arc magmatism to cease. The resulting emplacement of the Humber Arm and Hare Bay Allochthons of west Newfoundland has been documented by Williams and Stevens (1974) and others.

In the Central Volcanic Belt the pre-Caradocian island arc and underlying oceanic crust were tectonically emplaced onto the Fleur de Lys continental margin, resulting in deformation of the Fleur de Lys sedimentary rocks and imbrication and uplift of the western portion of the island arc and oceanic crust (Fig. 9.1B). Silurian-Devonian rocks of the Springdale Belt, which lie unconformably on the uplifted sequences, were deposited mainly in a terrestrial environment indicating that this area remained uplifted throughout the remainder of Paleozoic time. Since the most likely mechanism for uplift of the ophiolite and island arc sequences is tectonic emplacement onto a continental margin, then the ancient continental margin of North America may extend as far east as Halls Bay (Sheridan and Drake, 1968). This is the eastern limit of the Taconic Orogeny in Newfoundland and also coincides with the eastern limit of the terrestrial volcanic and sedimentary rocks of the post-Caradocian Springdale Belt.

Structures which can be positively dated as Taconic in age in the Central Volcanic Belt are difficult to define. The "schuppen zone" described by Norman and Strong (1975) from the Baie Verte Ophiolite at Mings Bight was probably formed by the imbrication of the ophiolite as it was thrust over the sedimentary rocks of the Fleur de Lys Terrain. Williams et al. (1977) have documented the Taconic deformation of the western margin of the Baie Verte Ophiolite (Birchy Complex of Williams et al., 1977) and the formation of the associated amphibolitic schists similar to those at the base of the Bay of Islands and Hare Bay Ophiolites in west Newfoundland. The early shear structures in chlorite schist zones associated with sulphide deposits in the Lushs Bight Group (Kennedy and DeGrace, 1972) may be Taconic in age. These schist zones appear to have been areas which have undergone sea-floor greenschist facies metamorphism and hence behaved as zones of structural weakness during the imbrication of the Lushs Bight Group. The major thrust faults dissecting the Lushs Bight Group may have been initiated by Taconic imbrication although there has been later southeast-directed thrust movements and possibly transcurrent movements on these faults.

The amphibolitic schists, meta-gabbro, deformed serpentinite and "virginite" at the western margin of the Baie Verte Ophiolite are the only recognized high grade metamorphic rocks associated with the Taconic deformation in the western part of the Central Volcanic Belt.

The final emplacement of the Humber Arm Allochthon and presumably the end of the Taconic Orogeny in Newfoundland is dated by the neoautochthonous Long Point Group (Bergstrom et al., 1974). Conodonts and shelly fossils from the Lourdes Limestone which forms the base of the group are of *Nemagraptus gracilis* Zone age. This time coincides with the cessation of volcanism in central Newfoundland and the rapid subsidence of that portion of the island arc lying east of Halls Bay. Although this subsidence cannot be strictly regarded as a Taconic event, it does mark the end of the Taconic Orogeny and a major change in the overall tectonic regime of the Central Volcanic Belt.

A major fault probably formed at this time in the area of Halls Bay to mark the boundary between the Taconic uplifted sequences to the west and the subsiding basin to the east. At present, this area is marked topographically by the South Brook Valley and geologically by a string of Devonian intrusive bodies which are locally overlain by Carboniferous red beds. This boundary is again evident in the Lloyds River Valley South of Red Indian Lake and appears to continue to the south to link with the Cape Ray Suture of Brown (1973).

As discussed in section 5.11, the Dunnage Mélange probably formed in Early Caradocian time by slumping of the lower portion of the Exploits Group and possibly material derived from an eastern continental margin in the older northeast portion. The formation of this huge mélange may be related to the Caradocian subsidence of the island arc or the tilting of the island arc resulting from the collision with the Fleur de Lys continental margin or with an eastern "Avalonian" continental margin. If the older portion of the Dunnage Mélange does contain material from an eastern continental margin, then continental crust may extend as far west as the Northern Arm-Reach Fault. If so, then the Dunnage Mélange may have formed as a single event in the Caradocian as a result of the collision and mixing of the island arc and eastern continental margin sediments. The Carmanville Mélange (Uzuakpunwa, 1974) which forms the structural base of the Davidsville Group may have formed in a similar setting and may be continuous with the Dunnage Mélange since the area between the two is covered by post Mid-Ordovician strata.

9.4. Post-Caradocian Subsidence, Sedimentation and Volcanism.

The pre-Caradocian island arc of the Central Volcanic Belt had collided with the western continental margin and possibly an eastern continental margin by Caradocian times. Thus the Proto-Atlantic Ocean was effectively reduced to a small subsiding basin. The island arc sequences east of Halls Bay sank 2 to 4 km. in the Caradocian and an additional 2 to 4 km of flysch sediments were subsequently deposited, probably causing further subsidence.

The cause of the post-Caradocian volcanism overlying these flysch sediments is problematic since active subduction had ceased by the Caradocian and there does not appear to have been any oceanic crust remaining as potential subduction material. The post-Caradocian volcanism in the Springdale, Roberts Arm and Botwood Belts is distinctly different from the subduction-related pre-Caradocian volcanism. Although it is "calc-alkaline", it is distinctly bimodal. Bimodal volcanism occurs most frequently in areas of tectonic rifting but there is no evidence for rifting in the Late Ordovician and Early Silurian of Central Newfoundland.

The post-Caradocian volcanism may be the result of melting of the subducted slab of oceanic crust remaining suspended after subduction ceased in the Caradocian (Fig. 9.1C, D). Sinking of this heavy slab of oceanic crust would cause it to melt resulting in the creation of new basaltic magma. This rising basalt melt would probably melt part of the overlying crust to create a felsic melt which would ascend together with the basalt to form the observed bimodal volcanism.

The nature of the overlying crust being melted would obviously have an influence on the composition and nature of the volcanism. In the Roberts Arm Belt, the crust involved would have been ophiolitic. Thus volcanism in this belt is dominated by basaltic volcanics with dacitic volcanics concentrated in volcanic centres during the waning stages of volcanism. If continental crust extends as far east at Halls Bay, the crust being melted in the Springdale Belt would be continental although probably thinned and containing a high percentage of basaltic dykes formed during the initial rifting of the Proto-Atlantic Ocean. Springdale Belt volcanism is dominanted by felsic volcanics and rhyolites are common, perhaps reflecting the involvement of melted continental crust. Botwood Belt volcanism is similarly dominated by subaerial felsic volcanics perhaps reflecting a continental basement east of the Northern Arm-Reach Fault. Continental crust must have been exposed to the east of the Botwood Belt in the Early Silurian since the sedimentary rocks of the Wigwam Formation are characterized by abundant detrital muscovite.

Alternative models for the origin of post-Caradocian volcanism may also have merit but the present model best explains the contrasting volcanism in the three belts whose boundaries coincide with proposed boundaries between underlying continental and oceanic crust.

9.5. Continental Squeeze--the Acadian Orogeny

The Devonian Acadian Orogeny may be interpreted as the results of the final stage of closing of the Proto-Atlantic Ocean. The orientation of structural features and the intensity of deformation varies greatly depending upon the configuration of the ancient continental margins and the distance separating them at that time. In southwestern Newfoundland, where deformation and metamorphism are most intense, the two continents appear to have collided along the Cape Ray Suture (Brown, 1973). In the Central Notre Dame Bay area, where deformation and metamorphism is least intense the two continental margins are still 150 km. apart.

The structural features of the Acadian Orogeny dominate the present structural pattern of the Notre Dame Bay area. These features are dominantly upright to overturned folds and steepened thrust faults. The intensity of folding varies depending on the stratigraphic-structural level of strata at that time. Folds increase in tightness in the deeper structural levels and are generally broad open flexures in upper stratigraphic units. Fold axes generally plunge to the northeast although north and east plunging axes are not uncommon. The degree of plunge increases with intensity of folding and structural level. Thus the tightest folds are generally the most steeply plunging.

North to northeast trending folds are dominant in the southern part of the area but these trends swing more east-west as the Lobster Cove-Chanceport Fault is approached from the south. Trends in the Roberts Arm-Pilleys Island-Long Island area are entirely east-west. These same trends continue through the northern half of the Fortune Harbour Peninsula and the Bay of Exploits-New World Island area. The northeast- to north-trending folds in the lower structural levels generally have an associated cleavage developed in the more fissile units. The higher structural levels, especially areas of east-west trending folds have very little cleavage development except in shaley strata near fold closures.

Very little metamorphism accompanied the Acadian deformation in Notre Dame Bay. Most of the strata has suffered only sub-greenschist facies metamorphism or is not metamorphosed at all. On the Burlington Peninsula, the Cape St. John and Pacquet Harbour Groups exhibit increasing metamorphism from south to north (DeGrace et al., 1976). The southern exposures of both groups are little deformed and metamorphosed but these become more intensely deformed and metamorphosed to the north where polyphase structures and upper greenschist to lower amphibolite facies metamorphism is common.

The Acadian Orogeny appears to have involved a great deal of tectonic transport from northwest to southeast. The southeast-directed thrust faults, which may signal the beginning of the Acadian Orogeny, resulted in the transport of large slices of volcanic rocks from the northwest to the southeast (Dean and Strong, 1977). Acadian folds which are overturned are consistently overturned to the southeast or south and associated cleavages dip northwest and north.

The area with the most intense Acadian deformation may be the eastern margin of the Central Volcanic Belt. This eastern margin is not well exposed and has not been intensively studied. However, several lines of evidence suggest extensive tectonic transport of the eastern margin of the Central Volcanic Belt onto the Gander metasedimentary terrain continental margin. Structures within the Gander Group east of the Gander River Ultramafic Belt are dominated by east-facing, flat-lying isoclinal folds (Kennedy and McGonigal, 1972). Structures within the Carmanville Mélange at the structural base of the Davidsville Group indicate eastward tectonic transport (Pickerill et al., 1978). Uzuakpunwa (1974) concluded that the Davidsville Group was transported, in nappe-like fashion, eastwards over the Gander Group and its gneissic basement.

The age of this eastward tectonic transport is best interpreted as Acadian since there are no apparent unconformities or contrast in structural style between the Davidsville Group and Silurian strata of the Botwood Group. Brown (1973) has described similar east-facing nappe-like structures of Devonian age east of the Cape Ray Fault in southwest Newfoundland.

Williams et al. (1972) and Kennedy and McGonigal (1972) have argued for a pre-Middle Ordovician deformation of the Gander Group. Kennedy and McGonigal reported metamorphic detritus in the sedimentary rocks of the Davidsville Group exposed near the contact with the Gander Group on Gander Lake. They postulated that the source of this detritus was the Gander Group metasediments which were deformed prior to deposition of the Davidsville Group. The age of the sedimentary rocks containing the metamorphic detritus and their relationship to fossiliferous Mid-Ordovician strata of the Davidsville Group are unknown. If these sedimentary rocks are in fact part of the Davidsville Group, then the detritus was not necessarily derived from the Gander Group, since it appears that the Davidsville Group is allochthonous with respect to the Gander Group. Hence, the Gander Group was not necessarily deformed prior to deposition of the Davidsville Group.

9.6. Post-Collision Cratonization--the Devonian Intrusions.

The large Devonian intrusive bodies of Central Newfoundland are generally considered to be part of the Acadian Orogeny. However, they post-date the Acadian deformation and are generally discordant with respect to Acadian structures, and some yield Carboniferous radiometric ages. They can perhaps best be considered to be the result of the compressional Acadian deformation and resulting crustal thickening. The extensive crustal thickening caused by the folding and thrusting during deformation probably resulted in the melting of the base of the crust underlying the entire area. This melting would result in the creation of large volumes of magma which would rise to form the granitoid bodies which effectively weld the various geological components of Central Newfoundland into a single Appalachian Orogen (Fig. 9.1.G).

The nature and composition of the underlying crust being melted would obviously have an influence on the magma generated and hence on the type of intrusion. West of Halls Bay, the intrusives are dominantly potash-rich granite, peralkaline granite, syenite and high level quartz-feldspar porphyry. Rb/Sr radiometric ages range from Late Devonian through Carboniferous using $\lambda^{87}Rb = 1.47 \times 10^{-11} yr^{-1}$ (Bell and Blenkinsop, 1977; Pringle, 1978). Sr^{87}/Sr^{86} ratios are high in some intrusions indicating possible involvement of melted continental crust.

Between Halls Bay and the Bay of Exploits, Devonian intrusives are characteristically composite consisting of an early diorite phase intruded by a later quartz monzonite and granite phase. This type is best exemplified by the Twin Lakes-Hodges Hill Batholith. Large areas of amphibolite within the Twin Lakes Diorite may be remnants of the melted oceanic crust which underlay the central portion of the Central Volcanic Belt.

Between the Bay of Exploits and the Gander River Ultramafic Belt, the most common type of Devonian igneous intrusion is a massive quartz diorite, exemplified by the Loon Bay and Rocky Bay Plutons. Two large batholiths in this area, the Fogo and Mount Peyton Batholiths are composite diorite-granite intrusions and are distinctly different from the smaller quartz diorite intrusions, perhaps indicating a somewhat different origin. The Devonian intrusions at the extreme eastern margin of the Central Volcanic Belt, such as the Island Pond and Aspen Cove Plutons, are two-mica granites which are more characteristic of intrusive types in the Gander Metasedimentary Terrain. This perhaps indicates that the metasedimentary terrain extends further to the west underneath the Davidsville Group.

9.7. Harbingers of the New Atlantic--Carboniferous Faulting and Mesozoic Intrusion.

Numerous northeast-trending faults transect Acadian structures and Devonian intrusions in the Notre Dame Bay Area. The best example is the Northern Arm-Reach Fault which transects the nose of a major Acadian fold north of Northern Arm and truncates three separate Devonian intrusions. This episode of faulting is most likely Carboniferous in age and may be related to rifting following the relaxation of Acadian compressional tectonics.

Gently dipping Carboniferous sedimentary rocks are preserved in low valleys in the Indian Pond, King's Point (12H/9), and South Brook (12H/1) areas. The rocks in the Indian Pond area are new exposures created by logging operations. The King's Point and South Brook beds were previously included in the Springdale Group (Neale and Nash, 1963). The rock types in all three areas are chiefly red, coarse sandstone and conglomerate with lesser amounts of mudstone and siltstone. The King's Point exposures also contain beds of grey shale, calcareous siltstone, fine sandstone and algal limestone. The King's Point beds overlie the Lushs Bight Group with pronounced unconformity and were deposited after the Acadian deformation of the latter. The beds along South Brook, previously interpreted as the base of the Springdale Group (Neale and Nash, 1963) rest unconformably on a Devonian granite and contain clasts of that granite. Similarly, the beds near Indian Pond contain clasts of "Topsails Type" granite.

The shallow basins in which these Carboniferous beds were deposited were probably topographic valleys created by the Carboniferous faulting.

Mesozoic alkali gabbro stocks at Dildo Pond (2E/7) and Budgell's Harbour (2E/6) (Strong and Harris, 1974) and the numerous Jurassic-Cretaceous lamprophyre dykes of Notre Dame Bay probably herald the opening of the Labrador Sea.

BIBLIOGRAPHY

Anderson, F. D. and Williams, H., 1970. Gander Lake (west half). Geol. Surv. Can., Map 1195A.

Aumento, F., Loncarevic, B. D., and Ross, D. I., 1971. Hudson Geotraverse: Geology of the mid-Atlantic Ridge at 45° N. Phil. Trans. Roy. Soc. Lond. A, 268, p. 623-650.

Baird, D. M., 1947. The geology of the Burlington Peninsula, Newfoundland. Ph.D. thesis, McGill Univ.

________ 1948. Copper Mineralization in the Betts Cove-Stocking Harbour district, Notre Dame Bay, Newfoundland. Can. Inst. Min. Met. Bull., v 41, p. 211-213.

________ 1950. Fogo Island Map area, Newfoundland. Geol. Surv. Can., Paper 50-22.

________ 1951. Geology of the Burlington Peninsula. Geol. Surv. Can., Paper 51-21.

________ 1953. Reconnaissance geology of part of the New World Island-Twillingate area. Geol. Surv. Nfld., Rept. No. 1, 20 p.

________ 1954. Geological Map of Newfoundland. 1 in.: 12 mi. Geol. Surv. Nfld.

________ 1958. Fogo Island Map Area, Newfoundland. Geol. Surv. Can., Mem. 301.

________ and Snelgrove, A. K., 1953. Mines and mineral resources of Newfoundland. Geol. Surv. Nfld., Inf. Circ. No. 4. (revised edition).

Bell, K. and Blenkinsop, J., 1977. Hercynian activity in Newfoundland--some geochronological evidence. Nature, v. 265, p.616-618.

Bergström, S. M., Riva, J. and Kay, K., 1974. Significance of conodonts, graptolites and shelly faunas from the Ordovician of western and north-central Newfoundland. Can. J. Earth Sci., v. 11, p. 1625-1660.

Berry, W. B. N. and Boucot, A. J., 1970. Correlation of the North American Silurian rocks. Geol. Soc. Am., Spec. Paper 102, 289 p.

Betz, F., Jr., 1948. Geology and mineral deposits of southern White Bay. Geol. Surv. Nfld., Bull. No. 24, 26 p.

Bird, J. M. and Dewey, J. F., 1970. Lithosphere plate-continental marginal tectonics and the evolution of the Appalachian Orogen. Geol. Soc. Am., Bull., v. 81, p. 1031-1060.

Bird, J. M., Dewey, J. F. and Kidd, W. S. F. 1971. Proto-Atlantic oceanic crust and mantle: Appalachian-Caledonian ophiolites. Nature Phys. Sci., v. 231, p. 28-31.

Blackwood, R. F. and Kennedy, M. J., 1975. The Dover Fault - western boundary of the Avalon Zone in Newfoundland. Can. J. Earth Sci., v. 12, p. 320-325.

Bostock, H. H., 1969. Physiographic subdivisions of Canada. In Geology and Economic Minerals of Canada, Douglas, R. J. W., (ed) Geol. Surv. Can., Econ. Geol. Rept. No. 1, p. 9-30.

Brown, P. A., 1973. Possible cryptic suture in southwest Newfoundland. Nature Phys. Sci., v. 245, p. 9-10.

Bursnall, J. T. and DeWit, M.J., 1975. Timing and development of the orthotectonic zone the Appalachian Orogen of northwest Newfoundland. Can. J. Earth Sci., v. 12, p. 1712-1722.

Church, W. R., 1969. Metamorphic rocks of the Burlington Peninsula and adjoining areas of Newfoundland and their bearing on continental drift in the North Atlantic. In North Atlantic-Geology and Continental Drift, Kay, M. (ed). Am. Assoc. Pet. Geol., Mem. 12, p. 212-233.

________ and Stevens, R. K., 1971. Early Paleozoic ophiolite complexes of the Newfoundland Appalachians as mantle-oceanic crust sequences. J. Geophys. Res., v. 76, p. 1460-1466.

Coish, R. A., 1973. Geology and petrochemistry of Trump Island, Notre Dame Bay, Newfoundland. B.Sc. thesis, Mem. Univ. Nfld., 68 p.

Constantinou, G. and Govett, G. J. S., 1972. Genesis of sulphide deposits, ochre and umber of Cyprus. Inst. Min. Metall., Trans., Sect. B., v. 81, p. 32-46.

Corliss, J. B., 1971. The origin of metal-bearing hydrothermal solutions. J. Geophys. Res., v. 76, p. 8128-8138.

Daly, R. A., 1903. Variolitic pillow-lava from Newfoundland. Am. Geol., v. 32, p. 65-78.

Dean, P. L., 1977. A report on the geology and metallogeny of the Notre Dame Bay area, to accompany metallogenic maps 12H/1, 8, 9 and 2E/3, 4, 5, 6, 7, 9, 10, 11 and 12. Nfld. Dept. Mines and Energy, Min. Dev. Div., Rept. 77-10, 17 p.

Dean P. L., and Strong, D. F., 1975. The volcanic stratigraphy, geochemistry and metallogeny of the Central Newfoundland Appalachians. Geol. Assoc. Can., Prog. and Abs., p. 745-746.

________ and Strong, D. F., 1977. Folded thrust faults in Notre Dame Bay, Central Newfoundland. Am. J. Sci., v. 277, p. 97-108.

Dean, W. T., 1970. Lower Ordovician trilobites from the vicinity of South Catcher Pond, northeastern Newfoundland. Geol. Surv. Can., paper 70-44.

________ 1973. Lower Ordovician trilobites from the Summerford Group at Virgin Arm, New World Island, northeastern Newfoundland. Geol. Surv. Can., Bull. 240.

DeGrace, J. R., 1971. Structural and stratigraphic setting of sulphide deposits in Ordovician volcanics south of Kings Point, Newfoundland. M.Sc. thesis, Mem. Univ. Nfld., 97p.

________ Kean, B. F., Hsu, E. and Green, T., 1976. Geology of the Nippers Harbour map area (2E/13), Newfoundland. Nfld. Dept. Mines and Energy, Min. Dev. Div., Rept. 76-3, 73p.

Dewey, J. F., 1969. Evolution of the Appalachian-Caledonian Orogen. Nature, v. 222, p. 124-129.

________ and Bird, J. M., 1971. Origin and emplacement of the ophiolite suite: Appalachian ophiolites in Newfoundland. J. Geophys. Res., v. 76, p. 3174-3266.

Donohoe, H. V., 1968. The structure and stratigraphy of the Halls Bay Head area, Notre Dame Bay, Newfoundland. Final report for British Newfoundland Exploration and Department of Geological Sciences, Lehigh University.

Douglas, G. V., Williams, D. and Rove, O.N., 1940. Copper deposits of Newfoundland. Geol. Surv. Nfld., Bull. No. 20, 176p.

Duke, N.A. and Hutchinson, R. W., 1974. Geological relationships between massive sulphide bodies and ophiolitic volcanic rocks near York Harbour, Newfoundland. Can. J. Earth Sci., v. 11, p. 53-69.

Eastler, T. E., 1969. Silurian geology of Change Islands and eastern Notre Dame Bay, Newfoundland. In North Atlantic Geology and Continental Drift, M. Kay (ed). Am. Assoc. Pet. Geol., Mem. 12, p. 425-432.

Elles, G. L. and Wood, E. M. R., 1901-1910. A Monograph of British graptolites. Paleontol. Soc. Lond. Monogr., 539 p.

Espenshade, G. H., 1937. Geology and mineral deposits of the Pilleys Island area. Nfld. Dept. Nat. Resources, Geol. Sect., Bull. No. 6, 56p.

Fleming, J. M., 1971. Petrology of the volcanic rocks of the Whalesback area, Springdale Peninsula, Newfoundland. M. Sc. thesis, Mem. Univ. Nfld., 107p.

Franks, S. G., 1974. Prehnite-pumpellyite facies metamorphism of the New Bay Formation, Exploits Zone, Newfoundland. Can. Mineral., v. 12, p. 456-462.

Fuller, J. O., 1941. Geology and mineral deposits of the Fleur de Lys area. Geol. Surv. Nfld., Bull. No. 15, 41p.

Gass, I. G. and Smewing, J. D., 1973. Intrusion, extrusion and metamorphism at constructive margins: Evidence from the Troodos Massif, Cyprus. Nature, v. 242, p. 26-29.

Geological Society of America Penrose Conference, 1972. Penrose field conferences on ophiolites. Geotimes, v. 17, no. 12, p. 25.

Gibbons, R. V., 1969. Geology of the Moretons Harbour area, Newfoundland, with emphasis on the environment and mode of formation of the arsenopyrite veins. M. Sc. thesis, Mem. Univ. Nfld., 164p.

Gibbons, R. V. and Papezik, V. S., 1970. Volcanic rocks and arsenopyrite veins of the Moretons Harbour ~~area,~~ Notre Dame Bay, Nfld. Geol. Assoc. Can. Proc., v. 22, p. 1-9.

Govett, G. J. S. and Pantaziz, T. L. M., 1971. Distribution of Cu, Zn, Ni and Co in the Troodos pillow lava series, Cyprus. Inst. Min. Metall., Trans., Sect. B., v. 80, p. 27-46.

Harris, I. McK. 1966. Geology of the Cobbs Arm area, New World Island area. Nfld. Dept. of Mines, Agric. and Res., Min. Res. Div., Bull. No. 37, 38p.

Haworth, R. T., Poole, W. H., Grant, A. C. and Sanford, B. V., 1976. Marine geoscience survey northeast of Newfoundland. Geol. Surv. Can., Paper 76-1A, p. 7-15.

Hayes, J. J., 1951a. Preliminary Map, Hodges Hill. Geol. Surv. Can., Paper 51-5.

________ 1951b. Preliminary Map, Marks Lake. Geol. Surv. Can., Paper 51-20.

________ 1951c. Geology of the Hodges Hill-Marks Lake area, northern Newfoundland. Ph.D. thesis, Univ. Mich., 163p.

S

Helwig, J. A., 1967. Stratigraphy and structural history of the New Bay area, north central Newfoundland. Ph.D. thesis, Columbia Univ., 211p.

_________ 1969. Redefinition of Exploits Group, Lower Paleozoic, northeast Newfoundland. In North Atlantic-Geology and Continental Drift, Kay, M. (ed). Am. Assoc. Pet. Geol., Mem. 12, p. 408-413.

_________ 1970. Slump folds and early structures, northeastern Newfoundland Appalachians. J. Geol., v. 78, p. 172-187.

_________ and Sarpi, E., 1969. Plutonic-pebble conglomerates, New World Island, Newfoundland, and the history of eugeosynclines. In North Atlantic-Geology and Continental Drift, Kay, M. (ed). Am. Assoc. Pet. Geol., Mem. 12, p. 443-466.

Heyl, G. R., 1936. Geology and mineral deposits of the Bay of Exploits area. Geol. Surv. Nfld., Bull. No. 3, 66p.

_________ 1937a. Geology and mineral deposits of the New Bay area, Notre Dame Bay, Newfoundland. Geol. Surv. Nfld., unpub. rept., 51p.

_________ 1937b. Lamprophyres of the Bay of Exploits, Newfoundland. Am. Mineral., v. 22, p. 213-214.

Hibbard, J. P., 1976. The southwestern extension of the Dunnage Mélange and its relationships to nearby groups. M. Sc. thesis, Mem. Univ. Nfld.

Hibbard, J. P., Stouge, S. and Skevington, D., 1977. Fossils from the Dunnage Mélange, north-central Newfoundland. Can. J. Earth Sci., v. 14, p. 1176-1178.

Horne, G. S., 1968. Stratigraphy and structural geology of southwestern New World Island area, Newfoundland. Ph.D. thesis, Columbia univ.

_________ 1969. Early Ordovician chaotic deposits in the central volcanic belt of northeastern Newfoundland. Geol. Soc. Am., Bull., v. 80, p. 2451-2464.

_________ 1970. Complex volcanic-sedimentary patterns in the Magog Belt of northeastern Newfoundland. Geol. Soc. Am., Bull., v. 81, p. 1767-1788.

_________ 1976. Geology of Lower Ordovician Fossiliferous strata between Virgin Arm and Squid Cove, New World Island, Newfoundland. Geol. Surv. Can., Bull. 261, p. 1-9.

_________ and Helwig, J. A., 1969. Ordovician Stratigraphy of Notre Dame Bay, Newfoundland. In North Atlantic-Geology and Continental Drift. Kay. M. (ed). Am. Assoc. Pet. Geol., Mem. 12, p. 308-407.

Horne, G. S. and Johnson, J. H., 1970. Ordovician algae from boulders in Silurian deposits of New World Island, Newfoundland. J. Paleontol., v. 44, p. 1055-1059.

Howley, J. P., 1907. Geological map of Newfoundland, 1: 108,800. (Reprinted 1915, 1925).

Hunt, S., 1861. On some points in American Geology. Am. J. Sci., v. 31, No. 93, p. 392-414.

Hussey, E. M., 1974. Geological and petrochemical data on the Brighton Complex, Notre Dame Bay, Newfoundland. B.Sc. thesis, Mem. Univ. Nfld. 66p.

Hutchinson, R. W. and Searle, D. R., 1971. Stratabound pyrite deposits in Cyprus and relations to other sulphide ores. Soc. Min. Geol. Japan., Spec. Issue 3, p. 198-205.

Jenness, S. E., 1954. Geology of the Gander River Ultrabasic Belt, Newfoundland. Ph.D. thesis, Yale Univ., 182p.

________ 1957. Gander Lake, preliminary map (east half). Geol. Surv. Can., Map 3-1957.

________ 1958. Geology of the Gander River Ultrabasic Belt, Newfoundland. Geol. Surv. Nfld., Rept. 14, 58p.

________ 1963. Terra Nova and Bonavista map areas, Newfoundland. Geol. Surv. Can., Mem. 327, 184p.

Jukes, J. B., 1843. General report of the Geological Survey of Newfoundland during the years 1839 and 1840. London, Murray (pub.), 160p.

Kalliokoski, J., 1951. Preliminary map, Gull Pond. Geol. Surv. Can., Paper 51-1.

________ 1953. Preliminary map, Springdale, Newfoundland. Geol. Surv. Can., Paper 53-5.

________ 1954. Second preliminary map, Gull Pond, Newfoundland. Geol. Surv. Can., Paper 54-4.

Karig, D. E., 1971. Origin and development of marginal basins in the western Pacific. J. Geophys. Res., v. 76, p. 2542-2561.

Kay, M., 1951. North American Geosynclines. Geol. Soc. Am., Mem. 48, 143p.

________ 1967. Stratigraphy and structure of northeastern Newfoundland and bearing on drift in the North Atlantic. Am. Assoc. Pet. Geol., Bull., v. 51, p. 579-600.

Kay, M., 1969a. (Editor) North Atlantic Geology and Continental Drift. Am. Assoc. Pet. Geol., Mem. 12, 1082p.

________ 1969b. Silurian of northeast Newfoundland coast. In North Atlantic Geology and Continental Drift. Kay, M. (ed). Am. Assoc. Pet. Geol., Mem. 12, p. 414-424.

________ 1970. Flysch and bouldery mudstone in northeast Newfoundland. Geol. Assoc. Can., Spec. Paper 7, p. 155-164.

________ 1972. Dunnage Mélange and lower Paleozoic deformation in northeastern Newfoundland. 24th Int. Geol. Congr., Proc., Sect. 3, p. 122-132.

________ 1973. Tectonic evolution of Newfoundland. In Gravity and Tectonics, DeJong, K. A. and Scholten, R. (eds). Wiley-Interscience, p. 313-326.

________ 1975. Campbellton Sequence: manganiferous beds adjoining the Dunnage Mélange, northeastern Newfoundland. Geol. Soc. Am., Bull., v. 86, p. 105-108.

________ 1976a. Ordovician history of Newfoundland. In The Ordovician System, Bassett, M.G. (ed). Univ. of Wales Press and Nat. Mus. of Wales, Cardiff, p. 251-262.

________ 1976b. Dunnage Mélange and subduction of the Protoacadic Ocean, northeast Newfoundland. Geol. Soc. Am., Spec. paper 175. 49p.

________ and Williams, H., 1963. Ordovician-Silurian relationships on New World Island, Notre Dame Bay, northeast Newfoundland. Geol. Soc. Am., Bull., v. 74, p. 807.

________ and Eldredge, N., 1968. Cambrian trilobites in the central Newfoundland volcanic belt. Geol. Mag., v. 105, p. 372-377.

Kean, B. F., 1973. Stratigraphy, petrology and geochemistry of volcanic rocks of Long Island, Newfoundland. M.Sc. thesis, Mem. Univ. Nfld., 155p.

________ and Strong, D. F., 1975. Geochemical evolution of an Ordovician island arc of the central Newfoundland Appalachians. Am. J. Sci., v. 275, p. 97-118.

________, Dean, P. L. and Strong, D.F., (in press). Regional Geology of the Central Volcanic Belt of Newfoundland. In the Geology of the Buchans Ore Deposits. Geol. Assoc. Can., Spec. Paper 20.

Kennedy, M. J., 1973. Pre-Ordovician polyphase structure in the Burlington Peninsula of the Newfoundland Appalachians. Nature Phys. Sci., v. 241, p. 114-116.

Kennedy, M. J., 1975. Repetitive orogeny in the northeastern Appalachians - new plate models based upon Newfoundland examples. Tectonophysics, v. 28, p. 39-87.

________ and Phillips, W. E. A., 1971. Ultramafic rocks of the Burlington Peninsula, Newfoundland. Geol. Assoc. Can., Proc., v. 24, p. 35-46.

________ and DeGrace, J. R., 1972. Structural sequence and its relationship to sulphide mineralization in the Ordovician Lushs Bight Group of western Notre Dame Bay, Newfoundland. Can. Inst. Min. Metall., v. 65, p. 300-308.

________ and McGonigal, M. H., 1972. The Gander Lake and Davidsville Groups of northeastern Newfoundland: New data and geotectonic implications. Can J. Earth Sci., v. 9, p. 452-459.

________, Neale, E. R. W. and Phillips, W. E., 1972. Similarities in the early structural development in the northwestern margin of the Newfoundland Appalachians and Irish Caledonides. 24th. Int. Geol. Congr., sect. 3, p. 516-531.

Kidd, W. S. F., 1974. The evolution of the Baie Verte Lineament, Burlington Peninsula, Newfoundland. Ph.D. thesis, Cambridge Univ., 294p.

Krank, E. H., 1952. Geology of the New Bay-Loon Bay-Lewisporte areas and of the southeast part of New World Island, Notre Dame Bay, Newfoundland. Geol. Surv. Nfld., unpub. rept., 48p.

Lambert, I. B. and Bubela, B., 1970. Banded sulphide ores: The experimental production of monomineralic sulphide bands in sediments. Miner. Deposita, v. 5, p. 97-102.

Logan, W. E., 1863. Geology of Canada: Report of progress from its commencement to 1863. Dawson Bros., Montreal (pubs), 983p.

MacLean, H. J., 1947. Geology and mineral deposits of the Little Bay area. Geol. Surv. Nfld., Bull. No. 22, 36p.

Malpas, J. and Strong, D. F., 1974. A comparison of chrome spinels in ophiolites and mantle diapirs of Newfoundland. Geochim. Cosmochim. Acta, v. 39, p. 1045-1060.

Marten, B. E., 1971. Stratigraphy of volcanic rocks in the Western Arm area of the central Newfoundland Appalachians. Geol. Assoc. Can., Proc., v. 24, p. 73-84.

Mattinson, J. M., 1975. Early Paleozoic ophiolite complexes of Newfoundland: Isotopic ages of zircons. Geology, v. 3, p. 181-183.

Melson, W. G. and van Andel, T. H., 1966. Metamorphism on the Mid-Atlantic Ridge, 22° north latitude. Marine Geol., v. 4, p. 165-186.

Mitchell, A. H. G., 1976. Tectonic setting for emplacement of subduction related magmas and associated mineral deposits. In Metallogeny and Plate Tectonics, Strong, D. F. (ed). Geol. Assoc. Can., Spec. paper 14, p. 3-21.

________ and Bell, J. D., 1973. Island-arc evolution and related mineral deposits. J. Geol., v. 81, p. 381-405.

Murray, A. and Howley, J. P., 1881. Geological Survey of Newfoundland from 1864 to 1880. Geol. Surv. Nfld. Pub., 536p.

McArthur, J. G., 1974. The Geology of the Stirling copper property, Springdale, Newfoundland. M.Sc. thesis, Mem. Univ. Nfld., 92p.

McCann, A. M., 1973. Structural and stratigraphic relationships in Silurian rocks of the Port Albert-Horwood area, Twillingate-Fogo districts, Newfoundland. M. Sc. thesis, Mem. Univ. Nfld., 102p.

McGonigal, M. H., 1970. Geology of the Springdale Group west of the Little Bay Road, northwest central Newfoundland. B.Sc. thesis, Mem. Univ. Nfld., 37p.

________ 1973. The Gander and Davidsville Groups: Major tectonostratigraphic units in the Gander Lake area, Newfoundland. M. Sc. thesis, Mem. Univ. Nfld., 121 p.

McKerrow, W. S. and Cocks, L. R. M., 1977. The location of the Iapetus Ocean Suture in Newfoundland. Can. J. Earth Sci., v. 14, p. 488-495.

Neale, E. R. W., 1957. Ambiguous intrusive relationships of the Betts Cove-Tilt Cove serpentinite belt, Newfoundland. Geol. Assoc. Can., Proc., v. 9, p. 95-107.

________ 1958a. Baie Verte, Newfoundland. Geol. Surv. Can., Map 10-1958.

________ 1958b. Nippers Harbour, Newfoundland. Geol. Surv. Can., Map 22-1958.

________ 1959. Fleur de Lys, Newfoundland. Geol. Surv. Can., Map 16-1959.

________, Nash, W. A. and Innes, G. M., 1960. Kings Point, Newfoundland. Geol. Surv. Can., Map 35-1960.

Neale, E. R. W. and Nash, W. A., 1963. Sandy Lake (east half), Newfoundland. Geol. Surv. Can., Paper 62-28.

________ and Kennedy, M. J., 1967a. Relationship of the Fleur de Lys group to younger groups of the Burlington Peninsula, Newfoundland. Geol. Assoc. Can., Spec. Paper 4, p. 139-169.

________ and Kennedy, M. J., 1967b. Guidebook and road log, Burlington Peninsula, Newfoundland. Geol. Surv. Can. Rept., 10p.

________, Kean, B. F. and Upadhyay, H. D., 1975. Post-ophiolite unconformity, Tilt Cove-Betts Cove area, Newfoundland. Can. J. Earth Sci., v. 12, p. 880-886.

Neuman, R. B., 1972. Brachiopods of Early Ordovician volcanic islands, 24th Int. Geol. Congr., Sect. 7, p. 297-302.

________ 1976. Early Ordovician (Late Arenig) brachiopods from Virgin Arm, New World Island, Newfoundland. Geol. Surv. Can., Bull. 261, p. 10-61.

Norman, R. E., 1974. Geology and petrochemistry of ophiolitic rocks of the Baie Verte Group exposed at Ming's Bight, Newfoundland. M.Sc. thesis, Mem. Univ. Nfld., 123p.

________ and Strong, D. F., 1975. The geology and geochemistry of ophiolitic rocks exposed at Ming's Bight, Newfoundland. Can. J. Earth Sci., v. 12, p. 777-797.

O'Brien, S. J., 1975. The stratigraphy, petrology and geochemistry of the extrusive and intrusive rocks of Little Bay Island, Newfoundland. B.Sc. thesis, Mem. Univ. Nfld., 70p.

Oversby, B. S., 1967. Geology of Upper Black Island, Bay of Exploits, Newfoundland. M. A. thesis, Columbia Univ., 68p.

Patrick, T. O. H., 1956. Comfort Cove, Newfoundland. Geol. Surv. Can., Paper 55-31.

Papezik, V. S. and Fleming, J. M., 1967. Basic volcanic rocks of the Whalesback area, Newfoundland. Geol. Assoc. Can., Spec. Paper 4, p. 181-192.

Peters, H. R., 1967. Mineral Deposits of the Halls Bay area, Newfoundland. Geol. Assoc. Can. Spec Paper 4, p. 171-179.

Peters, R., 1970. Geology of the Nickeys Nose-Harry's Harbour area, Lushs Bight Group. B. Sc. thesis, Mem. Univ. Nfld., 20p.

Payne, J. G., 1974. The Twillingate Granite and its relationships to surrounding country rocks. M.Sc. thesis, Mem. Univ. Nfld., 159p.

Payne, J. G. and Strong D. F., (in press). Origin of the Twillingate Trondhjemite, north central Newfoundland: Partial melting in the roots of an island arc. In Trondhjemites, Dacites and Related Rocks, Barker, F. (ed.), Elsevier.

Pickerill, R. K., Pajari, G. E., Currie, K. L. and Berger, A. R., 1978. Carmanville map-area, Newfoundland; the northeast end of the Appalachians. Geol. Surv. Can., Paper 78-1A, p. 209-216.

Pringle, I. R., 1978. Rb-Sr ages of silicic igneous rocks and deformation, Burlington Peninsula, Newfoundland. Can. J. Earth Sci., v. 15, p. 293-300.

Ruedemann, R., 1947. Graptolites of North America. Geol. Soc. Am., Mem. 19, 625p.

Sampson, E., 1923. The Ferruginous chert formations of Notre Dame Bay. J. Geol., v. 31, p. 571-598.

Sangster, D. F., 1972. Precambrian volcanogenic massive sulphide deposits in Canada. A review. Geol. Surv. Can., Paper 72-22.

________ and Thorpe, R. I., 1975. Sulphur, lead isotopes prove useful tools in current G. S. C. research on ore deposition. Northern Miner, v. 61, No. 37, p. B22-B23.

Sato, T., 1976. Origin of the green tuff metal province of Japan. In Metallogeny and Plate Tectonics, Strong, D. F. (ed). Geol. Assoc. Can., Spec Paper 14, p. 105-120.

Sayeed, U. A., 1970. The tectonic setting of the Colchester Plutons, Southwest Arm, Green Bay, Newfoundland. M. Sc. thesis, Mem. Univ. Nfld., 76p.

Schroeter, T. G., 1971. Geology of the Nippers Harbour area, Newfoundland. M. Sc. thesis, Univ. West. Ont., 93p.

Sheridan, R. E. and Drake, C. L., 1968. Seaward extension of the Canadian Appalachians. Can. J. Earth Sci., v. 5, p. 337-373.

Sillitoe, R. H., 1972. Formation of certain massive sulphide deposits at sites of sea-floor spreading. Inst. Min. Metall., Trans., Sect. B, v. 81, p. B141-B148.

Smitheringale, W. G., 1972. Low-potash Lushs Bight tholeiites: Ancient oceanic crust in Newfoundland? Can. J. Earth Sci., v. 9, p. 574-588.

________ and Peters, H. R., 1974. Volcanogenic copper deposits in probable ophiolitic rocks, Springdale Peninsula. In Plate Tectonic Setting of Newfoundland Mineral Occurrences, Strong, D. F. (ed). A guidebook for the NATO advanced studies institute on metallogeny and plate tectonics, p. 95-108.

Snelgrove, A. K., 1928. The geology of the central mineral belt of Newfoundland. Can. Inst. Min. Metal., Bull. No 197, p. 1057-1127.

________ 1931. Geology and ore deposits of the Betts Cove-Tilt Cove area, Notre Dame Bay, Newfoundland. Can. Inst. Min. Metal., Bull. No. 228, p. 477-519.

________ 1934. Chromite deposits of Newfoundland. Geol. Surv. Nfld., Bull. No. 1, 26p.

________ 1935. Geology of gold deposits of Newfoundland. Geol. Surv. Nfld., Bull. No. 2, 45p.

________ 1938. Mines and mineral resources of Newfoundland. Geol. Surv. Nfld., Info. Circ. No. 4, 149p.

Spooner, E. T. C. and Fyfe, W. S., 1973. Sub-Sea-floor metamorphism, heat and mass transfer. Contr. Mineral. Petrol., v. 42, p. 287-304.

Stevens, R. K., Strong, D. F. and Kean, B. F., 1974. Do some eastern Appalachian ultramafic rocks represent mantle diapirs produced above a subduction zone? Geology, v. 2, p. 175-178.

Strong, D. F., 1972. Sheeted diabases of central Newfoundland: New evidence for Ordovician sea-floor spreading. Nature, v. 235, p. 102-104.

________ 1973a. Lushs Bight and Roberts Arm Groups of central Newfoundland: Possible juxtaposed oceanic and island arc volcanic suites. Geol. Soc. Am., Bull., v. 84, p. 3917-3928.

________ 1973b. Plate tectonic setting of Appalachian-Caledonian mineral deposits as indicated by Newfoundland examples. Soc. Min. Eng. AIME,

________ 1974. (Editor). Plate tectonic setting of Newfoundland mineral occurrences. A guide book for the NATO advanced studies institute on metallogeny and plate tectonics, 171p.

________ 1976. (Editor). Metallogeny and Plate Tectonics. Geol. Assoc. Can., Spec. Paper 14, 660p.

________ 1977. Volcanic regimes of the Newfoundland Appalachians. Geol. Assoc. Can., Spec. Paper 16, p. 61-90.

________ and Kean, B. F., 1972. New fossil localities in the Lushs Bight terrane of central Newfoundland. Can. J. Earth Sci., v. 9, p. 1572-1576.

Strong, D. F. and Payne, J. G., 1973. Early Paleozoic volcanism and metamorphism of the Moretons Harbour-Twillingate area, Newfoundland. Can. J. Earth Sci., v. 10, p. 1363-1379.

________ and Harris, A. H., 1974. The petrology of Mesozoic alkaline intrusives of central Newfoundland. Can. J. Earth Sci., v. 11, p. 1208-1219.

________, Dickson, W. L., O'Driscoll, C. F., Kean, B. F. and Stevens, R. K, 1974. Geochemical evidence for an east-dipping Appalachian subduction zone in Newfoundland. Nature, v. 248, p. 37-39.

Stukas, V. and Reynolds, P. H., 1974. $^{40}Ar/^{39}Ar$ Dating of the Brighton Gabbro Complex, Lushs Bight Terrane, Newfoundland. Can. J. Earth Sci., v. 11, p. 1485-1488.

Swinden, H. S. and Strong, D. F., 1976. A comparison of plate tectonic models of metallogenesis in the Appalachians, the North American Cordillera, and the East Australian Paleozoic. In Metallogeny and Plate Tectonics, Strong, D. F. (ed). Geol. Assoc. Can., Spec. Paper 14, p. 441-470.

Thurlow, J. G., Swanson, E. A. and Strong, D. F., 1975. Geology and lithogeochemistry of the Buchans polymetallic sulphide deposits, Newfoundland. Econ. Geol., v. 70, p. 130-144.

Twenhofel, W. H., 1947. The Silurian of eastern Newfoundland with some data relating to physiography and Wisconsin glaciation of Newfoundland. Am. J. Sci., v. 245, p. 65-122.

________ and Shrock, R. R., 1937. Silurian strata of Notre Dame Bay and Exploits Valley, Newfoundland. Geol. Soc. Am., Bull., v. 48, p. 1743-1772.

________ and MacClintock, P., 1940. Surface of Newfoundland. Geol. Soc. Am., Bull., v. 51, p. 1665-1728.

Upadhyay, H. D., 1970. The geology of the Gullbridge copper deposit, central Newfoundland. M. Sc. thesis, Mem. Univ. Nfld., 134p.

________ 1973. The Betts Cove Ophiolite and related rocks of the Snooks Arm Group, Newfoundland. Ph.D. thesis, Mem. Univ. Nfld., 224p.

________, Dewey, J. F. and Neale, E. R. W., 1971. The Betts Cove Ophiolite complex, Newfoundland: Appalachian oceanic crust and mantle. Geol. Assoc. Can., Proc., v. 24, p. 27-34.

________ and Smitheringale, W. G., 1972. The Gullbridge copper deposit, Newfoundland: volcanogenic sulphides in cordierite-anthophyllite rocks. Can. J. Earth Sci., v. 9, p. 1061-1073.

Upadhyay, H.D. and Strong, D.F., 1973. Geological setting of the Betts Cove copper deposits, Newfoundland: An example of ophiolite sulphide mineralization. Econ. Geol., v. 68, p. 161-167.

Uzuakpunwa, A.B., 1974. Structural studies of the Gander and Davidsville Groups in the Carmanville-Ladle Cove areas, Newfoundland. M.Sc. thesis, Mem. Univ. Nfld., 136p.

Vokes, F.M. and Gale, G.H., 1976. Metallogeny relatable to global tectonics in southern Scandinavia. In Metallogeny and Plate Tectonics, Strong, D.F. (ed.). Geol. Assoc. Can., Spec. Paper 14, p. 411-440.

Wadsworth, M.E., 1884. Notes on the rocks and ore deposits in the vicinity of Notre Dame Bay, Newfoundland. Am. J. Sci., v. 28, p. 94-104.

Watson, K. deP., 1943. Mafic and Ultramafic rocks of the Baie Verte area, Newfoundland. J. Geol., v. 51, p. 116-130.

__________ 1947. Geology and mineral deposits of the Baie Verte-Mings Bight area. Geol. Surv. Nfld., Bull. No. 21, 48p.

Williams, H., 1957a. Petrology of the Tilting igneous complex, Fogo district. M.Sc. thesis, Mem. Univ. Nfld., 51p.

__________ 1957b. Petrology of the Tilting Igneous Complex. Geol. Surv. Nfld., Rept. No 13, 51p.

__________ 1962. Botwood Map Area (west half). Geol. Surv. Can., Paper 62-9.

__________ 1963a. Twillingate Map Area, Newfoundland. Geol. Surv. Can., Paper 63-36.

__________ 1963b. Botwood Map Area. Geol. Surv. Can., Map 60-1963.

__________ 1963c. Relationship between base metal mineralization and volcanic rocks in northeastern Newfoundland. Can. Min. J., v. 84, p. 39-42.

__________ 1964. The Appalachians in northeastern Newfoundland--a two sided symmetrical system. Am. J. Sci., v. 262, p. 1137-1158.

__________ 1967a. Island of Newfoundland. Geol. Surv. Can., Map 1231A.

__________ 1967b. Silurian rocks of Newfoundland. Geol. Assoc. Can., Spec. Paper 4, p. 93-137.

__________ 1972. Stratigraphy of Botwood map area, northeastern Newfoundland. Unpub. manuscript, Geol. Surv. Can., open file 113, 103p.

Williams, H., Kennedy, M. J. and Neale, E. R. W., 1972. The Appalachian structural province. In Variations in tectonic styles in Canada, Price, R. A. and Douglas, R. J. W. (eds). Geol. Assoc. Can., Spec. Paper 11, p. 181-261.

________, Kennedy, M. J. and Neale, E. R. W., 1974. The northeastern termination of the Appalachian orogen. In the Ocean Basins and Margins, the North Atlantic, v. 2. Nairn, A. E. and Stehli, F. G. (eds). Plenum Press, N. Y., p. 79-123.

________ and Stevens, R. K., 1974. The ancient continental margin of eastern North America. In the Geology of Continental Margins. Burk, C. A. and Drake, C. L. (eds). Springer-Verlag, p. 781-796.

________ and Payne, J. G., 1975. The Twillingate Granite and nearby volcanic groups: an island arc complex in northeastern Newfoundland. Can. J. Earth Sci., v. 12, p. 982-995.

________ and Hibbard, J. P., 1976. The Dunnage Mélange, Newfoundland. Geol. Surv. Can., Paper 76-1A, p. 183-185.

________, Dallmeyer, R. D. and Wanless, R. K., 1976. Geochronology of the Twillingate Granite and Herring Neck Group, Notre Dame Bay, Newfoundland. Can. J. Earth Sci., v. 13, p. 1591-1601.

________, Hibbard, J. P. and Bursnall, J. T., 1977. Geological setting of asbestos-bearing ultramafic rocks along the Baie Verte Lineament, Newfoundland. Geol. Surv. Can., Paper 77-1A, p. 351-360.

Wilson, J. T., 1966. Did the Atlantic close and then re-open? Nature, v. 211, p. 676-681.

APPENDIX 1.

CARADOCIAN GRAPTOLITES OF NOTRE DAME BAY

A.1. Shoal Arm Formation

Location 1: The south coast of Gull Island, Badger Bay, west side of a small cove. (2E/5).
Collected by P. Dean. Identified by J. Riva.

Climacograptus bicornis (Hall)
Dicellograptus sextans (Hall)
Climacograptus brevis Elles and Wood
Cryptograptus tricornis (Carruthers)
Orthograptus of the *calcaratus* group
Pseudoclimacograptus scharenbergi (Lapworth)
Glyptograptus cf. *euglyphus* Lapworth
Lasiograptus or *Hallograptus* sp.

Location 2: The northeast corner of the northern part of New Bay Pond. (2E/4).
Collected by H. Williams. Identified by L. M. Cumming.

Leptograptus flaccidus (Hall)
Climacograptus sp. either *bicornis* (Hall) or *diplacanthus* (Bulman)
Orthograptus sp.

Location 3: Western Arm Brook, 700 m. above mouth. (2E/6).
Collected by J. Helwig and B. Oversby. Identified by J. Riva.

Climacograptus bicornis Hall
Climacograptus brevis Elles and Wood
Climacograptus mohawkensis (Ruedemann)
Climacograptus spiniferus Ruedemann
Dicellograptus forchammeri (Geinitz)
Glyptograptus cf. *G. euglyphus* Lapworth
Orthograptus amplexicaulis (Hall)
Orthograptus quadrimucronatus s.s. (Hall)

Location 4: Road cut on Route 350, northwest of Mill Cove, Osmonton Arm.
Collected by H. Williams. Identified by B. D. Erdtmann.

Climacograptus cf. *C. diplacanthus* (Bulman)
Climacograptus cf. *C. tubiliferus* (Lapworth)
Climacograptus cf. *C. bicornis* (Hall)
Orthograptus sp.

A.2. Lawrence Harbour Shale (2E/6).

Location 1: Route 352, 1.6 km. north of Saltwater Pond.
Collected by J. Helwig and B. Oversby. Identified by J. Riva.

Climacograptus bicornis (Hall)
Climacograptus bicornis tridentatus Lapworth
Climacograptus brevis Elles and Wood
Cryptograptus tricornis (Carruthers)
Dicellograptus divaricatus (Hall)
Dicellograptus sextans (Hall)
Dicellograptus exilis Elles and Wood
Didymograptus superstes Lapworth
Glyptograptus teretiusculus (Hisinger)
Hallograptus mucronatus (Hall)
Nemagraptus gracilis (Hall)
Nemagraptus exilis (Lapworth)
Pseudoclimacograptus scharenbergi (Lapworth)

Location 2: South shore of Lawrence Harbour.
Collected by J. Helwig and B. Oversby. Identified by J. Riva.

Climacograptus bicornis (Hall)
Climacograptus brevis Elles and Wood
Corynoides sp.
Cryptograptus tricornis (Carruthers)
Dicellograptus divaricatus (Hall)
Dicellograptus sextans (Hall)
Dicellograptus sp. cf. *D. smithi* Ruedemann
Didymograptus serratulus (Hall)
Didymograptus superstes Lapworth
Glossograptus sp. cf. *G. ciliatus* (Emmons)
Glyptograptus euglyphus (Lapworth)
Glyptograptus teretiusculus (Hisinger)
Hallograptus mucronatus (Hall)
Nemagraptus gracilis (Hall)
Nemagraptus exilis (Lapworth)
Orthograptus calcaratus acutus (Lapworth)
Pseudoclimacograptus scharenbergi (Lapworth)

Location 3: West shore of Lawrence Harbour.
Collected by J. Helwig and B. Oversby. Identified by J. Riva.

Amplexograptus sp.
Climacograptus bicornis (Hall)
Climacograptus brevis Elles and Wood
Dicellograptus sextans (Hall)
Dicellograptus exilis Elles and Wood
Dicellograptus sp. cf. *D. smithi* Ruedemann

Location 3 (continued)

Dicranograptus furcatus (Hall)
Didymograptus serratulus (Hall)
Didymograptus superstes Lapworth
Glossograptus sp. cf. *G. hincksii* (Hopkins)
Glossograptus sp. cf. *G. ciliatus* (Emmons)
Glyptograptus euglyphus (Lapworth)
Nemagraptus exilis (Lapworth)
Orthograptus calcaratus acutus Lapworth
Pseudoclimacograptus scharenbergi (Lapworth)

Location 4: East side of Stocking Harbour, New Bay.
Collected by M. Kay and J. Helwig. Identified by J. Riva.

Climacograptus brevis Elles and Wood
Dicellograptus sextans (Hall)
Dicranograptus furcatus (Hall)
Dicranograptus ramosus (Hall)
Didymograptus serratulus (Hall)
Glyptograptus teretiusculus (Hisinger)
Nemagraptus gracilis (Hall)
Orthograptus calcaratus acutus Lapworth
Orthograptus calcaratus subspecies
Pseudoclimacograptus scharenbergi (Lapworth)

A.3. <u>Unnamed Argillites of the Exploits Group</u> (2E/6)

Location 1: Leading Tickles, south east end of Cull Island
Collected by J. Helwig. Identified by J. Riva.

Climacograptus caudatus Lapworth
Climacograptus mohawkensis (Ruedemann)
Climacograptus spiniferus Ruedemann
Cryptograptus insectiformis Ruedemann
Dicellograptus forchammeri (Geinitz)
Diplograptus multidens (Lapworth)
Neurograptus margaritatus (Lapworth)
Orthograptus amplexicaulis (Hall)
Orthograptus quadrimucronatus s.s. (Hall)
Pseudoplegmatograptus sp.

Location 1a: as above.
Collected by H. Williams. Identified by B. D. Erdtmann.

Climacograptus cf. *C. antiquus* (Lapworth)
Dicellograptus cf. *D. sextans exilis* Elles and Wood
Glyptograptus cf. *G. euglyphus* (Lapworth)

Location 2: South shore of Mussel Bed Island, Osmonton Arm, New Bay.
Collected by B. Oversby and J. Helwig. Identified by J. Riva.

Climacograptus mohawkensis (Reudemann)
Dicellograptus forchammeri (Geinitz)
Orthograptus amplexicaulis (Hall)

Location 3: North end of Beach Island, Osmonton Arm, New Bay.
Collected by J. Helwig. Identified by J. Riva.

Climacograptus mohawkensis (Ruedemann)
Glyptograptus sp.
Neurograptus margaritatus (Lapworth)

Location 3a: as above.
Collected by H. Williams. Identified by L. M. Cumming.

Leptograptus flaccidus macer (Hall)
Climacograptus bicornis peltifer (Lepworth)
"*Mesograptus*" sp.

Location 4: Bearpath Cove, Southwest Arm, New Bay.
Collected by J. Helwig. Identified by J. Riva.

Dicellograptus forchammeri Geinitz
Dicranograptus sp.
Leptograptus flaccidus (Hall)
Orthograptus amplexicaulis (Hall)
Orthograptus quadrimucronatus s.s. (Hall)

Location 5: Cooper's Farm, Southwest Arm, New Bay, opposite town of Point Leamington.
Collected by J. Helwig. Identified by J. Riva.

Climacograptus brevis Elles and Wood
Dicellograptus forchammeri Geintz
Glyptograptus cf. *G. euglyphus* Lapworth
Leptograptus capillaris (Carruthers)
Neurograptus margaritatus (Lapworth)
Orthograptus calcaratus basilicus Lapworth
Orthograptus quadrimucronatus micracanthus Elles and Wood
Orthograptus quadrimucronatus spiniqerus Lapworth
Pseudoclimacograptus modestus (Ruedemann)

Location 6: Northwest shore of Strong Island Sound, New Bay.
Collected by J. Helwig. Identified by J. Riva.

Climacograptus mohawkensis (Ruedemann)
Diplograptus multidens ssp. cf. *D. m. compactus* (Lapworth)
Leptograptus capillaris (Carruthers)
Orthograptus amplexicaulis (Hall)
Orthograptus quadrimucronatus s.s. (Hall)
Pseudoplegmatograptus sp.

Location 7: 914 m. north of Leamington Point, Southwest Arm, New Bay.
Collected by J. Helwig and B. Oversby. Identified by J. Riva.

Leptograptus flaccidus (Hall)
Orthograptus amplexicaulis (Hall)
Orthograptus quadrimucronatus (Hall)

Location 8: North shore of Lawrence Harbour.
Collected by J. Helwig. Identified by J. Riva.

Climacograptus sp. cf. *C. tubuliferus* Lapworth
Climacograptus sp., tiny form
Glyptograptus sp.
Leptograptus flaccidus (Hall)
Orthograptus amplexicaulus (Hall)
Orthograptus calcaratus basilicus (Lapworth)
Orthograptus quadrimucronatus (Hall)
Pleurograptus linearis (Carruthers)

Location 9: Route 352, 1.7 km. north of Saltwater Pond.
Collected by J. Helwig and B. Oversby. Identified by J. Riva.

Leptograptus capillaris (Carruthers)
Orthograptus amplexicaulis (Hall)
Orthograptus quadrimucronatus (Hall)

A.4. Summerford Group "Unit C". (2E/10, 2E/7)

Location 1: Northwest end of Farmers Island, Bay of Exploits.
Collected by H. Williams. Identified by B. D. Erdtmann.

Orthograptus cf. *O. truncatus* (Lapworth)
Dicellograptus ? branch fragments.

Location 2: On route 344, 1.6. km. northwest of Village Cove, New World Island.
Collected by H. Williams. Identified by L. M. Cumming.

Orthograptus whitfieldi (Hall)

Location 2a: as above.
Collected by M. Kay and G. Horne. Identified by J. Riva.

Climacograptus caudatus Lapworth
Climacograptus mohawkensis (Ruedemann)
Climacograptus sp. thin form
Dicellograptus forchammeri (Geinitz)
Glyptograptus sp.
Leptograptus capillaris (Carruthers)
Orthograptus amplexicaulis (Hall)
Orthograptus calcaratus basilicus Lapworth
Orthograptus quadrimucronatus ssp. cf.
O. q. micracanthus Elles and Wood.

Location 3: On road, 800 m. east of Lukes Arm, New World Island.
Collected by H. Williams. Identified by L. M. Cumming.

Dicellograptus sp. cf. *D. divaricatus salopiensis* Elles and Wood
Orthograptus sp.

Location 4: Fudge Cove, north shore of Summerford Arm, New World Island.
Collected by M. Kay and G. Horne. Identified by J. Riva.

Climacograptus spiniferus (Ruedemann)
Dicellograptus forchammeri (Geinitz)
Glyptograptus sp.
Orthograptus amplexicaulis (Hall)
Orthograptus calcaratus basilicus Lapworth
Orthograptus quadrimucronatus ssp. cf. *O. q. micracanthus* Elles and Wood

Location 5: 400 m. west of Fudge's Head, North shore of Summerford Arm, New World Island.
Collected by G. Horne. Identified by J. Riva.

Climacograptus caudatus Lapworth
Climacograptus spiniferus (Ruedemann)
Climacograptus sp. thin form
Cryptograptus insectiformis Ruedemann
Dicellograptus forchammeri (Geinitz)

Location 5 (continued)

Dicranograptus ramosus (Hall)
Neurograptus margaritatus (Lapworth)
Orthograptus calcaratus basilicus Lapworth
Orthograptus quadrimucronatus spinigerus Lapworth

Location 6: East shore of Intricate Harbour, New World Island. Collected by G. Horne. Identified by J. Riva.

Dicellograptus forchammeri (Geinitz)
Dicellograptus sp.
Orthograptus amplexicaulis (Hall)
Orthograptus calcaratus basilicus Lapworth
Orthograptus quadrimucronatus ssp. cf. *O. q. micracanthus* Elles and Wood
Orthograptus quadrimucronatus (Hall)

Location 7: West side of Virgin Arm, New World Island, on road 800 m. from Virgin Arm Point.
Collected by G. Horne. Identified by J. Riva.

Climacograptus sp.
Dicellograptus sp. cf. *D. forchammeri* (Geinitz)
Orthograptus quadrimucronatus micracanthus Elles and Wood
Pseudoplegmatograptus sp.

A.5. Rodgers Cove Shale (2E/10)

Location 1: End of road at Rodgers Cove, Cobbs Arm, New World Island.
Collected by M. Kay and J. Dewey. Identified by J. Riva.

Climacograptus sp., tiny form
Glyptograptus sp.
Leptograptus flaccidus (Hall)
Orthograptus amplexicaulis (Hall)
Orthograptus calcaratus basilicus Lapworth
Orthograptus quadrimucronatus (Hall)

Location 2: Southeast shore of Cobbs Arm, 1 km. northeast of bottom of Rodgers Cove.
Collected by H. Williams. Identified by L. M. Cumming.

Dicranograptus ramosus (Hall)
Orthograptus sp.

Location 3: Northwest shore of Cobbs Arm opposite limestone quarry.
Collected by H. Williams. Identified by L. M. Cumming.

Dicellograptus pumilus (Lapworth)

Location 4: First Cove north of Cobbs Arm, New World Island.
Collected by H. Williams. Identified by L. M. Cumming.

Orthograptus whitfieldi (Hall)
Climacograptus sp.

Location 5: Southeast shore of Duck Island, northeast of Cobbs Arm.
Collected by H. Williams. Identified by L. M. Cumming.

Orthograptus whitfieldi (Hall)
Orthograptus sp.

Location 6: Route 346, 1.6 km. east of the end of Burnt Arm, New World Island.
Collected by M. Kay. Identified by J. Riva.

Climacograptus sp. tiny form
Glyptograptus sp.
Leptograptus flaccidus (Hall)
Orthograptus amplexicaulis (Hall)
Orthograptus calcaratus basilicus Lapworth
Orthograptus quadrimucronatus (Hall)

Location 7: On coast, 1.6 km. east of Squid Cove, New World Island.
Collected by H. Williams. Identified by L. M. Cumming.

Dicranograptus cyathiformis Elles and Wood
Dicranograptus ramosus (Hall)

Location 8: East shore of Squid Cove, New World Island.
Collected by H. Williams. Identified by L. M. Cumming.

Dicellograptus forchammeri (Geinitz)
Dicellograptus caduceus (Lapworth)

Location 8a: As above.
Collected by W. Dean. Identified by P. Toghill.

Location 8a (continued)

Amplexograptus arctus Elles and Wood
Climacograptus brevis Elles and Wood
? *Climacograptus caudatus* Lapworth
Climacograptus ? sp.
Cryptograptus ? sp.
Dicellograptus sp. nov. aff. *caduceus* Lapworth
Dicellograptus forchammeri (Geinitz)
Orthograptus calcaratus s.l. (Lapworth)
Orthograptus calcaratus cf. *basilicus* Elles and Wood
Orthograptus truncatus s.l. (Lapworth)
Orthograptus truncatus intermedius Elles and Wood

A.6. Dark Hole Formation (2E/10)

Location 1: Joe Whites Cove, southeast New World Island.
Collected by H. Williams. Identified by B. D. Erdtmann.

Climacograptus aff. *C. bicornis* (Hall)
Climacograptus aff. *C. caudatus* Lapworth
Climacograptus aff. *C. raricaudatus* Ross and Berry
Dicellograptus cf. *D. forchammeri flexuosus* Lapworth
Dicellograptus sp.
Orthograptus cf. *O. quadrimucronatus* (Hall)
Orthograptus aff. *O. calcaratus* Lapworth
Orthograptus cf. *O. truncatus recurrens* Ruedemann
Orthograptus cf. *O. truncatus* Lapworth

Location 1a: As above.
Collected by M. Kay. Identified by J. Riva.

Climacograptus mohawkensis (Ruedemann)
Dicellograptus sp. cf. *D. forchammeri* Geinitz
Dicranograptus sp.
Glyptograptus sp.
Leptograptus sp. cf. *L. capillaris* (Carruthers)
Orthograptus amplexicaulis (Hall)
Orthograptus calcaratus basilicus Lapworth
Orthograptus quadrimucronatus micracanthus Elles and Wood

A.7. Caradocian Argillites south of the Bay of Exploits (2E/3, 2E/7)

Location 1: Southeast shore of Burnt Bay opposite Imperial Oil wharf at Lewisporte.
Collected by H. Williams. Identified by L. M. Cumming.

Dicranograptus ramosus longicaulis Lapworth
Climacograptus sp.

Location 1a: As before.
Collected by M. Kay. Identified by J. Riva.

Climacograptus sp.
Glyptograptus sp.
Orthograptus quadrimucronatus (Hall)

A.8. Davidsville Group (plate 1)

Location 1. Northwest shore of Weirs Pond, 4 km. from northwest end.
Collected by H. Williams. Identified by B. D. Erdtmann.

Climacograptus cf. *C. scharenbergi* type
Climacograptus sp.
Orthograptus sp. cf. *O. calcaratus grandis* Ross and Berry
Orthograptus sp. cf. *O. quadrimucronatus* type

Location 2: East shore of Gander Bay, 1.6 km. northeast of Main Point.
Collected by H. Williams. Identified by B. D. Erdtmann.

Dicellograptus sp.
Diplograptus cf. *D. multidens* (Lapworth)
or *Orthograptus* cf. *O. calcaratus* Lapworth

Location 3: Route 330, 400 m. east of Davidsville junction.
Collected by M. Kay. Identified by J. Riva.

Climacograptus sp.
Dicellograptus sp.
Orthograptus calcaratus Lapworth

Location 4: Route 330, 600 m. east of Davidsville junction.
Collected by M. Kay. Identified by J. Riva.

Dicellograptus sp.
Glyptograptus sp.

Location 5: Route 330, 800 m. east of Davidsville junction.
Collected by H. Williams. Identified by B. D. Erdtmann.

Leptograptus flaccidus (Hall)
Orthograptus quadrimucronatus spinigerus Lapworth
Orthograptus cf. *O. quadrimucronatus* (Hall)

Location 5a: As before.
Collected by M. Kay. Identified by J. Riva.

Dicellograptus sp.
Orthograptus amplexicaulis (Hall)
Orthograptus sp.

Location 6: Gander River 2.4 km. north of 49th parallel.
Collected by H. Williams. Identified by L. M. Cumming.

Climacograptus bicornis (Hall)
Orthograptus sp.

Location 7: Gander River, 1.6. km. north of 49th parallel.
Collected by H. Williams. Identified by L. M. Cumming.

Climacograptus bicornis (Hall)
Dicranograptus ramosus (Hall)
Dicranograptus sp.
Orthograptus sp.

Location 8: Gander River, 320 m. north of 49th parallel.
Collected by H. Williams. Identified by L. M. Cumming.

Climacograptus sp.
Orthograptus sp.

Location 9: Salmon Pond Brook, 1.1 km. west of Gander River.
Collected by H. Williams. Identified by L.M. Cumming.

Climacograptus bicornis (Hall)
Dicellograptus sextans exilis Elles and Wood

A.9. <u>Parsons Point Formation of Cutwell Group</u> (2E/12)

Location 1: South side of Lushs Bight Harbour, Long Island.
Collected by R. K. Stevens, D. Skevington and P. Dean. Identified by D. Skevington.

Climacograptus sp. cf. *C. brevis* Elles and Wood
Cryptograptus tricornis (Carruthers)
Didymograptus sp. cf. *D. saggiticaulis* Gurley
Glyptograptus sp. cf. *G. euglyphus* (Lapworth)

LIST OF MAPS

PREVIOUSLY COPYRIGHTED MATERIAL,

MAP AT END OF THESIS,

NOT MICROFILMED.

MAP: GEOLOGICAL COMPILATION OF THE
NEWFOUNDLAND CENTRAL VOLCANIC
BELT.

SCALE: 1:250, 000.
MAP: 7730

MINERAL DEVELOPEMENT DIVISION
DEPARTMENT OF MINES AND ENERGY
GOVERNMENT OF NEWFOUNDLAND AND LABRADOR

PREVIOUSLY COPYRIGHTED MATERIAL,

12 MAPS AT BACK OF THESIS

NOT MICROFILMED

THE MAPS NOT FILMED ARE THE
THE "REGIONAL GEOLOGY OF THE
CENTRAL VOLCANIC BELT OF NEWFOUNDLAND,"

BY B.F. KEAN, P.L. DEAN AND D.F. STRONG,
GEOLOGICAL ASSOCIATION OF CANADA SPECIAL
PAPER NO. 20,

THE BUCHANS FIFTIETH ANNIVERSARY
VOLUME, E.S. SWANSON, A. PRYSLAK
AND D.F. STRONG(EDITORS), 1977.

MAPS AVAILABLE FROM THE GEOLOGICAL
SURVEY OF CANADA, DEPARTMENT OF ENERGY
MINES AND RESOURCES, OTTAWA, ONTARIO

ALL MAPS ARE 1 INCH: 1 MILE

THE MAPS ARE:

BOTWOOD MAP SHEET
HODGES HILL MAP SHEET
ROBERTS ARM MAP SHEET
POINT LEAMINGTON MAP SHEET
COMFORT COVE MAP SHEET
FOGO MAP SHEET
TWILLINGATE MAP SHEET
EXPLOITS MAP SHEET
LITTLE BAY ISLAND MAP SHEET
GULL POND MAP SHEET
SPRINGDALE MAP SHEET
KING'S POINT MAP SHEET