VOLCANIC STRATIGRAPHY, PETROLOGY AND GEOCHEMISTRY OF THE MARYSTOWN GROUP, BURIN PENINSULA, NEWFOUNDLAND

SEAN JAMES FRANCIS O'BRIEN

VOLCANIC STRATIGRAPHY, PETROLOGY AND GEOCHEMISTRY OF THE MARYSTOWN GROUP; BURIN PENINSULA, NEWFOUNDLAND

by

Sean James O'Brien, B.Sc. (Hons.)

A Thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science

Department of Geology
Memorial University of Newfoundland
April, 1979

St. John's Newfoundland

ABSTRACT

The Marystown Group forms the southern extent of the Late Precambrian volcanic field which underlies much of the western Avalon Zone of Newfoundland. The Marystown Group is faulted against older submarine volcanic and sedimentary rocks of the Burin and Rock Harbour Groups and is disconformably overlain by Eocambrian to Cambrian strata of the Fortune Group.

The Marystown Group has been divided into seven separate stratigraphic units. In ascending stratigraphic order, these include: (1) Taylor's Bay Formation, (2) Garnish Formation, (3) Calmer Formation, (4, 5 and 6) Barasway Complex and the Hare Hills and Mount Saint Anne Formations (which are interpreted as being correlative), (7) Grand Beach Complex. The evolution of the Marystown Group includes three main volcanologically, petrologically and geochemically separate intervals. The earliest period of volcanism, represented by the Taylor's Bay Formation, produced a sequence of subaqueous and subaerial, basaltic to rhyolitic volcanic rocks of calc-alkaline to mild tholeiitic affinities. The Garnish and Calmer Formations together mark the onset of subaerial sedimentation and extrusion of extensive flood basalt fields of alkaline affinity. A period of felsic, subaerial volcanism represented by the Mount Saint Anne and Hare Hills Formations and the Barasway Complex marks the latest stage of evolution of the Marystown Group. The Grand Beach Complex is stratigraphically similar to the late felsic units of the rest of the Marystown Group but displays unique chemical features.

The main structural features of the Marystown Group are interpreted to be the result of an orogenic event which post-dates the deposition of

Cambrian rocks and pre-dates the intrusion of the lower Carboniferous St. Lawrence Granite. Recent geochronological results suggest that the main deformation is the result of the Acadian Orogeny. Late stage regional flexuring and related north-south and northwest-southeast faulting may represent the latest effects of the Acadian Orogeny or possibly the onset of the Variscan (or Hercynian) orogenic episode.

The internal stratigraphy of the Marystown Group coincides with late Precambrian volcanic sequences elsewhere in the western Avalon Zone of Newfoundland. Petrological and geochemical variations within the Marystown Group are similar to those documented in the Love Cove Group of the northwestern Avalon Zone. The tectonic significance of these variations is unclear. Similar geochemical trends have been documented in the Cenozoic evolution of the southwestern U.S.A.

ACKNOWLEDGEMENTS

The author wishes to thank all people involved in various aspects of this study, in particular Dave Strong who initially suggested the topic and made himself available for numerous discussions in the office and the field. His corrections and comments on initial drafts of this manuscript are greatly appreciated.

Special thanks also go to colleagues who were involved in the various stages of the "Burin Project" from its inception in 1975; in particular: S.W. Taylor, P.G. Strong, D.H. Wilton and J.L. Evans. Arguments and discussions in the field and office proved invaluable. Discussions with colleagues at Memorial University of Newfoundland and the Newfoundland Department of Mines and Energy, particularly C.F. O'Driscoll and E.M. Hussey contributed greatly to the author's understanding of various aspects of Avalon Zone geology.

The geochemical studies in this thesis could not have been carried out without the invaluable help of Dave Press and Gert Andrews.

W. Marsh, F. Thornhill, J. Ford, and L. Warford are thanked for their technical assistance.

Special thanks go to Doreen Peavy for typing the manuscript.

Thanks also go to the government and people of Newfoundland for the financial support given to the author during the 1975 and 1976 field seasons. The author was awarded a Newfoundland Government Fellowship during his stay at Memorial University.

Thanks and a word of apology goes to anyone the author may have inadvertently omitted from the acknowledgements. Finally, thanks go out to the non-academics for their encouragement and non-financial support during the duration of this study.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF PLATES

LIST OF PLATES (continued)

LIST OF PLATES (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF PHOTOMICROGRAPHS

LIST OF PHOTOMICROGRAPHS (continued)

LIST OF PHOTOMICROGRAPHS (continued)

LIST OF APPENDICES

1. INTRODUCTION

1.1 Location and Access

The study area includes parts of the Marystown (1M/3), St. Lawrence (1L/14), Grand Bank (1M/4), and Lamaline (1L/13) map areas which encompass the southern third of the Burin Peninsula of south-eastern Newfoundland, between north latitudes 46°45' and 47°15' and west longitudes 55°00' and 56°00'.

The largest communities in this area are Marystown, Burin, St. Lawrence, Grand Bank and Fortune, all of which are serviced by a peripheral road system, connected by Route 11 to the Trans-Canada Highway (Route 1), approximately 160 km to the north. The area is also serviced by Canadian National coastal boat service and there are small airfields at the communities of Winterland and Frenchman's Cove.

Much of the study area is accessible via trails, streams, "woods-roads" and the coastline. Fly camps and helicopter-assisted traverses are necessary in the more remote central parts of the area.

1.2 Physiography

The study area is physiographically a part of the Atlantic Upland of insular Newfoundland (Twenhofel and MacClintock, 1940). The topographic variations and physiographic characteristics of the area reflect both underlying bedrock type and movement of glacial ice.

Vanderveer (1976) concluded that the Burin Peninsula was glaciated by ice centred on the main part of the Island of Newfoundland to the northwest during the Late Wisconsin glacial maximum, with a later radial glaciation from a smaller cap in the central part of the peninsula. This latter ice cap was nearer the south coast during the waning stages of glaciation, resulting in weaker northward ice flow towards Fortune Bay and up to 18 metres of marine overlap.

The area can be broadly divided into 4 contrasting physiographic zones (Figure 1:1):

1. An irregular, gently undulating plateau rising from an average elevation of 70 m at the southern coast of the peninsula to approximately 200 m in the central parts of the peninsula (e.g. near Lunch Pond)
2. A central, broad, flat and boggy plain between Winterland and Grand Beach
3. An area of valleys, ridges and lakes north of Garnish River
4. An irregular series of prominent ridges in the western part of the area, forming the Eastern and Western Hare Hills

The southern plateau is underlain mainly by mafic and felsic volcanic rocks of the Marystown Group and by intrusive rocks of the St. Lawrence Granite. The undulatory nature of the southern plateau is in places abruptly broken by monadnocks and roches moutonées which are sculpted from resistant welded tuffs, coarse breccias and hornfelsed sedimentary and volcanic rocks. The ruches moutonées are elongate with cliff towards the south, indicating a dominantly southward movement of ice. Mount Margaret, Mount St. Anne and Mount Lucy Anne are excellent examples of such features (plate 1.1). Similarly, the numerous lakes and ponds are aligned to the south and southeast, reflecting glacial control. Locally this trend is offset and parallels the northeast trend of the regional foliation of bedrock. In the western portion of the southern plateau, drainage and topographic features reflect the presence of north-south faults. An increase in intensity of faulting in the southern and eastern parts of the area (e.g. near Roundabout) is reflected by the irregular topography of that region.

Depositional features of glacial action (e.g. kames, terraces, eskers and glacial till) are common throughout this area. Exposure varies from 20 to 30% in the southern plateau region.

The central plains region (2) is characterized by poor drainage which is reflected in the extensive marsh and bog development in this area. The two largest lakes in the study area occur in this central plain. The major tributary in this area runs in a west-northwest, east-southeast direction, a feature interpreted by Strong et al. (1978b) to reflect different periods and directions of glaciation. It is worth noting, however, that this drainage orientation is localized near a regional flexure in the shape of a peninsula. Northwest-trending faults exposed elsewhere on the Burin Peninsula (O'Brien, 1978) coincide with similar flexures. Therefore, the drainage pattern in this area may also reflect similar unexposed bedrock structures.

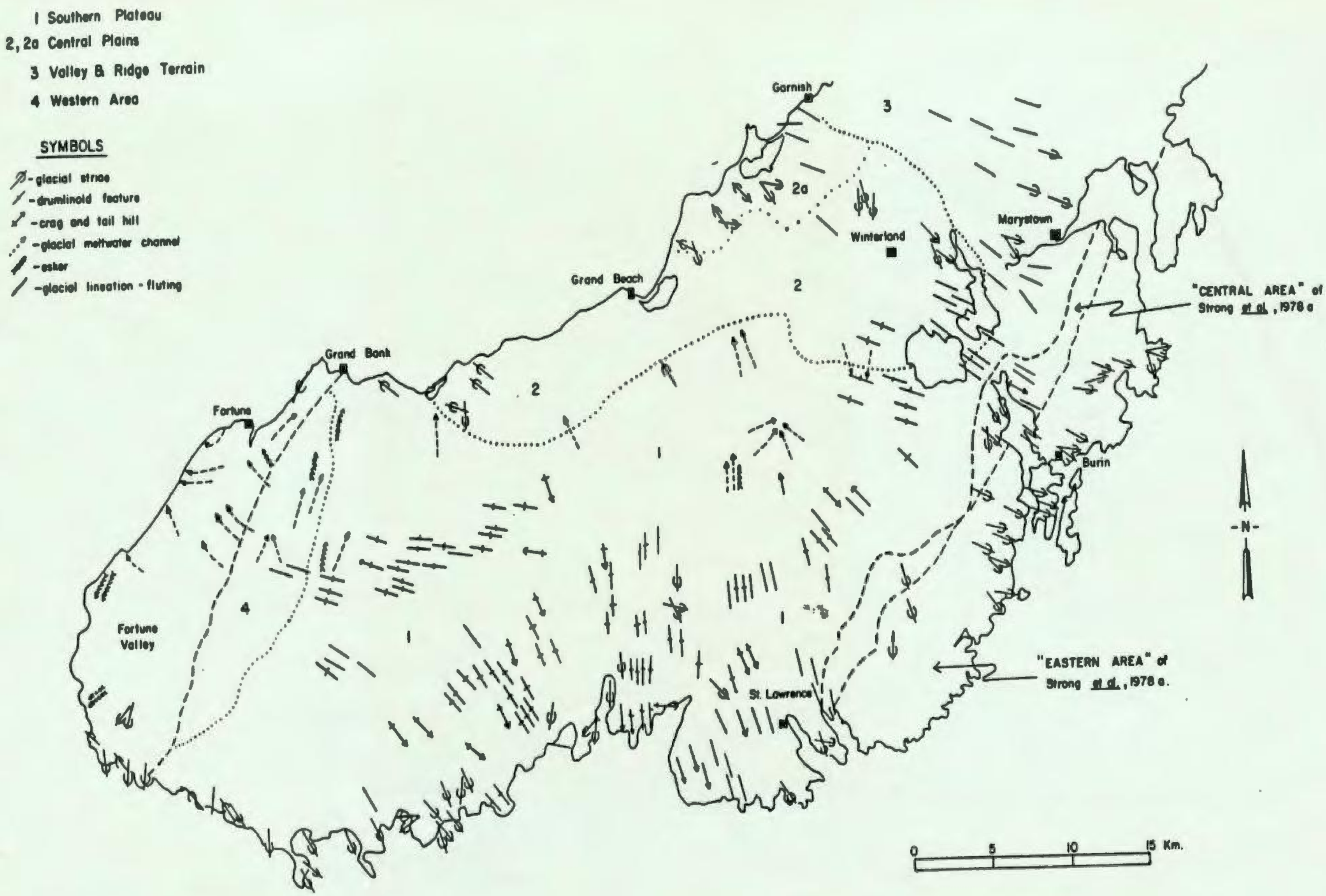


Figure 1:1 Physiographic subdivisions of the southern Burin Peninsula

Plate 1:1 Roche moutonée on the southern Burin Peninsula: Mount Margaret.

Most of the central plains region is underlain dominantly by the Barasway and Grand Beach Complexes. The northwestern part of the central plains (2a) is underlain by volcanics of the Barasway Formation. Physiographically this area is transitional with the valley and ridge terrain to the north.

The northern valley and ridge terrain (3) is underlain by the Barasway and Calmer Formations of the Marystown Group and is characterized by the northwest trend of the valleys, ridges and lakes in that area. These features are lithologically controlled, resulting from alternations of basaltic, rhyolitic and tuffaceous sedimentary rocks of varying resistance to erosion, all of which are gently dipping and strike towards the northwest. In areas of dominantly basaltic or rhyolitic volcanic rocks the region is physiographically similar to parts of the southern plateau area.

The amount of exposure in this area is highly variable and ranges from 10 to 50%.

The topography of the western region is generally a refelction of bedrock lithology. The prominent ridges (e.g. Fortune Tolt, Eastern and Western Hare Hills) are underlain by resistant welded ash-flow tuffs and rhyolite flows of the Hare Hills Formation, whereas the westerly adjacent Fortune Valley is underlain by less resistant Eocambrian-Cambrian sedimentary rocks. The highest elevation in thie area is approximately 300 m (Eastern Hare Hills) and may represent an erosional remnant of the Long Range Peneplain (Twenhofel and MacClintok, 1940).

1.3 Previous Work

A variety of published and unpublished work based upon both re-connaissance and detailed mapping, deals with various aspects of southern Burin Peninsula geology.

Aside from the earliest geological reconnaissance by Murray and Howley (1881) no major reported investigations were carried out in the area until 1927, when N.C. Dale published the results of his reconnaissance work on the Precambrian and Paleozoic geology of the Fortune Bay area. Kauffman (1936) mapped the St. Lawrence area, with emphasis on the fluorite mineralization there, as part of the early Princeton University expeditions to Newfoundland. Van Alstine (1948) produced the first regional map of the area, as part of a Ph.D. thesis at the same institution.

In 1948, T.N. Walthier mapped the volcanic and sedimentary rocks in the vicinity of Grand Bank under the auspices of the Geological Survey of Newfoundland. Later that year, he undertook detailed mapping of the sulphide occurrences in Cambrian rocks near Lawn. Potter's (1951) unpublished thesis was based on a detailed study of the Eocambrian - Cambrian sedimentary rocks in the Fortune area undertaken at the same time.

The acquisition of concession areas in the southern Burin Peninsula by the Newfoundland and Labrador Corporation (NALCO) resulted in reconnaissance mapping of the entire area (e.g. Willars, 1953). Jooste (1954) did similar mapping for the Newfoundland Fluorspar Limited on their Burin Peninsula concession area.

The geology of the St. Lawrence area is discussed in detail by Williamson (1956) in an unpublished report to the Newfoundland Department of Mines, Agriculture and Resources. Bartlett (1967) discussed the silica potential of the Eocambrian sequences of the western Burin Peninsula.

The only publication by the Geological Survey of Canada which pertains to the study area is a 1:250,000 reconnaissance map of the Belleoram map area produced by Anderson (1965).

Interest in the mineralization associated with granitoid rocks in the study area increased in the early to mid- 1970's and resulted in the production of a variety of unpublished maps and reports by several mining companies, notably: CERA (David S. Robertson Ltd.), Allied Chemical Corporation, SEREM Ltée., EASTEX and Radex Minerals Ltd. Exploration of the area by British Petroleum (Minerals) Ltd. was initiated in 1976 and is still ongoing.

Systematic, 1:50,000 scale mapping of the Burin Peninsula was initiated by the Newfoundland Department of Mines and Energy in 1975. Strong et al., 1975, 1978b, described the geology of the St. Lawrence (1L/14) and Marystown (1M/3) map sheets. The regional geology of the western half of the southern Burin Peninsula was described by O'Brien et al., 1977 and Strong et al. (1979). The regional geology, including descriptions of the stratigraphy and discussion of the tectonic evolution of the area was published by Strong et al., 1978b. Much of this work was based upon work by Memorial University of Newfoundland graduate students, e.g. Teng (1974), but notably Taylor (1976), Wilton (1977), Strong (1977) and O'Brien (this thesis).

1.4 Present Investigation

Field work was initiated in 1975 as a part of a larger project of regional mapping carried out under contract between Memorial University of Newfoundland (D.F. Strong) and the Newfoundland Department of Mines and Energy. During 1975, mapping was mostly confined to the western half of the Marystown (1M/3) map sheet with limited mapping of the extension of the Marystown Group into the adjacent St. Lawrence (1L/14) and Marystown east-half map sheets. 1976 field work concentrated mostly on exposures of the Marystown Group in the Grand Bank (1M/4) and Lamaline (1L/13) map sheets.

Field observations were recorded on aerial photographs and "Forest Inventory" maps at a scale of 1:15,840. Data were replotted on 1:25,000 and 1:50,000 scale from which the final 1:100,000 map was prepared.

Petrographic and geochemical studies were initiated in the autumn of 1975 and completed early in 1977. Thin sections of approximately two hundred rock samples were studied, the least altered of which were chosen for major and trace element geochemical work.

The main aims of the present study were to establish an internal stratigraphy for the Marystown Group and to provide petrographic and chemical data for these rocks in the hope of demonstrating their tectonic setting. Also the structural history of the area was to be documented with reference to the regional setting of the western Avalon Zone.

2. REGIONAL SETTING

2.1 Distribution of the Avalon Zone

The Burin Peninsula is situated in the western part of the Avalon Zone (Williams et al., 1974) of the Newfoundland Appalachians (Figure 2:1). The total width of this zone is in excess of 700 kilometers (Poole, 1976), approximately twice the width of the rest of the Appalachian orogenic belt. In North America, "Avalon-type" rocks have been identified in Nova Scotia (Schenk, 1971; Keppie, 1977), New Brunswick (Rast et al., 1976), Maryland (Rodgers, 1972), Massachussets (Murray et al., 1978), Virginia (Rodgers, 1970; p. 197), the Carolinas (Seiders & Wright, 1977) and Georgia (Whitney et al., 1978). Similar rocks in the subsurface have been described from Florida (Rodgers, 1972). The distribution of the Avalon Zone in the Appalachian orogenic belt is shown in Figure 2:2.

Equivalents of the Avalon Zone may be represented in the British Caledonides by the Arvonian volcanics of North Wales and the Longmyndian red beds and Uriconian volcanics of England (Wright, 1969).

Possible correlatives of the Avalon Zone outside the Appalachian - Caledonian orogen in Morocco have been described by Hughes (1972). Similar correlations between the Avalon terrain and the late Precambrian of North Africa have been made by Schenk, (1971) and Brückner, (1974). Strong et al., 1978a, suggested that the oceanic basaltic rocks of the Avalon Zone (Burin Group; Taylor, 1976) may be equivalent to the Proterozoic oceanic crust on the margins of the West African

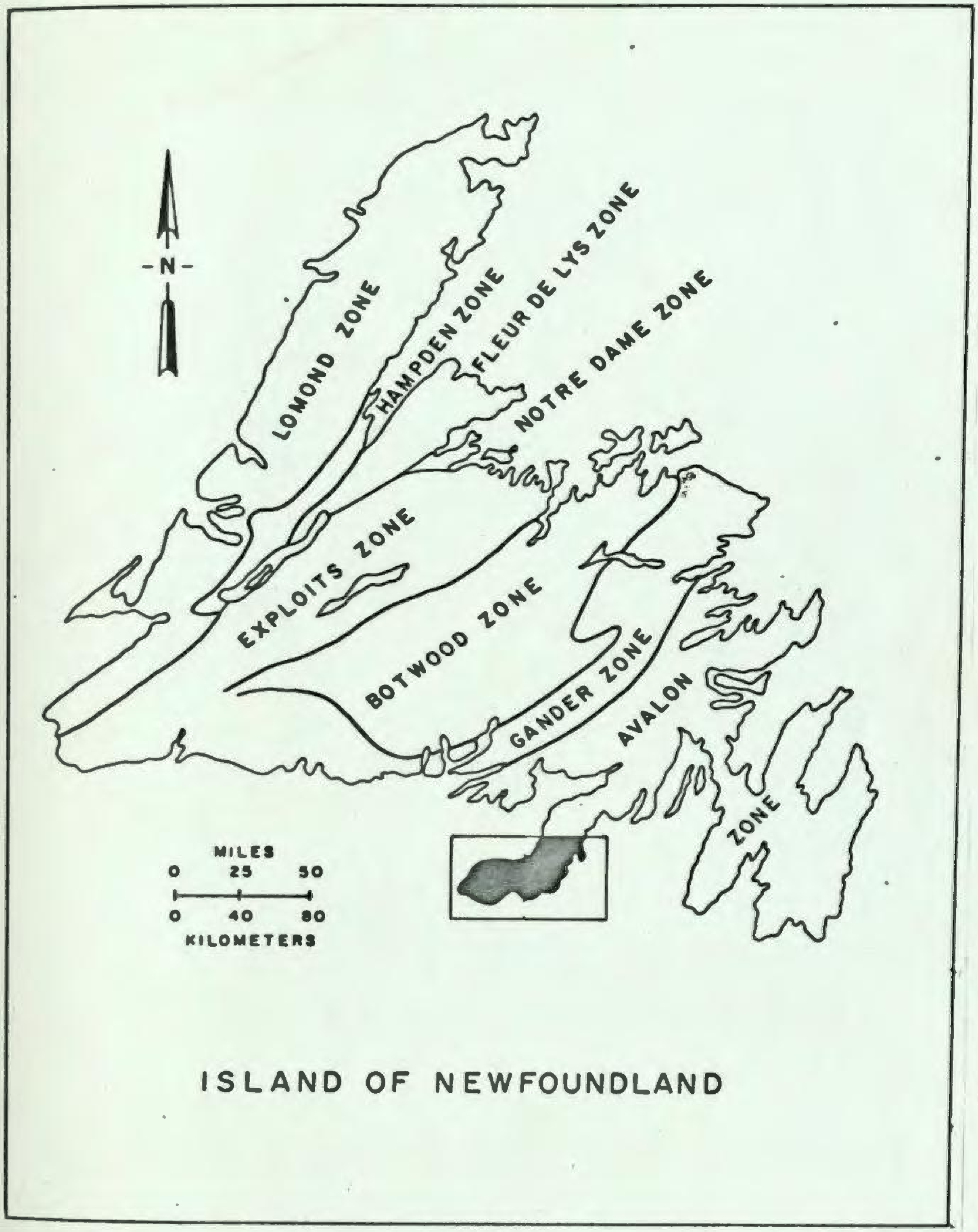


Figure 2:1 Map of the tectonostratigraphic subdivisions of the Newfoundland Appalachians (after Williams et al., 1974) showing the location of the study area.

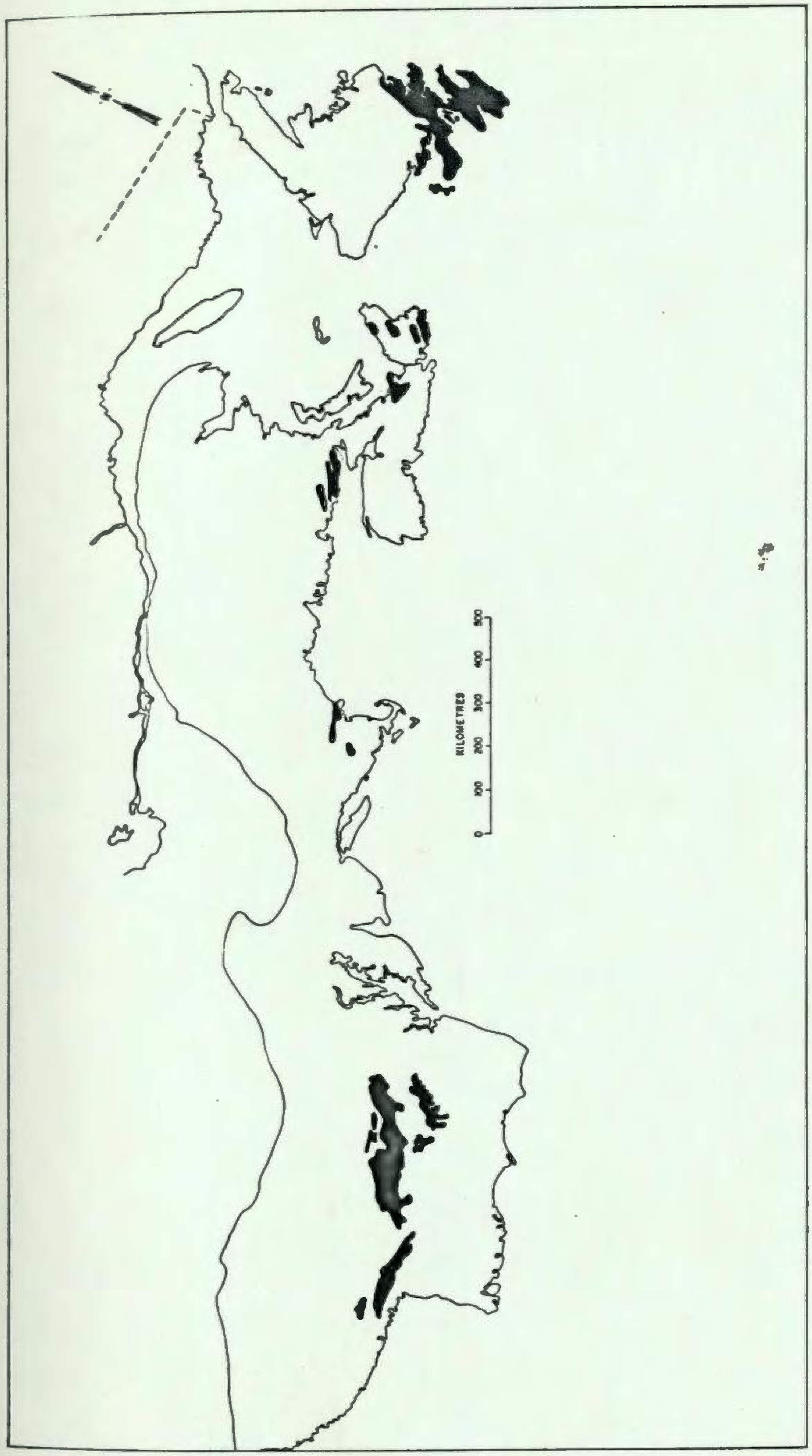


Figure 2:2 Distribution of the Avalon Zone in the Appalachian Orogen, after Williams, (1979a).

Craton at Bou Azzer, Morocco (cf. Le Blanc, 1976).

The generalized global distribution of the Avalon Zone and its possible correlatives is shown in Figure 2:3.

2.2 Regional Geology of the Avalon Zone

2.2.1 General Statement

In general, the geology of the Avalon Zone in Newfoundland can be described as a sequence of late Proterozoic volcanic and associated sedimentary rocks overlain by both marine and continental sedimentary rocks of Late Proterozoic age. These rocks are conformably to unconformably overlain by shallow water to terrestrial sedimentary rocks of lower to mid- Paleozoic age. The entire sequence has been intruded by plutonic rocks ranging in age from late Proterozoic to Carboniferous.

2.2.2 Historical Development of Ideas: Newfoundland Avalon Zone

The pioneer work on Avalon Zone geology was carried out between 1843 and 1925. The findings of the early workers are documented in several publications, e.g. Jukes, (1843);Murray and Howley, (1881), etc. and are summarized below in Table 2:1. Most of this work consisted of isolated observations which produced a disjointed view of regional Avalonian geology, however, the major elements of Avalon geology were initially outlined by these workers.

E.R. Rose's (1952) systematic mapping marked the first major contribution to the understanding of the regional geology of the

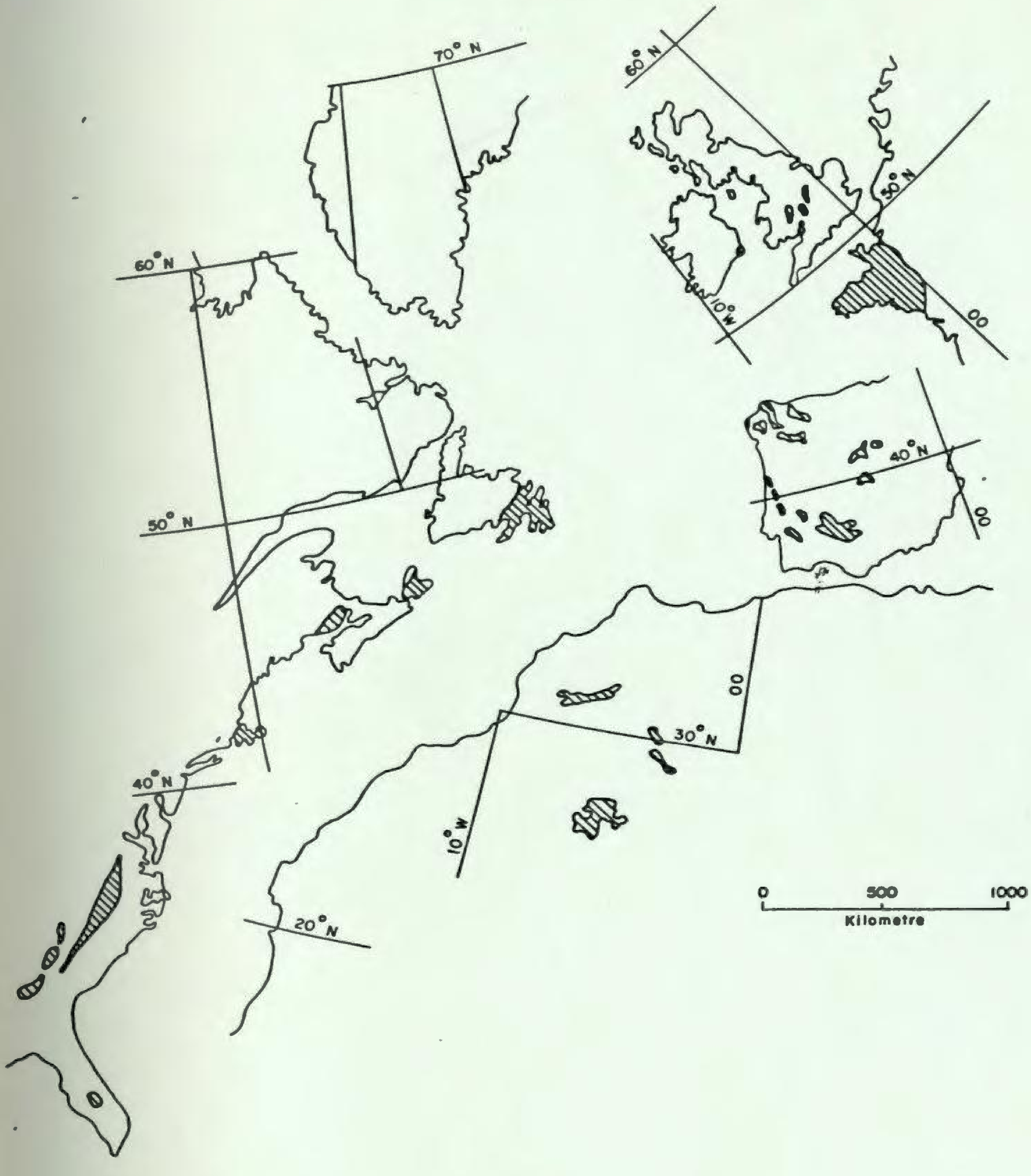
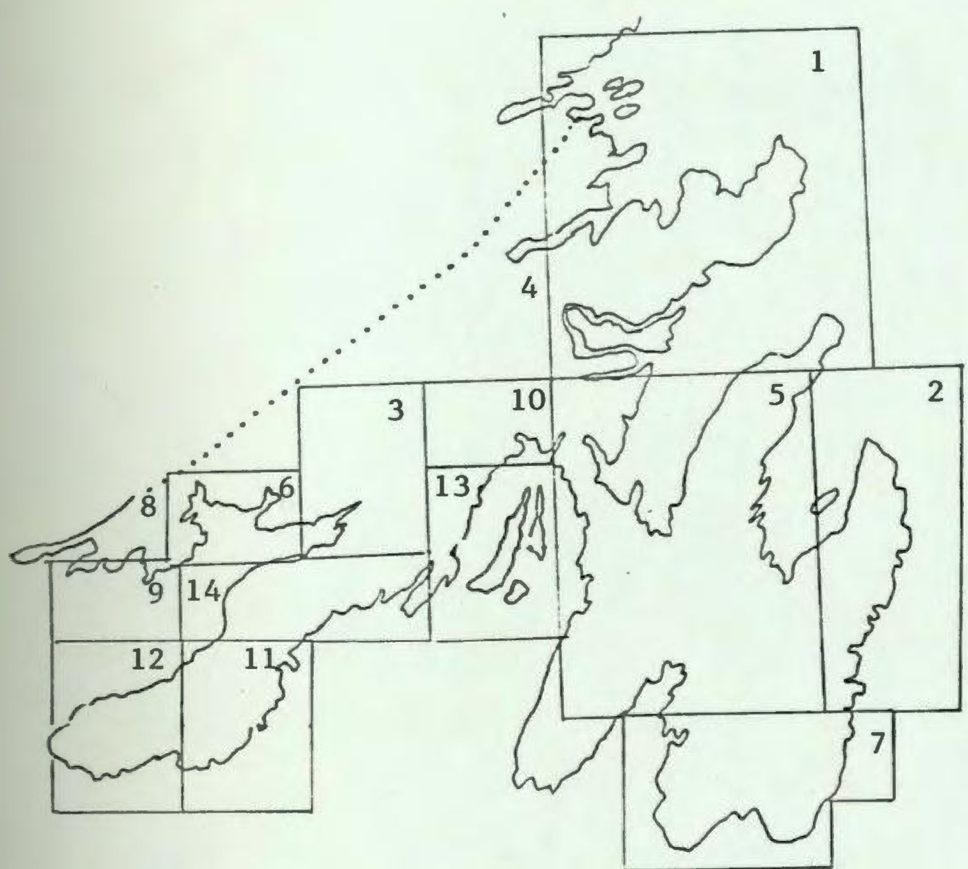


Figure 2:3 Distribution of "Avalon Zone" in North America, Northwest Africa, and Western Europe (in part after Strong *et al* 1978).

Table 2:1 Early workers in the Avalon Zone of Newfoundland

Jukes	1843	- Recognized "Upper and Lower Slate Formations" (correspond in part with the Cambro-Ordovician sediments and the Cabot and Hodgewater Groups respectively).
Murray and Howley Howley and Murray	1881 1918	- Divided the Proterozoic rocks of the Avalon Peninsula into the "Laurentian Gneiss" and "Metamorphic Slates and Sandstones" (roughly equivalent to the Holyrood Granite and the Conception Group).
Walcott	1899	- Noted that the "Avalon terrain" (equivalents of the Cabot, Hodgewater and Musgravetown Groups) overlay the "Archean Gneisses" (equivalent to the Harbour Main Group) - Introduced the name "Avalonian Series" which he subdivided into the "Torbay Slates" and the "Conception Slates".
Buddington	1919	- Introduced the name "Avondale Volcanics" to replace Walcott's "Archean Gneisses"
Howell	1925	- Introduced the name "Harbour Main Volcanics" for the "Avondale Volcanics" of Buddington.



1	Christie, 1950	8	Greene, 1975
2	Rose, 1952	9	Greene and O'Driscoll, 1976
3	Bradley, 1962	10	O'Driscoll & Hussey, 1977
4	Jenness, 1963	11	Strong et al., 1978
5	McCartney, 1967	12	O'Brien et al., 1977
6	Williams, 1971	13	O'Driscoll & Muggridge, 1979
7	Williams & King, 1976	14	O'Brien & Taylor, 1979

Figure 2:4 Index to 1:50,000 scale geological mapping in the Avalon Zone of Newfoundland

Avalon Zone and his terminology is, for the most part, retained in the current literature. He recognized and redefined the three major components of the Proterozoic geology of the eastern Avalon Zone; e.g. the Harbour Main, Conception and Cabot Groups, and established their stratigraphic relationships.

Systematic mapping on a regional scale by Hutchinson, (1962); Bradley, (1962); Jenness, (1963); Anderson, (1965); McCartney, (1967); Williams, (1971); Williams and King, (1976); O'Brien et al., (1977); O'Driscoll and Hussey, (1977) and Strong et al., 1978b) resulted in the development of the Proterozoic and Paleozoic stratigraphy in the various parts of the Avalon Zone shown in Figure 2:4. The stratigraphic relationships determined by some of these workers are summarized in the generalized correlation charts (Tables 2:2 & 2:3). A more detailed summary of some of these authors' observations is given below (Sections 2.2.3 and 2.3). Various formation names are given in Table 2:3.

The earliest interpretations of the tectonic setting and regional depositional environments of the Proterozoic succession of the Avalon Zone were made by Papezik (1969, 1970 and 1972) and Hughes and Brueckner, (1971).

Papezik suggested that the volcanic rocks of the Avalon Peninsula may have been the result of alkalic continental volcanism, related to block faulting of a late Precambrian continental platform. This "Basin and Range environment" interpretation was supported by Strong et al., (1974); Nixon, (1974); and Strong and Minatides, (1975).

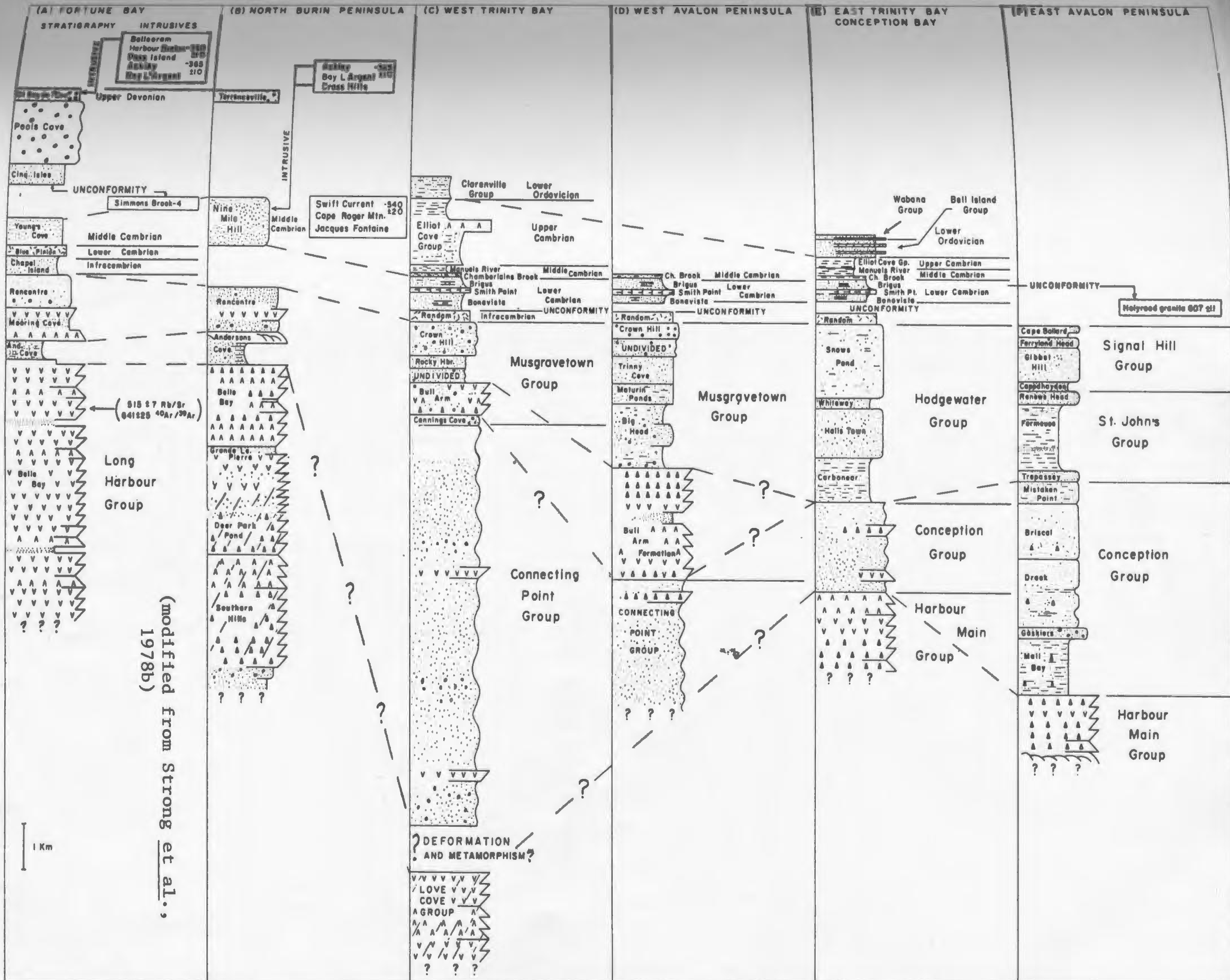


TABLE 2:2 Generalized correlation chart for the Avalon Zone

(modified from Strong et al., 1978b)

AGE	HEADINGS	EASTERN AVALON Formation	EASTERN AVALON Lithology	WESTERN AVALON Formation	WESTERN AVALON Lithology	NORTHERN AVALON Formation	NORTHERN AVALON Lithology
Carboniferous	Silurian to Carboniferous Sediments			Spanish Room[16]	Conglomerate, black shale, sandstone, limestone		
Devonian				Terrenceville[12]	Conglomerate, shale, siltstone, sandstone.		
				Boxey Point[20]	Basalt		
				Great Bay de l'Eau[21]	Purple conglomerate, black shale, gray siltstone, red sandstone		
				Pool's Cove[22]	Red conglomerate, sandstone, shale		
				Cinq Isles[22]	Red sandstone, conglomerate, shale, red limestone		
Silurian		Wabana[1] Bell Island[1]	Gray shale, siltstone, sandstone.			Clarenville[6]	Gray shale, siltstone, sandstone
Ordovician	Eocambrian to Ordovician Sediments	Elliott Cove[7]	Black shale, limestone	Nine Mile Hill[12]	Green slate, quartzite	Elliott Cove[7]	Gray shale and siltstone
		Manuels River[3]	Black shale	Youngs Cove[21]	Gray shale, siltstone, sandstone	Manuels River[3]	Black shale
Cambrian		Chamberlains Brook[8]	Green shale, minor limestone	Pleasant View Farm[17]	Black, red, green shale, limestone	Chamberlains Brook[8]	Red shale, limestone
		Brigus[3]	Red shale, limestone	Salt Pond[17]	Red, green shale, pink limestone	Brigus[3]	Red, green shale, pink limestone
		Smith Point[8]	Pink limestone	Blue Pinion[21]	Qtz. sandstone	Smith Point[6]	Pink limestone
		Bonavista[7]	Red, green shale, pink limestone	Chapel Island[21]	Gray siltstone, sandstone	Bonavista[7]	Red, green shale, pink limestone
		Random[6]	Quartzite, sandstone, gray shale	Bay View[17]	Gray siltstone, qtz. sandstone	Random[8]	Quartz sandstone gray shale
	Late Proterozoic Continental Sediments	St. John's[2]	Siltstone, shale	Rencontre[22]	Red conglomerate, sandstone, siltstone, shale	Musgravetown[9] Love Cove (in part)[10]	Red, green sandstone, conglomerate, siltstone
		Signal Hill[2] Hodgewater[4]	Red, green sandstone, siltstone, conglomerate				
Precambrian	Proterozoic Marine Sediments (some units in part interbedded with Proterozoic Volcanics)	Big Head[8] Conception[1]	Laminated siltstone, sandstone, minor conglomerate and tillite	Anderson's Cove[22]	Laminated siltstone and graywacke	Connecting Point[9]	Green graywacke siltstone, sandstone, conglomerate.
				Davis Cove[10]	Gray siltstone and sandstone		
				Sandy Harbour River[10]	Gray siltstone and sandstone		
				Great Island[15]	Gray siltstone		
				Southern Hills (lower)[12]	Gray conglomerate, siltstone, graywacke		
				Rock Harbour[11]	Gray siltstone, sandstone and limestone		
	Proterozoic Volcanics (in part interbedded with Proterozoic Marine Sediments)	Bull Arm[8] Harbour Main[1]	Mostly acidic and basic volcanics	Mortier Bay[18]	Basalt	Bull Arm[8] Love Cove (in part)[10]	Mostly acidic and basic volcanics
				Mooring Cove[22]	Basalt		
				Doughball Point[15]	Basalt		
				Belle Bay[22] Marystown[16] Tickle Point[15] Grand Le Pierre[12] Deer Park Pond[12] Sound Island[14] Southern Hills (upper)[12]	Acidic and basic volcanics for the most part		
				Burin[13]	Pillowed basalt and limestone		

1 Rose (1952)
2 Williams and King (1976)
3 Hutchinson (1962)
4 Hutchinson (1953)
5 Howell (1925)
6 Walcott (1900)
7 Van Ingen (1914)
8 McCartney (1967)
9 Hayes (1948)
10 Jenness (1957)
11 Jooste (1954)
12 Bradley (1962)
13 Strong et al. (1976)
14 O'Driscoll (1977b)
15 O'Driscoll (1977a)
16 Strong et al. (1978b)
17 Taylor (1977)
18 O'Driscoll and Hussey (in press)
19 O'Driscoll and Muggridge (in press)
20 Smith (1976)
21 Widmer (1950)
22 White (1939)
23 Van Alstine (1948)
24 Strong et al. (1974a)

TABLE 2:3 Table of various groups and formations which comprise the five main sedimentary and volcanic components of the Avalon Zone in Newfoundland .

An alternate model, proposed by Hughes and Brueckner, (1971) suggested that the Avalon Peninsula represents a volcanic island complex which was active until the latest Precambrian. Strong et al., (1978 a, b), first recognized the presence of oceanic crust in the Avalon Zone and suggested a model of rifting of continental crust, resulting in "continental volcanism", rupturing of the continental crust to form an oceanic basin, and "abortion" of this oceanic basin followed by resumption of continental type volcanism.

Tectonic models for the formation of the Avalon Zone and its equivalents elsewhere in the Appalachians have been published by Rast et al., (1976) and Whitney et al., (1978). Rast et al., (1976) speculated that the Proterozoic volcanism and plutonism of the Avalon Zone was related to an ensialic volcanic arc. Whitney et al., (1978) suggested that silicic volcanic rocks of the Slate Belt of Georgia and South Carolina represent the remnants of a primitive oceanic island arc.

2.2.3 Stratigraphic Development of the Avalon Zone

The geology of the Avalon Zone in Newfoundland has been reviewed in some detail in the recent literature; e.g.: Williams et al., (1972, 1974); King et al., (1974); Rast et al., (1976); Strong et al., (1978 a,b); King, (in press). Therefore the following section is designed to present only a brief stratigraphic resumé in order to provide a framework for later discussion (e.g. chapters 4, 8), and will deal mostly with the Proterozoic evolution of the region.

The Proterozoic and Paleozoic evolution of the Avalon Zone in Newfoundland can be best summarized in terms of seven major geological components, the distribution of which is shown in Figure 2:5.

Proterozoic volcanic rocks are widespread throughout the Avalon Zone and represent the oldest rocks recognized within it. The contact of these dominantly subaerial, silicic and basic volcanic rocks with the overlying Proterozoic marine sediments has been interpreted as being disconformable to conformable (Williams, 1971; Williams and King, 1976; O'Brien and Taylor, 1978; Hussey, 1979.). Late Proterozoic, dominantly continental sediments conformably and gradationally overlie these marine sediments in the eastern Avalon Zone (Williams and King, 1976). In the west, the marine sediments are not as widely developed and locally the continental sediments directly overlie the Proterozoic volcanic assemblage (Williams, 1971; O'Brien et al., 1977; Hussey, 1979). The late Proterozoic continental sediments are conformably to disconformably overlain by shallow water marine Eocambrian-Cambrian sedimentary rocks (McCartney, 1967; Williams, 1971; O'Brien et al., 1977). These early Paleozoic sediments locally unconformably overlie both the Proterozoic volcanic and marine sedimentary terrains.

Post-Cambrian sedimentary rocks have been documented throughout the Avalon Zone but are of limited aerial extent. In the west these rocks unconformably overlie Proterozoic volcanic rocks and pre-Ordovician granitoids (Bradley, 1962; Williams, 1971). In the east, the contact relations between Ordovician and older rocks is not preserved.

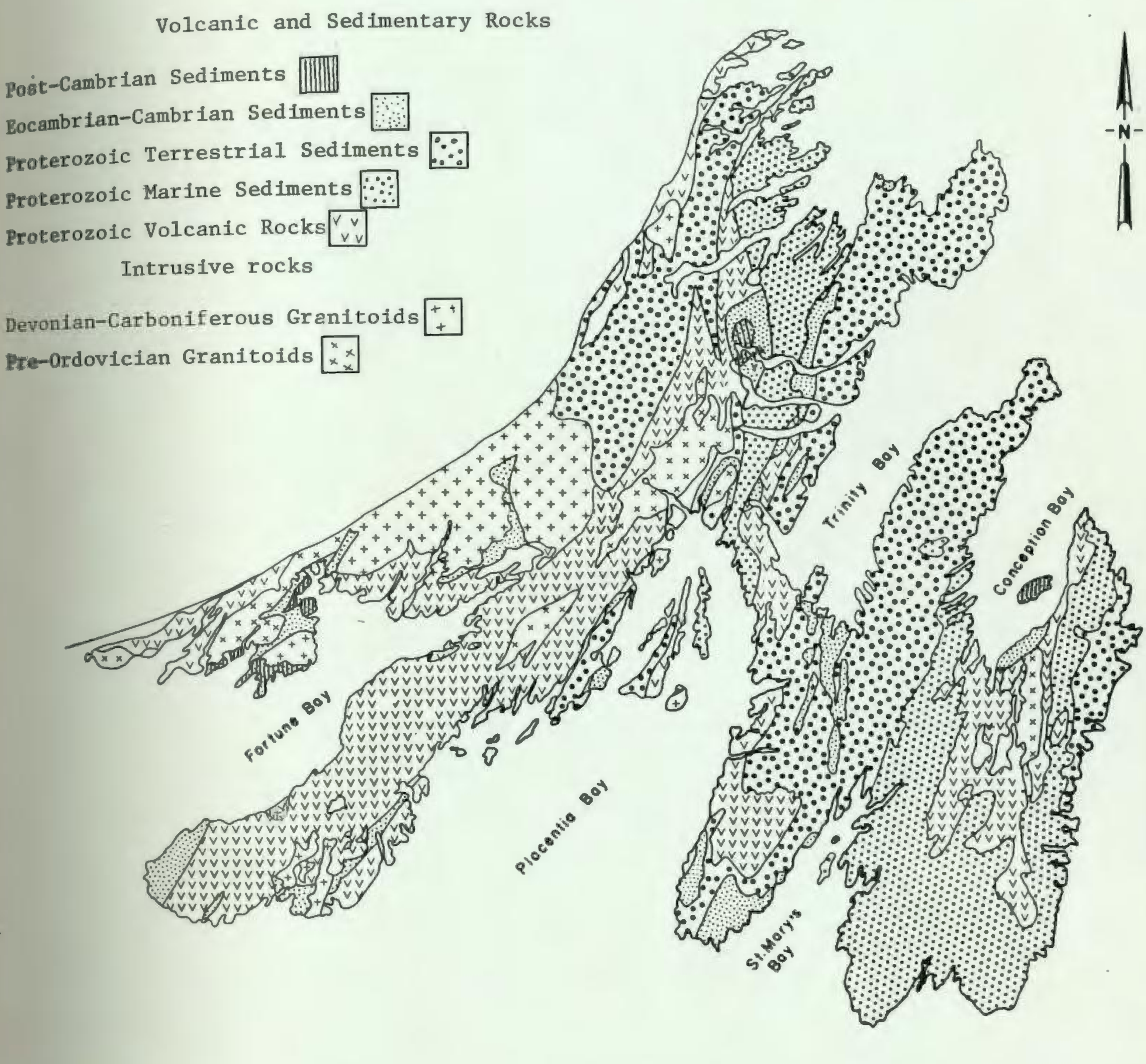


Figure 2:5 Major geological components in the Avalon Zone of Newfoundland after Williams (1967).

Paleozoic volcanic rocks are of limited areal extent within the Avalon Zone. Cambrian basalts in the Norman's Cove belt have been discussed briefly by McCartney (1967). Fletcher (1972) documented middle Cambrian basaltic flows in the St. Mary's Bay area on the Avalon Peninsula. Devonian and Carboniferous volcanic rocks have been described from the Hermitage (Smith, 1975) and Burin (Strong et al., 1978 a,b) Peninsulas.

Plutonic rocks of the Avalon Zone can be divided into two broad categories. The Pre-Ordovician intrusions are dominantly massive to foliated hornblende-biotite granites, syenites and granodiorites with lesser amounts of quartz diorite, diorite and gabbro. The Devonian-Carboniferous plutonic rocks are mainly alaskitic granite, biotite and hornblende-biotite granite with minor diorite and gabbro.

2.2.3.1 Proterozoic Development of the Avalon Zone

Avalon Peninsula

The base of the stratigraphic section on the Avalon Peninsula is the Harbour Main Group (Howell, 1925). Stratigraphic relationships within the Group are poorly understood; however, the major lithologies are subaerial felsic volcanic rocks (e.g. ash-flow tuffs, rhyolite flows), basaltic flows and marine and terrestrial volcaniclastic sediments. The base of the Harbour Main Group is unexposed, however McCartney (1967) estimated its thickness to be greater than 1,800 m.

The Harbour Main Group is overlain by marine sedimentary rocks of the Conception Group (Rose, 1952). There is some ambiguity regarding the relationship of these two major rock units. The existence of a local angular unconformity was interpreted by Rose (1952) and McCartney (1967) to represent an extensive erosional unconformity beneath the Conception Group. Hughes and Brueckner (1971), however, suggested that the presence of "Conception-like" rocks in the Harbour Main Group, combined with the occurrence of tuffaceous beds and lavas within the Conception Group indicated a penecontemporaneous development of these two groups. Mapping in the southern Avalon Peninsula by Williams and King (1976) has suggested that in that area, the bulk of the Conception Group conformably to disconformably overlies the Harbour Main Group.

The Conception Group is overlain by a sequence of terrestrial and locally marine sedimentary rocks known in the eastern Avalon Peninsula as the Cabot and St. John's Groups (Williams and King, 1976). Similar lithologies in the west (e.g. Hodgewater Group) are thought to be correlative with the Cabot Group. These rocks are interpreted as conformably overlying the Conception Group (Williams and King, 1976).

Bonavista Bay Region

The geology of the northwestern Avalon Zone is poorly understood and the topic of controversy; e.g. Jenness, (1963): Younce, (1970); O'Driscoll and Hussey, (1977); Hussey, (1979).

The schistose, felsic to intermediate volcanic and subordinate sedimentary rocks of the Love Cove Group (McCartney, 1957) are considered by some authors (e.g. Jenness, 1963) to be the oldest rocks in this area and correlative with the Harbour Main Group in the east.

The Connecting Point Group (Jenness, 1963) is a sequence of siliceous siltstones, shales and greywacke reaching an approximate thickness of 7,300 metres. Interpretations of the stratigraphic relationships of these groups are tenuous, since their contact is not exposed.

Red terrestrial sedimentary and minor volcanic rocks of the Musgravetown Group (Jenness, 1963) appear to have ambiguous contact relationships with the underlying Connecting Point Group. Jenness (1963) recognized an angular unconformity above the Connecting Point Group, whereas McCartney (1967) interpreted the Bull Arm Formation of the Musgravetown Group as conformably and gradationally overlying the Connecting Point Group.

Fortune Bay Area (exclusive of the Burin Peninsula)

The oldest rocks in the Fortune Bay area are the mafic and felsic subaerial volcanic and sedimentary rocks of the Connaigre Bay (Widmer, 1950) and Long Harbour (White, 1939) Groups. The internal stratigraphy of these groups is very similar, although different formational names have been proposed by Williams (1971) for the Long Harbour Group and O'Driscoll (1977) for the Connaigre Bay Group.

The base of both groups is a sequence of flow-banded and autobrecciated rhyolites with interbedded massive andesites and basalts known as the Tickle Point (O'Driscoll, 1977) and Belle Bay (Williams, 1971) Formations. Locally, these volcanic rocks are conformably overlain by grey and purple sedimentary rocks and interbedded mafic tuffaceous sedimentary rocks of the Great Island (O'Driscoll, 1977) and Andersons Cove (Williams, 1971) Formations. These rocks are locally and conformably overlain by undivided dominantly mafic and lesser felsic volcanic rocks of the Doughball Point (O'Driscoll, 1977) and Mooring Cove (Williams, 1971) Formations. They are conformably overlain by red, fine-grained, micaceous sedimentary rocks of the Down's Point (O'Driscoll, 1977) and Rencontre (Williams, 1971) Formations. Williams has shown that the Rencontre Formation is in conformable contact with fossiliferous Cambrian strata.

2.3 Regional Setting of the Southern Burin Peninsula

The geological evolution of the southern Burin Peninsula can be documented by means of five major geological entities, the distribution of which is shown in Figure 2:6.

A major northeast-trending suture, beneath Eocambrian-Cambrian sediments and sandwiched between the Lewins Cove and Little Bay Faults (Strong et al., 1975), divides the Proterozoic geology of the Peninsula into two contrasting terrains. The area to the west of this zone is underlain mainly by volcanic rocks of the Marystown Group (Strong et al., 1976) which represent a period of extensive subaerial volcanism. Rocks to the east of the suture, the Burin and Rock Harbour Groups (Strong et al., 1976; Jooste, 1954) are the products of deep water marine sedimentation and volcanism.

Sedimentary rocks of Eocambrian-Cambrian age (Inlet Group) are distributed in fault-bounded outliers throughout the peninsula.

Figure 2:6 Simplified geological map of the southern Burin Peninsula (modified after O'Brien <u>et al</u>., 1977 and Strong <u>et al</u>., 1978b).

Mid-Paleozoic intrusive (St. Lawrence Granite) and extrusive (Rocky Ridge Complex) rocks are localized in the south-central parts of the peninsula.

2.3.1 Proterozoic subaerial volcanism

Subaerial volcanic and associated sedimentary rocks of the Marystown Group underlie most of the area between the Lewins Cove Fault in the eastern part of the peninsula and the Eocambrian-Cambrian Fortune Group in the west.

The Marystown Group consists of a lower unit of mixed mafic and felsic subaerial volcanic rocks, locally overlain by terrestrial sedimentary rocks which are in turn overlain by a later volcanic unit. The upper volcanic sequence can be subdivided into a lower, dominantly mafic and an upper, dominantly felsic unit.

Descriptions of the lithology, stratigraphy, petrology, structure and geochemical features of the Marystown Group are given in the following chapters and will not be discussed here.

2.3.2 Proterozoic submarine sedimentation

The Rock Harbour Group (Jooste, 1954) is a sequence of Precambrian sedimentary rocks that crop out along the eastern side of the Burin Peninsula over a distance of 25 kilometers. The maximum exposed thickness of the Rock Harbour Group is approximately 2000 metres (Taylor, 1976; O'Brien, 1978). The base of the Rock Harbour Group has not been recognized on the southern Burin Peninsula.

Three major lithological assemblages can be recognized within the Rock Harbour Group. Cross-bedded sandstones and greywackes and medium to coarse grained boulder conglomerates occupy the lowest stratigraphic levels of the Group. These rocks are overlain by a turbidite-type facies (Taylor, 1976; O'Brien, 1978) of graded gray and green siliceous siltstones and argillites. Stromatolitic limestone-bearing breccias with black shale matrices and coarse chaotic sedimentary breccias appear to be localized in the upper stratigraphic levels of the Group (Strong et al., 1978b; O'Brien and Taylor, 1979).

The upper contact of the Rock Harbour Group with mafic pillow lavas of the Burin Group is considered to be conformable in the southern parts of the Burin Peninsula (Taylor, 1976). Elsewhere, the contact of the Rock Harbour Group with all adjacent units is either faulted or unexposed.

2.3.3 Proterozoic submarine volcanism

The Burin Group (Strong et al., 1976) is a west-facing sequence of mafic pillow lavas, aquagene tuffs and a gabbroic sill which reaches a maximum total thickness of approximately 4 kilometres. Taylor (1976) divided the Burin Group into four separate formations.

The Pardy Island Formation is a basal unit of alkalic pillowed basalt which conformably overlies the Rock Harbour Group. The Port au Bras Formation is a sequence of mafic aquagene tuffs, agglomerates and pillowed basalt which locally displays a conformable contact with the underlying Pardy Island Formation. The Port au Bras Formation is overlain by pillowed tholeiitic basalts of the Path End Formation. The top of this formation is irregularly truncated by the Wandsworth Formation, a 1.5 kilometre thick gabbroic sill, locally differentiated to quartz diorite. The Beaver Pond Formation is the uppermost stratigraphic unit of the Burin Group and consists of a sequence of large (2-3 metre) aphyric, pillowed basalt which is in fault contact with the adjacent Inlet Group.

The contact of the Burin and Marystown Groups is faulted but evidence suggesting that the Marystown Group unconformably overlies the Burin Group has been described by Strong (1976) and Strong et al., (1978 a,b).[1]

2.3.4 Eocambrian-Cambrian sedimentation

Shallow water marine sedimentary rocks of Eocambrian to Cambrian age crop out in three belts on the southern Burin Peninsula.

The eastern belt is underlain by the Inlet Group (Taylor, 1976), a 60 kilometre-long band of uppermost Hadrynian to middle Cambrian sedimentary rocks. The Inlet Group is overthrust by the Marystown Group in the west and is both downfaulted against and unconformably overlying the Burin Group in the east (Strong et al., 1978 a).

The base of the Group is the Bay View Formation; a sequence of purple, gray and red, ripple marked micaceous siltstones and sandstones overlain by gray siltstone and quartzite. It is conformably overlain

[1] Recent, unpublished U-Pb zircon dates from the Burin and Marystown Groups supports this unconformity (Krogh, pers. comm.).

by red and green shale, red shale with limestone nodules and minor gray shales of the Salt Pond Formation. The top of the Inlet Group is marked by the Pleasant View Farm Formation. It consists of a sequence of green and gray manganiferous shales and mudstones and black, rusty weathering shales. Middle Cambrian trilobites have been identified from black shales of this formation (Van Alstine, 1948; Taylor, 1976).

The central outlier is a narrow (< 1 km) fault bounded belt of uppermost Hadrynian, shallow-water marine clastic rocks which is adjacent to the Marystown Group in the south-central parts of the Burin Peninsula. The main rock types in this belt are red and purple, ripple marked, micaceous siltstones and sandstones. The geology of the western belt is described in detail by Strong et al. (in press), upon which the following description is based. The western belt is underlain by the uppermost Hadrynian to middle Cambrian Fortune Group. The base of the Group is the Admiral's Cove Formation, a series of red micaceous mudstones and sandstones inferred to disconformably overlie the Marystown Group (O'Brien et al., 1977; Strong et al., in press). The Grand Bank Formation is a sequence of green and gray, thinly bedded siltstones, red siltstones and gray limestone which conformably overlies the Admiral's Cove Formation. The Duck Point Formation locally overlies equivalents of the Grand Bank Formation. It consists of pink limestones and red, green and purple mudstones with limestone nodules. In areas where the Duck Point Formation is missing due to non-deposition, the Grand Bank Formation is disconformably overlain by micaceous green siltstones and white quartzites of the Pieduck Point

Formation. The Fortune River Formation consists of red and green mudstone and fossiliferous (Callavia-zone) limestones which overlie the Pieduck Point Formation. The stratigraphic top of the Fortune Group is represented by the Little Danzic Cove Formation, a sequence of fossiliferous, middle Cambrian black and gray shales with limey concretions.

2.3.5 Carboniferous rocks

The St. Lawrence Granite is an alkaline to peralkaline alaskitic granite which intrudes the Marystown and Inlet Groups in the southern parts of the peninsula. Bell and Blenkinsop (1975) dated the granite at 315 ± 10 Ma. (Rb-Sr whole rock isochron; $\lambda\ Rb^{87} = 1.47 \times 10^{-11}$ $year^{-1}$) making this the only dated Carboniferous intrusive rock in the area.

Carboniferous sedimentary rocks occur in a small (< 5 km^2) outlier in the eastern part of the peninsula. Typical lithologies are white and pink limestone, red sandstone, red calcareous mudstone and limestone with lesser amounts of black shale. A Tournaisian age for these rocks in tentatively indicated by microfossils from the shales (Strong et al., 1978 b).

Small areas of volcanic rocks with chemical and petrological features similar to the St. Lawrence Granite, occur in the northern parts of the pluton. These similarities suggest that these rocks represent the volcanic expression of the Carboniferous plutonic activity in the area.

A Carboniferous age (326 ± 5 Ma.) from a plagioclase separate from the Grand Beach Complex has been documented by Stukas,(1978).

2.4 Tectonic History: Southern Burin Peninsula

A seven-stage tectonic model for the evolution of the southern Burin Peninsula was proposed by Strong et al., (1978 a,b). The following is a summary of their tectonic model.

The uplift and erosion of a subaerial volcanic and plutonic terrain resulted in the deposition of the coarse conglomerates and sandstones of the Rock Harbour Group in near-shore environments. A deepening of the depositional basin is reflected in the presence of turbidite facies rocks in the sequence. The presence of slump breccias and stromatolitic limestone bearing megabreccias reflects continued instability at the edge of the depositional basin. The presence of pillowed basaltic rocks with oceanic tholeiitic affinities reflects the rifting of continental crust by continuing extensional tectonics and breakthrough of mantle-derived lavas of the Burin Group. A period of deformation and greenschist facies metamorphism followed the cessation of the oceanic volcanism. The deformation and metamorphism is interpreted to be the result of the relaxation of tension and gravitational collapse of the thick volcanic pile.

A reversion to tensional tectonics resulted in the subaerial volcanism of the Marystown Group. Gradual cessation of volcanism accompanied by gradual submergence in the late Hadrynian and Cambrian resulted in the deposition of the Fortune and Inlet Groups.

High level, peralkaline plutonic activity and associated volcanism and sedimentation in the mid-Paleozoic reflected the initiation of an extensional environment at this time. The peralkaline nature of the St. Lawrence Granite is interpreted to reflect "hot spot"-type magmatism which is assumed to be an early indicator of the rifting which formed the present Atlantic Ocean.

3. SUBAERIAL VOLCANIC TERRANES: AN OVERVIEW

3.1 Nomenclature

Before any meaningful discussion of the rocks produced by subaerial felsic volcanism, some terms must be clearly defined. This section is reserved to define the terminology used throughout this thesis.

Classification schemes for volcaniclastic rocks are common in the literature, e.g. Wentworth and Williams, (1932); Smith, (1960); Fisher, (1960, 1961, 1966); Wright and Bowes, (1963); Parsons, (1969), etc. This profusion of published material has also led to discrepancies amongst original definition, classification and current usage of the terms describing the volcaniclastic rocks.

Fisher (1961) subdivided the volcanic clastic (or volcaniclastic) rocks into pyroclastic, autoclastic and epiclastic types. His subdivision is based on the primary origin and grain size of the fragments. Fisher's (1960, 1961, 1966) classifications of pyroclastic fragments and volcaniclastic rocks, which are adopted for use in this thesis, are given in Table 3:1. The finer-grained tuffaceous rocks of this classification can be compositionally subdivided on the basis of the lithic, crystal-and vitric-fragment component of the tuffaceous rocks as shown in Figure 3:1.

The term "pyroclastic" was originally defined by Wentworth and Williams (1932, p. 24-25) as "an adjective applied to rocks produced by

Table 3:1. Terminology and Grain-Size for Pyroclastic Fragments (after Fisher, 1961)

Grain-Size (mm)	Epiclastic Fragments	Pyroclastic Fragments	
	boulders, blocks	coarse	blocks
256			and
	cobble	fine	bombs
64			
	pebble	lapilli	
2			
	sand	coarse	ash
1/16			
	silt		
1/256		fine	ash
	clay		

explosive or aerial ejection of material from a volcanic vent...". Ash-flow tuffs (Smith, 1960) or ignimbrites (Marshall, 1935), tuff breccias (Fisher, 1960), vent agglomerates and sillars (Fenner, 1948) are examples of pyroclastic rocks.

Fisher (1960) maintains that autoclastic rocks contain fragments that were produced (1) within, but not necessarily extruded from, volcanic vents, (2) during movement of lava flows, or (3) by gas explosions from stagnant flows. This broad category includes such rock types as flow breccias, autobreccias, intrusion breccias and-or tuffisites. The former two lithologies are formed at the surface, whereas the latter two rock types are the result of subsurface activity.

Epiclastic volcanic rocks can be defined as those derived by weathering and erosion of lithified or solidified volcanic rocks. Lahars (Fisher, 1960a; Mullineaux and Crandell, 1962) are examples of epiclastic volcanic rocks. Fisher (1960) defined laharic breccias as those formed by volcanic mudflows carrying, dispersing and depositing coarse- and fine-grained volcanic fragments and/or mixed non-volcanic sediments.

Possibly the most common type of subaerial siliceous pyroclastic rocks are the ash-flow tuffs. An ash-flow is defined by Smith (1960, p. 795) as "the basic unit of most pyroclastic deposits known as welded tuffs, tuff flows, pumice flows or ignimbrites", or as "the deposit resulting from the passage of one nuée ardente... it consists of 50 or more weight percent of ash and fine ash exclusive of foreign inclusions" (Smith, ibid., p. 701). The nomenclature to be used in this thesis for describing various aspects of ash-flow tuffs has been taken from Smith (1960, pp. 800-801).

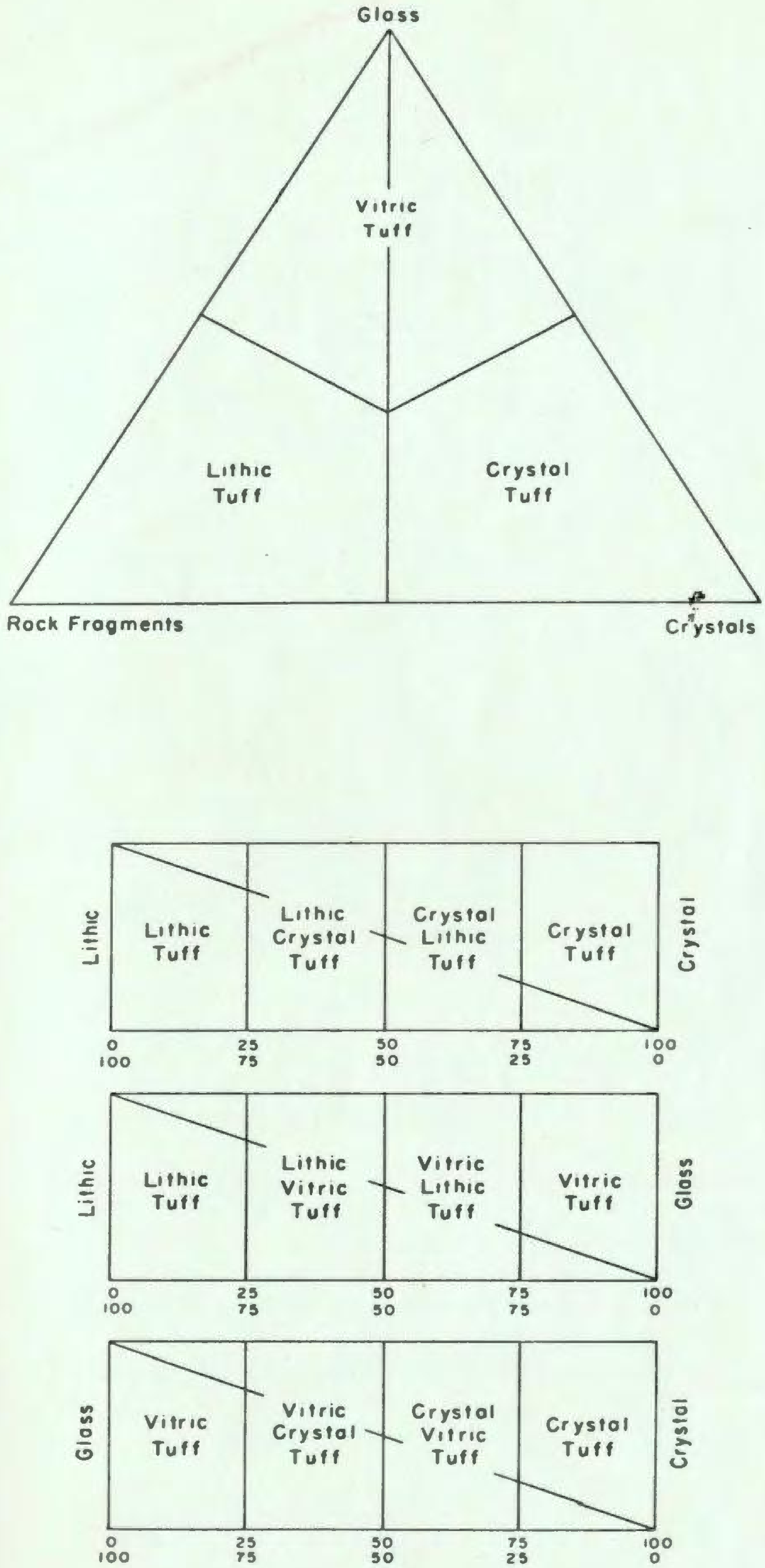


FIGURE 3.1 Classification of pyroclastic rocks based on crystal,lithic and vitric components, from Pettijohn (1975, p.306

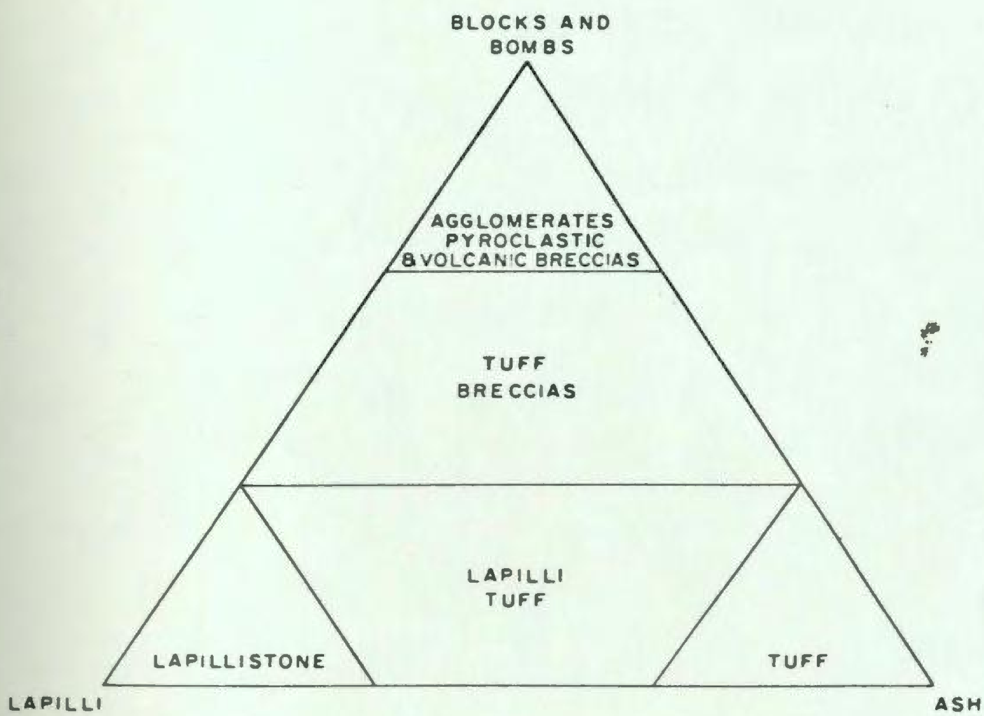


FIGURE 3.2 Mixture terms and end members for pyroclastic rocks (after Fisher,1966)

3.2 Subaerial Volcanic Fields

The following section is designed to present a simplified overview of the difficulties and inherent problems involved in mapping in deformed subaerial volcanic fields such as the Marystown Group. The problems involved in recognition of ash-flow tuffs and related rocks of their source areas are outlined. The nature of eruption of these rocks is discussed as is the nature of the facies variations within the deposits. The problems involved in ascertaining immediate and ultimate origins of the magma which produced the volcanic rocks is briefly summarized. A brief summary of some aspects of subaerial mafic volcanism and problems involved in the understanding of mafic volcanic fields is presented.

3.2.1 Ash Flow Tuffs and Related Rocks

Ash flow tuffs often constitute a dominant proportion of the siliceous subaerial volcanic rocks in continental areas. Several major problems must be overcome before such volcanic fields can be understood clearly.

An appreciation of problems of recognition involved in the study of areas of Precambrian siliceous subaerial volcanism can be gained from the literature, e.g. Hjelmquist, 1955; Rittman, 1962; Theime, 1970. One of the most basic difficulties arises in distinguishing in the field between ash-flow tuffs and tuffaceous rocks of other origin, and between rhyolite flows and welded tuffs. In the former case, often such a distinction can only be made where it is possible to recognize the zonal variations in welding, which are characteristic in many ash flows. The distinction between ash flow and air fall tuffs which have undergone deformation can usually only be done petrographically, sometimes with limited success.

In many cases, as pointed out by Smith (1960), single ash-flows can be undistinguishable in multiple flow cooling units. In such examples, the scale of mapping often governs whether or not a single lithologic unit represents a heterogeneous volcanic field or a texturally unique zone of a single ash flow.

Because of the complex nature of eruption (and hence deposition) in some of the larger volcanic fields such as the Absaroka Field of the southern U.S.A. (Smith and Bailey, 1968) and the Toba Field of the Sumatra (van Bemmelen, 1949), the concept of single flows developed by Smith (1960, p. 811) has to be modified. In such cases, one is often dealing with a series of compound flows in which it may be conceivable to encounter all possible variations seen in welded tuffs, with the exception of incompatible chemical composition.

The location and characteristics of the volcanic vents and/or source areas of ash flow tuffs are often the most perplexing problems encountered in the study of these rocks. Nuées ardentes erupted from central vents such as volcanic domes and open craters characteristically result in deposits of restricted distribution and small volume, e.g. Mount Pelée, La Soufrière, (McDonald, 1972) while the larger deposits seem to result from fissure eruptions (e.g. Valley of Ten Thousand Smokes). In the latter case, the ash flow tuff deposits often obscure the fissure vents. Some of the largest volumes of ash flow tuffs have resulted from the mechanism of caldera collapse (e.g. San Juan Mountains volcanic field; Smith and Bailey, 1968). Post-ash flow collapse and resurgent doming often obscures the original vents. Such features have been documented by Smith and Bailey, 1968 in the Valles Caldera, New Mexico.

Another perplexing problem deals with the immediate and ultimate origins of the magma which produced the ash flow and associated pyroclastic deposits. Large volume ash flow tuff deposits are usually associated with areas of continental orogenesis on wide island arc terrains (Lipman et al., 1972; Smith , 1960). The ultimate origin of these deposits appears to involve the melting of continental crust. Whereas smaller deposits have their immediate origin within a volcanic dome or cone, deposits of larger volume, such as those due to caldera collapse are probably derived from shallow magma reservoirs (Smith and Bailey, 1968). These granitic to dioritic complexes of varying size are not always traceable into deep seated bodies of batholithic sizes. However, Smith (1960) and Smith and Bailey (1968) have demonstrated that the tectonic settings and regional grouping of some of the ash flow fields of the southwestern U.S.A. suggest a common origin from such batholiths.

Difficulties also arise in establishing whether rhyolite ash flows arise from granitic magmas, or whether they are derived from the differentiated parts of large bodies of granodiorite or quartz monzonite. Similar difficulties are encountered in areas where rhyolitic, dacitic and latitic ash flow tuffs occur together (e.g. Cox et al., 1965; Noble, 1965a).

It is often difficult to establish whether these rock types have common origins or whether they are the result of separate and unique magma sources.

3.2.2 Mechanism of deposition of some pyroclastic rocks

Many of the major difficulties encountered in stratigraphic correlation of subaerial pyroclastic rocks are due primarily to the mechanism of deposition of these rocks. Lithological, petrological and geochemical variations in rock types are common tools in the stratigraphic studies of submarine flows and pyroclastic rocks. Subaerial pyroclastic rocks, however, often display both systematic vertical variations which are dependent upon variations in the original magma chamber and lateral variations give rise to the greatest difficulties encountered in the stratigraphic and structural analysis of deformed subaerial volcanic fields. The difficulties in stratigraphic analysis are greatly compounded in deformed areas. Because of the facies variations, the correlation of units across fold hinges and faults becomes problematic in many cases.

In order to understand the origin of these facies variations, one must have some insight into the mechanism of flow movement. The following brief description of pyroclastic flow movement is taken primarily from Smith, 1960 and Fisher, 1966. In the majority of subaerial pyroclastic flows, deposition can occur at any time and at any location along the length of the flow. The equal tendency of heavy and lightweight particles to be deposited often inhibits the sorting of material within these deposits, although density stratification and/or gravity settling in these deposits have been reported in the literature (e.g. Lipman, 1967; Gibson, 1970; Elson and Smith, 1970; Walker, 1972). The density and forward motion of a thinning flow is maintained as deposition from the flow increases.

In any one vertical section of a deposit, the youngest rocks are represented in the stratigraphically highest part of the section. Fisher (1966) points out, however, that vertical sections far away from the source are younger than vertical sections near the source because laterally equivalent lithologic zones are not time equivalent. This manner of deposition explains why vertical sections through pyroclastic sequences, such as ash flows, display a reverse stratigraphic order to their original location within the magma chamber.

The lateral and vertical variation in crystal content

and whole rock and crystal chemistry which results from this depositional process is discussed at length by various authors (e.g. Scott, 1966; Walker, 1972; Sparkes et al., 1976, etc.) but is beyond the scope of this discussion. The importance of these variations, however, should be taken into account when discussing the general geochemical features of a subaerial volcanic suite.

The mechanism of eruption of other pyroclastic rock types often result in difficulties in stratigraphic analysis. Agglomerates generally form within the throat of the volcano itself, or on the flanks close to the vent, and are therefore often interpreted as reflecting the presence of vents within a volcanic terrane. These deposits are not generally areally extensive and hence often make poor lithostratigraphic marker horizons over a large area.

Similar difficulties occur in the study of epiclastic volcanic rocks. Mudflow breccias or lahars commonly form on the flanks of a volcanic cone. In some cases, mudflows have traveled in excess of 200 kilometers (e.g. Osceola mudflow; Crandell and Waldron, 1956), however, frequently the flows travel only short distances after they reach the gentle slopes at the base of the volcanic cone. In such cases, the deposits do not serve as good stratigraphic markers within a volcanic sequence.

In many cases, the deposition of both ash flows and mudflows is dependent on paleotopography; the deposits often being localized in valleys and lowlying areas. This depositional feature leads to marked variations and nondeposition, which occurs within stratigraphic horizons containing such deposits. In places, many of the above facies variations occur within single lithostratigraphic units of the Marystown Group. These variations have been interpreted to be the result of the processes similar to those described above. Individual examples are documented in the following chapter which discusses the volcanic stratigraphy and depositional environments of the Marystown Group.

3.2.3 Continental basaltic volcanism

Flood or plateau basalts are the most important type of mafic continental volcanism and are common throughout the Phanerozoic and Proterozoic. These rocks are generally the result of fissure eruptions and often cover vast areas. Some of the largest known plateau basalt fields are the Columbia River Province of the northwestern U.S.A. (Waters, 1961), the Deccan plateau of Western India (West, 1958), the Karoo Province of West Africa (Cox et al., 1965), the tholeiitic basaltic fields of Antarctica (Gunn, 1966) and the Late Cenozoic basalts of the southern Rocky Mountains (Lipman and Mehnert, 1965). The basalts of the Paraná basin of central South America are thought to cover over 1 million square kilometers of Brazil and adjacent countries (Carmichael et al., 1974).

In some volcanic fields (e.g. Columbia River Province), basaltic rocks show little variation in petrological or petrochemical characteristics (Waters, 1961, 1962). Abrupt changes in these characteristics do occur at widely spaced intervals but gradational variations are rare. In areas such as the Columbia River Plateau it is often difficult to ascertain whether this episodic, "uniform" volcanism is the result of fractional crystallization of a mafic magma or several magma types of independent origin (Waters, 1961, 1962; Cox et al., 1965, 1967; Lipman and Mehnert, 1965; ...). There is no general consensus in the literature as to the exact mechanism of producing such large volumes of relatively uniform magma with strong temporal and spatial restrictions but most authors consider it to be the result of mantle melting under a tensional tectonic environment. The exact physical-chemical conditions of such magma conditions remains a debatable issue.

Abrupt chemical and petrological changes do occur in volcanic fields such as the African Nuanetsi Province and the Scottish Tertiary Province (Cox et al., 1967; Thompson et al., 1972). In these areas there is no strong evidence that these spatially associated, chemically diverse magmas are genetically related.

It is also important to realize that in many cases (e.g. the Basin and Range Province of the southwestern U.S.A.) the vast eruptions of continental basalts represent limited episodes in much larger tectono-magmatic events.

In summary, one of the most important problems in studying areas with large volumes of subaerial mafic volcanic rocks is to ascertain if petrological and geochemical diversities do occur within the sequence; and if so, what these variations represent in terms of magma generation and the larger tectonic setting of the volcanic field.

The preceding sections have outlined some of the problems involved in understanding various aspects of subaerial volcanic terrains. The following chapter presents a discussion of the stratigraphy and lithology of the Late Proterozoic Marystown Group. The nature of formation and the depositional environment of the dominantly subaerial volcanic sequence are outlined in light of some of the aspects of subaerial volcanology described above. The Marystown Group was deformed during the Paleozoic and the effect of this deformation is discussed below. The petrology and geochemical features and their relation to the tectonic setting of the Marystown Group are also discussed in the following chapters.

4. STRATIGRAPHY

4.1 General Statement

The name "Marystown Group" was first used by Strong et al., 1975 to designate the thick and areally extensive sequence of subaerial silicic and mafic volcanic and sedimentary rocks which underlie the area west of the Lewins Cove Fault on the southeastern Burin Peninsula. The Marystown Group in that area was tentatively divided into seven formations based on unique facies and depositional environment. It was recognized, however, that these subdivisions did not necessarily represent a true stratigraphic sequence; i.e. certain formations were possibly lateral equivalents. Continued mapping in the southwestern parts of the Peninsula (O'Brien et al., 1977; Strong et al., (1979). confirmed this, but neither of these authors proposed a formal stratigraphic subdivision for the Group.

The volcanic rocks which underlie the southern Burin Peninsula between the eastern and western Cambrian outliers are now considered to form a continuous succession of Late Precambrian age and are assigned to a single group, the Marystown Group. Throughout most of the southern Burin Peninsula, the Marystown Group can be divided into five formations and two complexes: viz. Taylor's Bay Formation, Garnish Formation, Calmer Formation, Mount Saint Anne Formation, Hare Hills Formation, and the Barasway and Grand Beach Complexes.[1] The first four formations are listed in order of decreasing age, but the Hare Hills Formation and the Barasway Complex are considered to represent facies equivalents within

1 The stratigraphic nomenclature introduced in this thesis is informal.

TABLE 4:1 Table of Formations for the Marystown Group and adjacent rocks, southern Burin Peninsula

	WESTERN BURIN PENINSULA	EASTERN BURIN PENINSULA
CAMBRIAN	Fortune Group	Inlet Group
	– – – disconformable, locally faulted – – –	
LATE PROTEROZOIC	*Grand Beach Complex (197 m)	
	Barasway Complex (?) and Hare Hills Formation ($\geq$ 300 m)	Mount Saint Anne Formation ($\geq$ 300 m)
	– – – conformable – – –	
MARYSTOWN GROUP (ca. 5 km)	Calmer Formation ($\geq$ 500 m)	
	– – – conformable – – –	
	Garnish Formation ($\geq$ 1400 m)	
	.... apparent structural conformity	
	Taylor's Bay Formation (base not exposed, ca. 2000 m?)	
	~~ fault modified unconformity ~~~	
PROTEROZOIC		Burin Group (ca. 4 km)
		– – – conformable, locally fault modified – – –
		Rock Harbour Group (ca. 2 km) (base not exposed)

* May be Paleozoic in age

the same stratigraphic unit which overlies the Calmer Formation. The Grand Beach Complex appears to occupy the same stratigraphic position as the Hare Hills Tuff and the Barasway Complex but there is some question as to its absolute age (see section 4.8.3).

A complete section of the Marystown Group is nowhere continuously exposed, but an aggregate thickness of the individual units suggests that a minimum thickness of the Group would be in the order of five kilometres.

4.2 Taylor's Bay Formation

4.2.1 Definition and Distribution

The Taylor's Bay Formation is a new name proposed for the areally extensive sequence of intercalated rhyolitic and basaltic, dominantly pyroclastic volcanic rocks which form the lowermost recognizable stratigraphic division of the Marystown Group on the southern Burin Peninsula. The Formation includes rocks which had been previously included in the Branching Rivers, Mount Lucy Anne and Beacon Hill Formations of Strong et al., 1975, 1978 b.

The Taylor's Bay Formation is the most extensive of the subdivisions of the Marystown Group. It underlies the central parts of the Marystown and St. Lawrence map areas and the eastern and central parts of the Lamaline and Grand Bank map areas respectively. The Formation is well exposed only in the area around the community of Taylor's Bay, on the south coast of the Burin Peninsula.

Poor exposure and repetition within the sequence caused by recognized (and possibly unrecognized - see Chapter 6) folding and faulting prevent any reliable determination of the internal stratigraphy of the Taylor's Bay Formation or a reliable estimate of its thickness.

4.2.2 Lithology

The Taylor's Bay Formation consists of a wide variety of rhyolitic and basaltic volcanic rocks and minor tuffaceous and arkosic sedimentary rocks.

That part of the Formation which outcrops east of the Tilt Hills Syncline (i.e. east and southwest of Strouds Pond) consists of a sequence of intercalated and tectonically interleaved basaltic flows and tuffs and rhyolitic pyroclastic rocks. The basaltic rocks occur both as thin (≤ 100 m) discontinuous lenses and areally extensive flows of varying thickness which are traceable along strike for up to 2 kilometres. The basalts are typically massive and structureless and only locally plagiophyric. Hornfelsing adjacent to the St. Lawrence Granite locally results in the formation of large (≤ 2 cm) magnetite porphyroblasts in the basaltic flows. Minor amounts of bedded and massive mafic to intermediate lithic tuffs and fine grained volcanic breccias occur as discontinuous lenses intercalated with both the massive basaltic and rhyolitic volcanic rocks. In areas of intense shearing related to faulting in this area (section 6.2.3) the basaltic rocks have been metamorphosed to chlorite schists.

The main types of rhyolitic volcanic rocks in the Taylor's Bay Formation east of the Tilt Hills Syncline are unwelded rhyolitic lithic-lapilli and crystal-lithic tuffs, with lesser amounts of rheoignimbrites and flow banded rhyolites. The lithic tuffs are fine to medium grained and contain lapilli of felsic and lesser amounts of mafic and intermediate volcanic rocks in a very fine grained, locally crystal rich matrix. The unwelded nature of these tuffaceous rocks makes them susceptible to deformation and metamorphism associated with the regional deformational event, and hence they are commonly metamorphosed to sericite schist. In places, the tuffaceous rocks are more coarse grained and are best described as volcanic breccias.

The rhyolite flows are flow banded and spherulitic and locally display autobrecciation features (Plate 4:1). In places these flows are spatially associated with rheoignimbrites which display discontinuous flow-like features. These rocks are uncommon in the eastern exposures of the Taylor's Bay Formation but are more extensive in the western outcrops in the Beacon Hill Anticline. The massive rhyolitic volcanic rocks are resistant to the effects of regional deformation which are preferentially developed in the adjacent tuffaceous volcanic rocks. Near Strouds Pond, in the central part of the peninsula, rhyolite flows of the Taylor's Bay Formation have been hydrothermally altered by the St. Lawrence Granite, resulting in a secondary assemblage of pyrophyllite, dumortierite and andalusite being developed in these rocks.

Epiclastic volcanic and tuffaceous sedimentary rocks comprise a minor proportion of the Taylor's Bay Formation. The sedimentary and epiclastic rocks are typically unsorted but display grading and cross-lamination in places. Their detrital assemblage is similar to the clast lithology of the unwelded tuffaceous rocks. These rocks are interpreted to be the result of reworking of tuffaceous rocks in a subaqueous environment.

The scattered exposures of the Taylor's Bay Formation in the Beacon Hill Anticline consist of unwelded rhyolitic pyroclastic rocks, rhyolite flows and rheoignimbrites, and basaltic tuffaceous rocks.

The unwelded pyroclastic rocks are lithic tuffs which, for the most part, are similar to those which crop out to the east of the Tilt Hills Syncline. Exposures of mafic (and very locally, intermediate) lithic tuffs are more common in the western exposures of the Formation, but nevertheless, constitute a minor proportion of it. The felsic pyroclastic rocks are spatially associated with massive and banded rhyolite flows. The latter locally display flattening features, in part primary, which have been intensified by the regional, locally co-planar, foliation.

The major differences between the eastern and western belts of the Taylor's Bay Formation are in the distribution and nature of the mafic volcanic rocks. The dominant basaltic rock types are lithic tuffs and fine grained breccias which occur as discontinuous lenses within the rhyolitic pyroclastic rocks, up to 100 m long by 50 m wide. Thick and extensive basalt flows are notably rare in this area.

4.2.3 Contact relations and correlation

The base of the Taylor's Bay Formation is not exposed on the southern Burin Peninsula. The Formation is overlain with apparent structural conformity by the Garnish and Calmer Formation although its contacts are often poorly exposed and locally fault-modified. In places, there exists an apparent structural contrast between the rocks of the Taylor's Bay Formation and the overlying units of the Marystown Group. The possible reasons for and significance of this is discussed in sections 6 .5 and 8.2.

The Taylor's Bay Formation is thrust over Eocambrian sedimentary rocks (possible Admiral's Cove Formation equivalents) in the central part of the Lamaline map area, near Salmonier River. The Formation is in fault contact with felsic volcanic rocks of the Mount Saint Anne Formation (section 4.7) in the eastern part of the Burin Peninsula, between Mount Saint Anne and Mount Lucy Anne.

The contacts of the Taylor's Bay Formation with the Hare Hills Formation (section 4.6) and the Barasway (section 4.5) and Grand Beach Complexes (section 4.8) are not exposed in the study area.

The Taylor's Bay Formation is lithologically very similar to volcanic sequences elsewhere in the western Avalon Zone. The Formation stratigraphically underlies extensive basaltic flows of the Calmer Formation and clastic sedimentary rocks of the Garnish Formation. Its stratigraphic position is similar to that of the Belle Bay Formation (Williams, 1971) and Tickle Point Formation (O'Driscoll, 1977) of the western Fortune Bay area. On the northern Burin Peninsula similar rock types with a similar stratigraphic position (Deer Park Pond Formation) have been described by Bradley, 1962. In the Bonavista Bay area, Hussey (1979) has described a sequence of subaerial mafic and felsic volcanic rocks (White Point Formation of the Love Cove Group) which conformably underlies basaltic flows and clastic sedimentary rocks.

On the basis of these stratigraphic and lithologic similarities, the Taylor's Bay Formation is correlated with the Belle Bay and Tickle Point Formations of the Long Harbour Group, the White Point Formation of the Love Cove Group and the Deer Park Pond Formation.

4.3 Garnish Formation

4.3.1 Definition and Distribution

The name "Garnish Formation" was first used by Strong et al., 1975 to designate the mafic volcaniclastic and associated red clastic sedimentary rocks which crop out near the community of Garnish. This original usage is retained, but the designation is expanded to include rocks of similar lithology, overlying the Taylor's Bay Formation which crop out along the western shore of L'Anse au Loup and in the synclinal core to the east of the Eastern Hare Hills. Similar rock types which crop out near Tapley Hill, north of the community of Lamaline are tentatively correlated with the Garnish Formation.

The Garnish Formation attains a maximum exposed thickness of approximately 1400 metres along the western shore of L'Anse au Loup.

4.3.2 Lithology

The main rock types exposed in the basal portions of the Garnish Formation are red conglomerates and intercalated red, locally arkosic sandstones. This level of the Formation is best exposed in the vicinity of Deepwater Point where cross-laminated, shallow-dipping red sandstones are interbedded with and overlain by medium to coarse grained red conglomerates (Plate 4.2). The sandstones are typically poorly sorted but graded bedding is locally preserved. Cross-laminations, ranging in amplitude from 2 cm to 20 cm are locally developed but paleocurrent directions have not been determined.

The conglomerates consist of subrounded to rounded clasts (≤ 15 cm) of mainly fine-grained feldsparphyric felsic volcanic and plutonic rocks. Massive and flow-banded rhyolites, rhyolite porphyries, rheo-ignimbrites and fine-grained red clastic sedimentary rocks are the main components of the detrital assemblage. Mafic volcanic and plutonic clasts are notably rare.

The upper stratigraphic levels of the Garnish Formation are best exposed in the western parts of the peninsula where the formation reaches its maximum thickness, e.g. near L'Anse au Loup. In this area the lower, dominantly conglomeratic unit passes upwards into a sequence of fine- to medium-grained red arkosic sandstones and red sandy silt-stones. The coarser-grained sandstones are locally crossbedded whereas the finer sandstones and siltstones display dessication cracks in places. Thin (≤ 1m) horizons of fine grained felsic and oxidized mafic lithic tuffs occur in the upper parts of the sequence.

Plate 4:1 Rhyolite flow of Taylor's Bay Formation, near Taylor's Bay. Note autobrecciation features.

Plate 4:2 Reddish brown conglomerate of the Garnish Formation, south of L'Anse au Loup.

The fining-upwards nature of the sequence, combined with poor sorting and commonly preserved crossbedding in the red, coarser grained clastic rocks suggest that these rocks were deposited in a fluviatile environment (see section 4.9).

4.3.3 Contact Relationships and Correlations

Red conglomerate and sandstone of the Garnish Formation disconformably overlie felsic volcanic rocks of the Taylor's Bay Formation approximately 3 miles south of L'Anse au Loup. Elsewhere the basal contact relationships are obscured by faulting or lack of exposure. The absence of deformed detritus in the sedimentary rocks of the Garnish Formation indicates that these rocks were deposited prior to the deformation of the underlying Taylor's Bay Formation.

The contact of the Garnish Formation with the overlying mafic volcanic rocks of the Calmer Formation is exposed near Garnish. The red clastic rocks are intruded by 1 metre wide diabase dykes which are interpreted to feed the overlying mafic flows. At Frenchman's Head the red sedimentary and mafic tuffaceous rocks of the formations are intercalated, suggesting a gradational contact. A conformable and gradational contact of red conglomerates with overlying Calmer Formation equivalents has been described in the vicinity of Point Enragée, north of this area (O'Brien and Taylor, 1979). At this locality the red sedimentary rocks are interbedded with green tuffaceous sediments of the Anderson's Cove Formation (Bradley, 1962) suggesting that these two sedimentary units may be in part correlative.

The Garnish Formation occupies a stratigraphic position similar to that of the Anderson's Cove and Great Island Formations of the western Fortune Bay area (Williams, 1971; O'Driscoll, 1977). The lack of green tuffaceous sedimentary rocks in the southern Burin Peninsula may be the result of facies variations within the unit. Similar facies variations have been documented in equivalent lithologies to the north (e.g.: Terrenceville area, Bradley, 1962; Clode Sound region, Hussey, 1979; and in the vicinity of Point Enragée, O'Brien and Taylor, 1978).

4.4 Calmer Formation

4.4.1 Definition and Distribution

The name "Calmer Basalts" was introduced by Strong et al., 1978 to describe the basaltic and minor volcaniclastic rocks which crop out on the southern coast of the peninsula, near the deserted community of Calmer. Similar rock types are exposed along the northern shoreline of the peninsula where they underlie the Grand Beach and Barasway Complexes. The rocks form a mappable unit of formational status in these areas and similar lithologies in the central and northern parts of the peninsula are clearly separable from the underlying Taylor's Bay and Garnish Formations and overlying Hare Hills Formation and Grand Beach and Barasway Complexes.

Rocks assigned to the Calmer Formation include the Mortier Bay Group, the Branching Rivers Formation and the Tilt Hills Complex of Strong et al. (1977 b).

The thickness of the Calmer Formation varies throughout the map area. The formation attains a maximum exposed thickness of approximately 500 metres near Calmer (O'Brien et al., 1977; Strong et al., 1979). Similar thicknesses of probable Calmer Formation equivalents have been documented north of the present study area, near Point Enragée (O'Brien and Taylor, 1978).

4.4.2 Lithology

The subaerial basalts of the Calmer Formation show little lithological variation throughout the southern Burin Peninsula. The major variation within the formation is in the amount of sedimentary and epiclastic material intercalated with the basaltic flows. Minor discontinuous lenses of rhyodacitic and rhyolitic tuffs occur in the eastern exposures of the formation. Distinctive coarse-grained plagioclase-porphyritic flows and sills occur in the east-central exposures of the formation, notably in the vicinity of Tilt Hills.

Exposures of the Calmer Formation are typified by vesicular and amygdaloidal subaerial basaltic flows containing amygdules of calcite, prehnite, quartz and chlorite which range in diameter from 1 mm to ≤ 5 cm (Plate 4:3). The thicknesses of individual flows vary but none in excess of 15 metres have been documented. The flows locally display megascopic textures diagnostic of subaerial deposition, e.g. - ropy flow surfaces, oxidized scoriaceous flow tops and breccias, pipe vesicles feeding coalescing amygdules (Plates 4:4 and 4:5).

Mafic tuffaceous rocks occur as 1 to 5-metre thick horizons intercalated with the mafic flows. These mafic tuffs occur throughout the outcrop area of the formation and are not restricted to any specific

Plate 4:3 Coarse-grained amygdules in Calmer Formation basaltic flows, near Point May.

Plate 4:4 Scoriaceous top of an amygdaloidal basalt flow, Calmer Formation, Famine Back Cove.

Plate 4:5 Vesicle pipes, Calmer Formation basalt, Famine Back Cove.

Plate 4:6 Bedded mafic tuffs, Calmer Formation, near Calmer.

stratigraphic level within it. These tuffs are usually poorly sorted but locally show evidence of crude grading and crossbedding, the latter feature suggesting that the tuffs are in part waterworked (Plate 4:6). The detrital assemblage of the tuffaceous rocks is characterized by fine to medium-grained red clastic sedimentary rocks and minor rhyolitic volcanic lithologies in a scoriaceous mafic matrix.

Red, medium grained conglomerates and sandstones are intercalated with the basaltic flows near Frenchman's Cove, Garnish Tolt and Sharp Peak. These rocks are lithologically similar to the sedimentary rocks of the underlying Garnish Formation and may reflect the interdigitation and penecontemporanity of both formations.

Thin, discontinuous lenses of felsic pyroclastic rocks (e.g. felsic lithic tuffs and fine-grained volcanic breccias) occur sporadically throughout the Calmer Formation.

The largest of these lenses occurs within the poorly exposed outcrop area of the formation in the vicinity of Wet Tilt Hill. The paucity of exposure in this area makes it difficult to establish whether the felsic lithologies are intercalated with the Calmer Formation or if they represent inliers of the underlying Taylor's Bay Formation exposed in anticlinal cores.

Dykes and sills of feldsparphyric basalt with epidotized plagioclase phenocrysts up to 2 cm long intrude these felsic rocks (Plate 4.7). Similar lithologies occur as flows within the Calmer Formation southwest of Wet Tilt Hill. These coarse-grained feldsparphyric basalts also occur as large blocks, in excess of 1 metre in diameter, in a coarse grained, mixed (mafic and felsic) volcanic breccia. The occurrence of such lithologies led Strong et al. (1979) to postulate the presence of a volcanic vent in this area. The lack of exposure prohibits the establishment of the relationship of this "vent complex" to the surrounding rocks.

4.4.3 Contact Relationships and Correlations

The Calmer Formation conformably and gradationally overlies the Garnish Formation on the south shore of Fortune Bay near Frenchman's Cove and on the western side of L'Anse au Loup. In the southern and eastern parts of the map area, the Calmer Formation lies directly on silicic volcanic rocks of the Taylor's Bay Formation. The contact appears conformable in local outcrops but the absence of the Garnish Formation suggests regional disconformity. The Calmer Formation is conformably overlain by the later felsic volcanic units (Hare Hills, Barasway and Grand Beach Complexes) in the western parts of the area.

The Calmer Formation is lithologically similar to the Mooring Cove Formation (Williams, 1971) and Doughball Point Formation (O'Driscoll, 1977) of the western Fortune Bay area. The Mooring Cove and Doughball Point Formations conformably overlie possible equivalents of the Garnish Formation (section 4.3.3) and disconformably overlie possible equivalents of the Taylor's Bay Formation (section 4.2.3) and are therefore interpreted to occupy a similar stratigraphic position to the Calmer Formation.

Plate 4:7 Coarse-grained feldsparphyric basalt, Tilt Hill.

Plate 4:8 Eutaxitic foliation in pumice-rich, welded ash-flow tuff, Barasway Formation, near Garnish.

4.5 Barasway Complex

4.5.1 Definition and Distribution

The name "Barasway Complex" was originally proposed by Strong et al., 1975, to designate the sequence of felsic agglomerates, ash-flow tuffs, massive and autobrecciated rhyolite flows and epiclastic volcanic breccias which crop out in the area immediately east and southeast of the Great Garnish Barasway. The Barasway Complex lies directly on the Calmer and Garnish Formations. The latter contact is fault-modified north of Garnish River, but is interpreted to represent a local disconformity. The stratigraphic top of the Garnish Formation is not exposed.

The complex nature of deposition of the rocks of the Barasway Complex results in rapid lithological variation along strike (see 3.2) which impair the establishment of a stratigraphic subdivision of this unit, although several lithologically unique divisions of the Complex can be recognized. These rapid facies variations, combined with local faulting and folding, prevent accurate estimates of total thicknesses for the Complex.

4.5.2 Lithology

Ash-flow tuffs and fine-grained heterolithologic breccias are the most common rock types within the Barasway Complex and are confined mostly to the eastern half of it. The ash-flow tuffs are best exposed along route 11 in the northwestern part of the Marystown map sheet and along the Garnish River. Macroscopically, two major types of welded tuffs are recognizable. One is a red to maroon-colored, densely welded, fine-grained, feldsparphyric crystal tuff. The other major type is a strongly flattened, highly altered, pumice-rich lithic tuff (Plate 4:8). The latter lithology is locally underlain by coarse grained volcanic breccias containing large (≤ 50 cm), chaotic, locally welded blocks of red porphyritic rhyolite and red volcaniclastic sediments in a highly altered tuffaceous matrix. These lithologies may be akin to the basal pyroclastic flow deposits described by Fischer (1972).

Most of the southern exposures of the complex consist of a monotonous sequence of undivided crystal, lithic and vitric tuffs with intercalated fine grained agglomerate and volcanic breccias. The scattered outcrops in this area display various degrees of welding and flattening but well developed macroscopic eutaxitic textures are rare.

The noncontinuous exposure and deformation of the ash flow tuffs of the Barasway Complex make it difficult to outline individual cooling units on a regional scale. In individual outcrops it is possible to recognize non-welded, partially welded and densely welded zones, but these zonal subdivisions cannot be extended on a regional scale.

Massive, autobrecciated and flow-banded rhyolites occur in several localities within the outcrop area of the Barasway Complex but do not appear to form a continuous stratigraphic marker. Massive flows of red and white aphanitic to feldsparphyric rhyolite are present only in a few localities; e.g. immediately north of Frenchman's Hill, on the Fox Hummocks and in the area immediately southwest of Devil's Brook Head. Flow-banded and autobrecciated rhyolites are associated with the massive flows and coarse-grained pyroclastic rocks of the complex but also intertongue with the ash flow tuffs in the area immediately north of Frenchman's Hill. In this locality the rhyolites exhibit coarse, highly contorted flow banding, with individual bands varying in width from 10 mm to approximately 2 cm (Plate 4.9)

Red sandstones and associated epiclastic volcanic rocks occur sporadically throughout the complex and are usually associated with the coarse-grained pyroclastic and epiclastic rocks.

The most diagnostic lithologies of the Barasway Complex are medium-to very coarse-grained monolithologic and heterolithologic epiclastic and pyroclastic breccias and agglomerates.

Two main types of pyroclastic breccias occur within the Barasway Complex. The first is a series of agglomerates and pyroclastic breccias containing blocks and bombs ranging in diameter from ≤ 15 cm to ≤ 2 m (Plate 4:10). The dominant clast lithologies are fine grained porphyritic felsic volcanic and plutonic rocks. Massive, flow-banded and porphyritic rhyolites, rhyodacite and rhyolitic tuffs are the most common volcanic rock types present. Plutonic fragments range in composition from felsites and granites to quartz diorites and tonalites. Fragments of mafic composition are notably uncommon in the breccias. Red mudstone, crystal-rich tuffaceous sediments and ash occur both as blocks and matrix in the agglomerates. Small (≤ 2 m x 1 m) tongues of brecciated, porphyritic, locally spherulitic felsite represent discontinuous flows and/or intrusions associated with the agglomerates. The well-rounded to subrounded nature of the blocks and bombs appear to

Plate 4:9 Coarse flow banding in rhyolite of the Barasway Formation, near Garnish.

Plate 4:10 Coarse grained volcanic breccia of the Barasway Complex; community of Garnish in background.

reflect the gaseous activity involved in the formation of these explosion breccias. Concentric oxidation zones within the fragments are interpreted to be the result of late stage deuteric alteration by percolating groundwater (Plate 4:11).

The second important pyroclastic rock type in the Barasway Complex is a fine-to coarse-grained felsic agglomerate containing dominantly rhyolitic and lesser amounts of mafic blocks in a felsic matrix. In the western outcrop area of the complex, these rocks directly overlie mafic flows of the Calmer Formation. The agglomerates consist typically of chilled bombs of massive, flow-banded and devitrified rhyolite in a fine grained, highly altered felsic volcanic groundmass. The bombs are commonly fluidized and often display various degrees of welding and flattening. These features suggest that these lithologies are primary pyroclastic deposits, e.g. agglomerates. They differ from the epiclastic breccias in that they do not display features suggestive of redeposition.

Coarse-grained epiclastic breccias outcrop in the northwesternmost part of the area, approximately 1 km north of Garnish. These rocks contain similar sized blocks of similar lithologies as the coarse-grained pyroclastic facies. The blocks are not as well rounded as those in the explosive facies and seldom show the extensive alteration of the latter. The breccias are interbedded with dominantly red epiclastic sandstone and unwelded ash-and crystal tuffs. These lithologies are also the dominant component of the matrix to these breccias. The above features suggest that these rocks may represent laharic deposits,

Plate 4:11 Alteration rim in a bomb in breccia of the Barasway Complex, near Garnish.

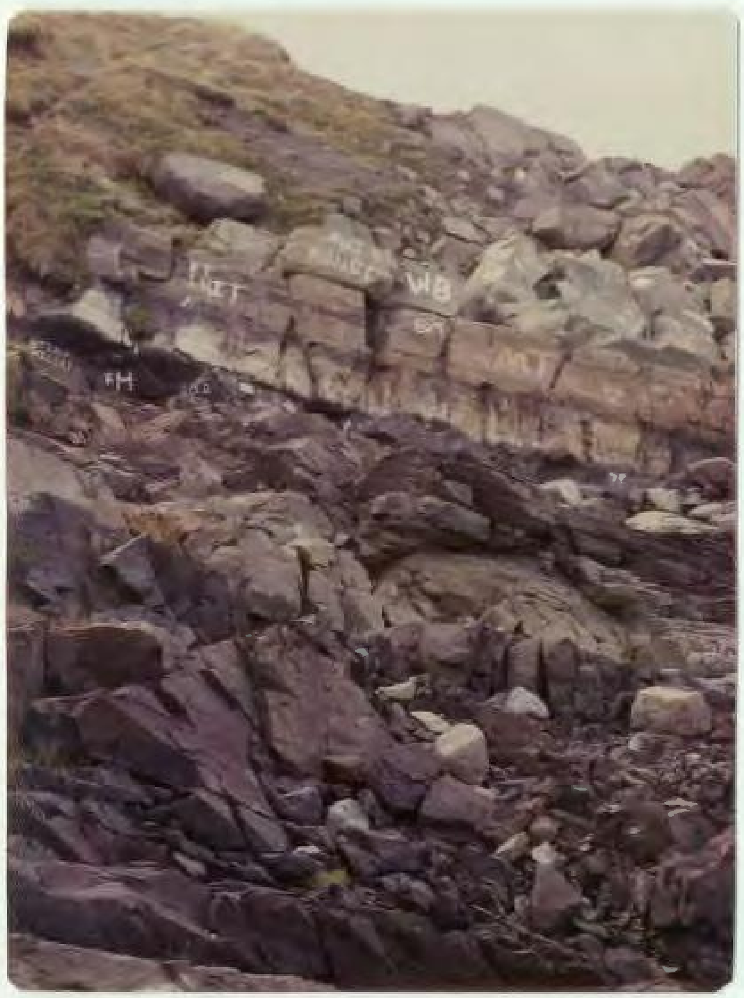


Plate 4:12:

Waterlain tuffaceous rocks of the Hare Hills Formation, Grand Bank.

possibly formed on the flanks of an eruptive centre marked by the coarse grained explosive pyroclastic facies.

4.5.3 Contact Relationships and Correlation

The Barasway Complex conformably to disconformably overlies mafic tuffaceous sediments and basaltic flows of the Calmer Formation near White Point on the east shore of Fortune Bay. Interdigitation of the two units does not occur at this locality; however, outcrops of intercalated mafic tuffs and flows and rhyolite flows along Beacon Hill Brook may reflect the gradational contact of the Barasway Complex and the Calmer Formation. Correlatives of the Calmer Formation to the north of the Garnish River are in fault contact with the Barasway Complex. North of the present study area, the Barasway Formation and its equivalents lie directly on both mafic flows (Calmer Formation correlatives) and red conglomerates (Garnish Formation correlatives); O'Brien and Taylor,(1979). The contact of the Barasway Complex and adjacent sedimentary rocks of the Garnish Formation is not exposed in the area.

The Barasway Complex occupies the same stratigraphic position as the Hare Hills Formation to the west and may contain the eruptive centres for the Hare Hills volcanism. Present data are not sufficient to establish if the Grand Beach Complex can be correlated with the Barasway Complex (see section 4:8:3), but a Carboniferous $^{40}Ar/^{39}Ar$ date from plagioclase separates from the Grand Beach Complex (Stukas, 1978) suggests that such a correlation is not probable.

The Baraswav Complex may be correlative with some of the silicic agglomerates and ash-flow tuffs which Williams (1971) includes in the Mooring Cove Formation of the Long Harbour Group in the northern Fortune Bay.

Rocks of similar lithology as the Barasway Complex have been described from the Clode Sound area of the northwestern Avalon Zone (Hussey, 1979). These rocks have a stratigraphic position similar to the Barasway Complex (i.e. overlying an extensive mafic volcanic unit) and are thus tentatively interpreted as being correlatives (see section 8:3).

Recent mapping in the central Burin Peninsula (O'Brien and Taylor, 1978) has outlined similar rock types overlying Calmer Formation equivalents that extend over 15 km north of the present study area.

4.6 Hare Hills Formation

4.6.1 Definition and Distribution

The name "Hare Hills Tuff" was introduced by O'Brien et al., 1977 to designate a series of densely welded rhyolitic and rhyodacitic tuffaceous rocks which disconformably underlie Eocambrian-Cambrian strata in the western Burin Peninsula between Point May and Grand Bank. Strong et al., 1979 extended the boundaries of this unit to include similar rock types along strike which had previously been mapped as undivided Marystown Group and renamed it the Hare Hills Formation. The nomenclature proposed by Strong et al., 1979 is retained in this thesis.

The Hare Hills Formation conformably overlies mafic flows of the Calmer Formation in the western part of the Burin Peninsula. It is correlated with felsic volcanic rocks of the Barasway Complex which locally display similar contact relationships with the underlying Calmer Formation. However, the lithological variations which occur along strike for approximately 70 kilometres prohibits including all these felsic volcanic rocks within a lithostratigraphic unit of formational status.

The most complete section of the Hare Hills Formation is exposed along the north coast of the Burin Peninsula, between Kelly's Cove and the community of Grand Bank. The Formation attains a minimum thickness of approximately 300 metres at this locality.

4.6.2 Lithology

The base of the Hare Hills Formation in this locality consists of a series of nonwelded felsic crystal-vitric tuffs intercalated with oxidized mafic tuffs, agglomerates and red tuffaceous sediments of the Calmer Formation. The crystal-vitric tuffs are gradationally overlain by gray lithic tuffs and intercalated medium grained felsic volcanic-breccias. A thin horizon of mafic breccias and red volcaniclastic sandstones separates these lithologies from a sequence of medium-grained felsic agglomerates overlain by fine-grained welded plagiophyric crystal tuffs. Faulting at this stratigraphic level repeats the lower, mafic levels of the unit along the coastline northwest of Lewis Hill.

A gap in exposure, along Trimms Beach, separates the lower parts of the Hare Hills Formation from an upper unit of densely welded tuffs and waterlain tuffaceous rocks (Plate 4:12). The easternmost exposures of the upper unit of the Hare Hills Formation consist of a minimum of several tens of metres of red, fine-grained-plagiophyric crystal tuffs. These rocks pass upwards into approximately 15 metres of medium-to coarse-grained welded and strongly flattened lithic tuffs which are in turn overlain by 6 metres of a similar lithology displaying more moderate degrees of flattening. This welded unit passes conformably upwards into approximately 10 metres of green, unwelded, highly epidotized lithic-lapilli tuffs which are overlain by a red lithic tuff, locally vesiculated, which grades upwards into approximately eight metres of red and green, fine-to medium-grained waterworked epiclastic and clastic sedimentary rocks (Plate 4:13). The reworked tuffaceous rocks pass upwards into a three-metre thickness of red, medium-grained, felsic tuffs which fines upwards into laminated crystal tuffs (Plate 4:14) which are locally intercalated with laminated red and green volcaniclastic sediments. These rocks are overlain by approximately twenty metres of unwelded, green and yellow, epidotized lithic tuffs (Plate 4:15) which are in fault contact with red densely-welded crystal and lithic ash-and lapilli tuffs. These welded tuffaceous rocks comprise the most characteristic lithology of the Hare Hills Formation. A minimum of 300 metres of red to maroon-colored densely welded and locally flattened rhyodacitic and rhyolitic crystal, lithic and vitric tuffs are exposed along the coast immediately east of Bouilli Point.

Inland exposures of the Hare Hills Formation consist mainly of a variety of reddish-brown lithic, lapilli and ash-flow tuffs with densely welded vitric groundmasses. These lithologies crop out on the Eastern

Plate 4:13:

Red and green, waterworked epiclastic rocks, Hare Hills Formation, near Bouilli Point.

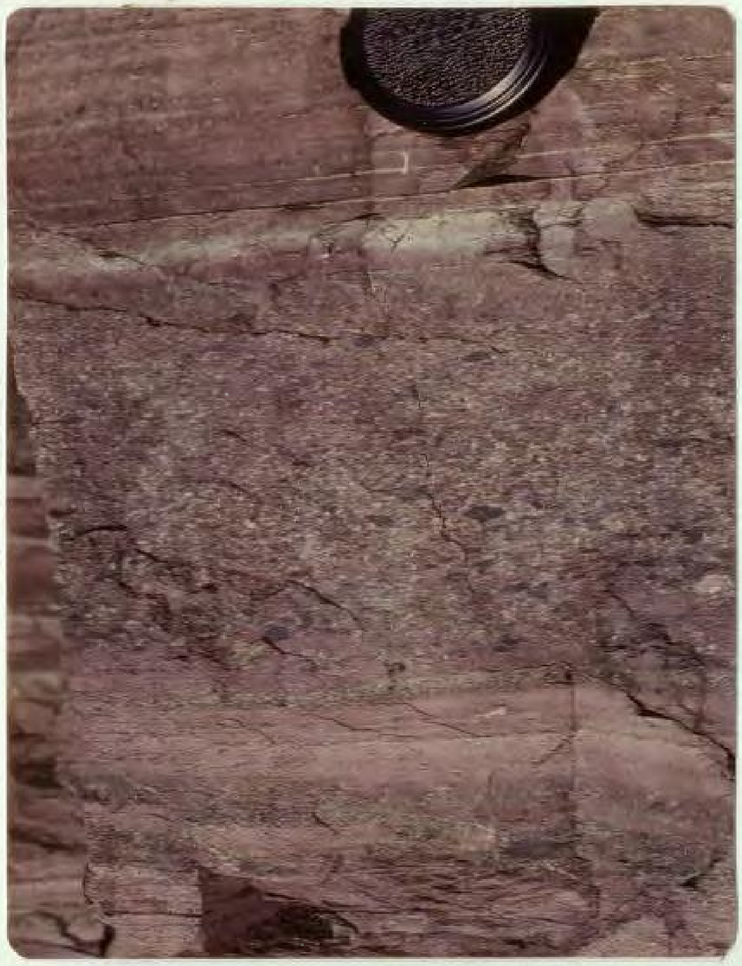


Plate 4:14

Waterlain, laminated tuffaceous siltstones, Hare Hills Formation, near Bouilli Point.

and Western Hare Hills, but significant lithological variations are rarely mappable on a regional scale. Fine grained pink rhyolite flows, red vitric tuffs and densely welded, unflattened porphyritic vitric and crystal tuffs are common on Fortune Tolt and Fugle Hill. The isolated hills north of the Eastern Hare Hills are underlain by green flinty rhyolite flows and black densely welded porphyritic vitric tuffs.

4.6.3 Contact Relationships and Correlation

The Hare Hills Formation stratigraphically overlies mafic volcanic rocks of the Calmer Formation east of Point May. The intercalation of the mafic and felsic rocks of these units near L'Anse au Loup suggests that its contact with the underlying Calmer Formation may be gradational in this area. Rocks of similar lithology to the Hare Hills Formation overlie the Calmer Formation in the Piercey Hill Anticline on the southern coast of the Peninsula east of Point May.

The contact of the Hare Hills Formation with the Eocambrian-Cambrian sequence in the western part of the peninsula has been interpreted as a disconformity (O'Brien et al., 1977; Strong et al., 1979). Possible correlatives of the Hare Hills Tuff on Allan's Island are disconformably overlain by Eocambrian red sandstones, although this contact has also been slightly modified by minor faulting.

The Hare Hills Tuff occupies a similar stratigraphic position as the Barasway Complex - i.e. the stratigraphic top of the Marystown Group, conformably overlying the Calmer Formation.

The Hare Hills Formation is interpreted to be correlative with parts of the Mooring Cove and Doughball Point Formations of the Long Harbour Group in the Fortune Bay area (Williams, 1971; O'Driscoll, 1977) and parts of the Southwest River Formation of the Love Cove Group in the Clode Sound region of Trinity Bay (Hussey, 1979).

4.7 Mount Saint Anne Formation

4.7.1 Definition and Distribution

The name "Mount Saint Anne Formation" was originally proposed by Strong et al., 1975 to designate the north- to northeast-striking sequence of rhyolitic ash flow tuffs and spherulitic rhyolite flows which crop out in the north-central and east-central parts of the Marystown map-area. This original usage is expanded to include lithologically similar rocks which crop out along the west shore of Lawn Bay. The Mount Saint Anne Formation is thrust over the easterly adjacent Cambrian age Inlet Group. Its western contact with volcanic rocks of the Taylor's Bay Formation is faulted. The Mount Saint Anne Formation appears to occupy a stratigraphic position similar to the Hare Hills Formation and Barasway Complex, but has not been included within these stratigraphic units for reasons discussed below (section 4.7.3).

4.7.2 Lithology

Lack of facing criteria, combined with later faulting and folding causes difficulty in establishing the internal stratigraphy of the

Plate 4:15:

Volcaniclastic sediments overlain by unwelded, epidotized lithic tuffs, Hare Hills Formation, Grand Bank.

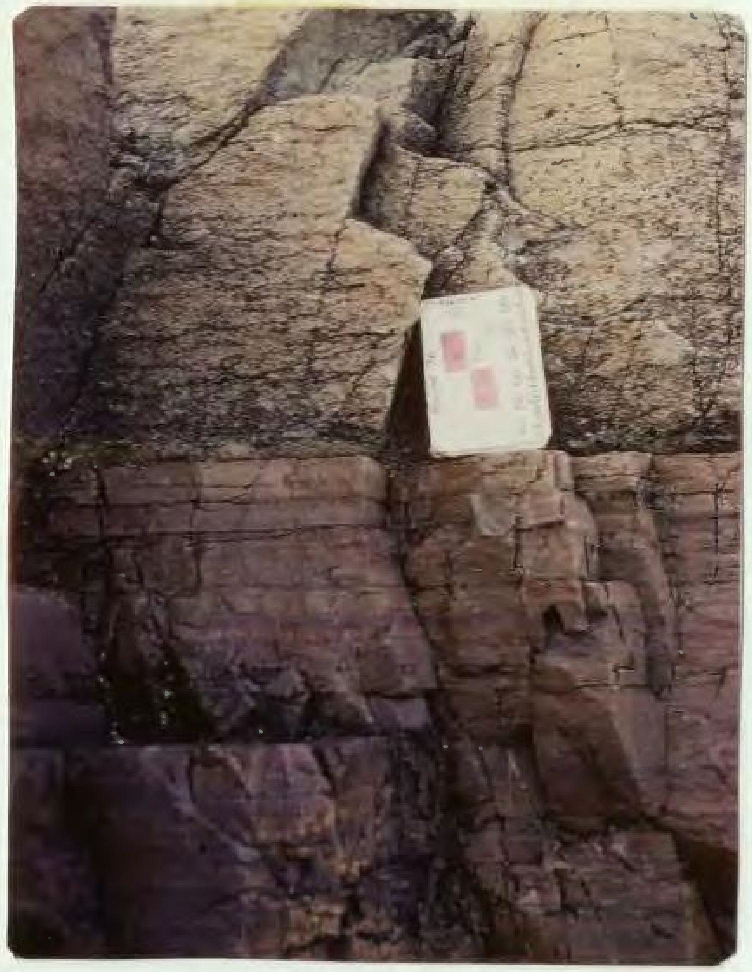


Plate 4:16 Flow-banded rhyolite of the Mount Saint Anne Formation.

Mount Saint Anne Formation. The eastern and northern exposures of the Formation form a moderate-to steep-dipping sequence of flow banded rhyolites and red to maroon-colored welded and unwelded lithic tuffs. The rhyolite flows display thin (≤ 10 millimeter) flowage bands which are in places highly contorted. Locally the individual flows are autobrecciated (Plate 4:17). The flows often show megascopic devitrification features, the most common of which are spherules. The spherulitic rhyolites locally consist of almost 100% spherules up to 2 centimeters in diameter (Plate 4:18). The preponderance of rhyolitic flows within the Mount Saint Anne Formation and its correlatives to the northeast (Taylor, 1976) may indicate proximity to a volcanic source area. The occurrence of coarse-grained felsic agglomerates and volcanic breccias in equivalents of the Mount Saint Anne Formation near Marystown Tolt (Taylor, 1976) supports this possibility.

The westernmost exposures of the Mount Saint Anne Formation consist of welded to unwelded red to purple rhyolitic and rhyodacitic lithic and crystal-lithic tuffs (Plate 4:19). The rocks are lithologically similar to the ash-flow tuffs of the Hare Hills Formation and the Barasway and Grand Beach Complexes.

Sheared, fine-grained volcanic breccias and schistose, sericitized rhyolitic tuffs are most common in the westernmost exposures of the Formation but occur sporadically throughout it. At several localities southwest of Salmonier Hill, these rock types coincide with topographic linears, possibly indicating that the schistose tuffs resulted from shearing associated with faulting.

Plate 4:17:

Autobrecciated rhyolite of the Mount Saint Anne Formation.

Plate 4:18 Spherulitic rhyolite of the Mount Saint Anne Formation, east of Rocky Pond.

The southwestern exposures of the Mount Saint Anne Formation consist of a lowermost unit of thixotropically deformed tuffaceous sediments which conformably overlie basaltic rocks in a thin fault wedge near Lords Cove (Plates 4:20 and 4:21). These volcaniclastic sediments are interbedded with red, locally laminated lithic tuffs which pass upwards into red, welded and unwelded lithic and crystal, ash and lapilli tuffs. The latter rock types are lithologically similar to the tuffaceous rocks which are interbedded with possible Eocambrian sediments adjacent to the Pump Cove Thrust Fault.

4.7.3 Contact Relationships and Correlations

In the study area the contact of the Mount Saint Anne Formation with the adjacent Eocambrian-Cambrian rocks of the Inlet Group is marked by the Lewins Cove Thrust Fault. However, Taylor (1976) stated that adjacent to the Lewins Cove Thrust Fault near Little Bay, felsic volcanic rocks of the Mount Saint Anne Formation are conformably overlain by Eocambrian sedimentary rocks. Rhyolitic lithic tuffs of the Mount Saint Anne Formation are intercalated with red, micaceous sedimentary rocks of possible Eocambrian age immediately north of the Pump Cove Thrust Fault. At this locality, the interbedded sediments and volcanics are thrust over Eocambrian red and grey sandstones and quartzites. The nature of the upper contacts of the Mount Lucy Anne Formation at these two localities suggests that the Formation occupies the stratigraphic top of the Marystown Group in the eastern Burin Peninsula.

Plate 4:19 Yellow rhyolitic, unwelded lithic tuff, Mount Saint Anne Formation, near Roundabout.

Plate 4:20 Soft sediment deformation features in waterlain tuffs of Mount Saint Anne Formation, near Lord's Cove.

The original nature of the contact of the Mount Saint Anne Formation with the westerly adjacent Taylor's Bay Formation has been obscured by lack of exposure and later faulting. The nature of the movement along the fault which separates these Formations is unknown, but inferred stratigraphic relationships would indicate a component of reverse movement.

At Lords Cove, on the south coast of the peninsula, a narrow fault wedge of basaltic rocks, equivalents of the Calmer Formation are conformably overlain by tuffaceous sediments of the Mount Saint Anne Formation.

The intrusive contact of the Anchor Drogue Pluton (Strong et al., 1975) and the Mount Saint Anne Formation is exposed along the southern shore of Anchor Drogue Pond. Small ($\leq$ 100 m^2) roof pendants of rhyolitic volcanic rocks of the Formation are common within the Anchor Drogue Pluton.

Rhyolite flows and felsic lithic tuffs of the Mount Saint Anne Formation are hornfelsed adjacent to the St. Lawrence Granite, near Rocky Pond, Saint Anne Mount and Lawn Lookout.

The stratigraphic position of the Mount Saint Anne Formation suggests that it is correlative with other lithostratigraphic units which directly underlie Eocambrian-Cambrian strata in the western Burin Peninsula (e.g. Hare Hills Formation). This correlation is also supported by the lithologic similarities outlined above. Nevertheless, because of the wide geographic separation of these units combined with

Plate 4:21:

Tuffaceous sediments of the Mount Saint Anne Formation overlying Calmer Formation basalts at Lord's Cove.

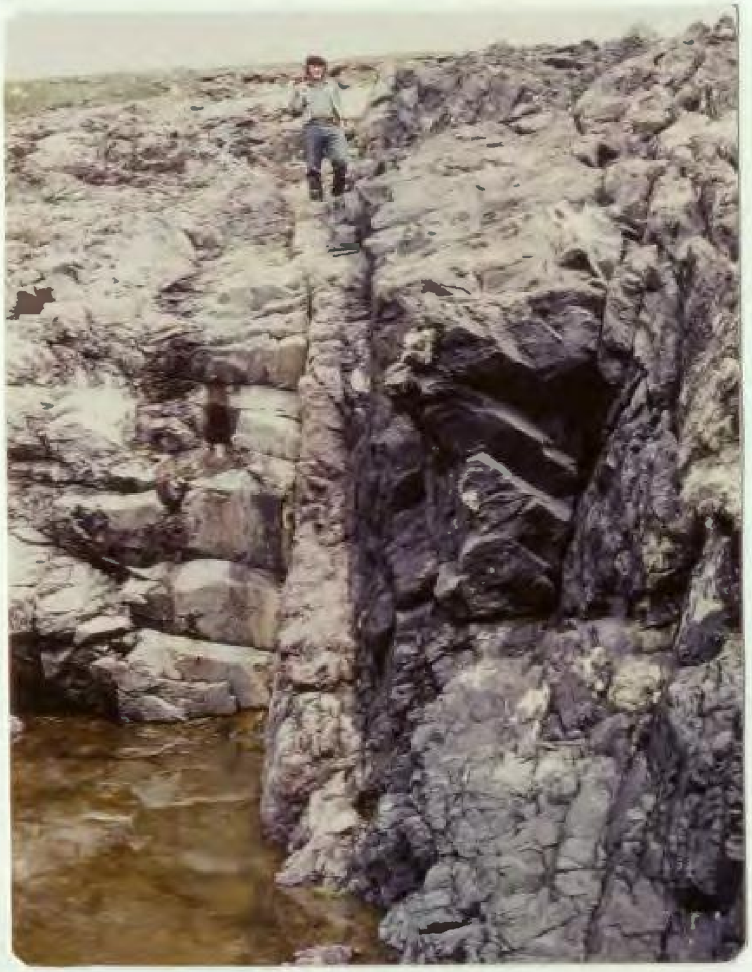


Plate 4:22 Volcanic breccia of the Grand Beach Complex overlying Calmer Formation basalts near Famine Back Cove.

some lithological variation along strike, separate nomenclature has been established in each case.

4.8 Grand Beach Complex

4.8.1 Definition and Distribution

The name "Grand Beach Complex" was introduced by O'Brien et al., 1977 to designate the sequence of felsic volcanic and volcaniclastic rocks with associated comagmatic porphyries which overlie equivalents of the Calmer Formation in the north-central part of the southern Burin Peninsula. The easternmost exposures of the Complex had previously been divided into an intrusive phase, the Grand Beach Porphyry, and an extrusive phase, the Clancey's Pond Complex (Strong et al., 1975). Subsequent mapping showed that such a division was not valid because the "porphyry" phase is clearly extrusive, rather than intrusive, in origin and in many places was unseparable from parts of the Clancey's Pond Complex.

The true thickness of the Complex could not be ascertained since its stratigraphic top is not exposed, however a minimum thickness would be in the order of 125 metres. Recent exploratory diamond drilling indicates that in its central parts, the Grand Beach Complex attains a maximum thickness of 197 metres (personal communication, British Petroleum Minerals staff).

4.8.2 Lithology

The base of the Grand Beach Complex is exposed at Famine Brook and Famine Back Cove. At the former locality a 5 metre thick, flat-lying epiclastic unit overlies vesicular basalts of the Calmer Formation. The unit consists mainly of red sandstones and interbedded red sedimentary breccia with minor conglomerate. Fragments in the breccia are as large as 50 centimetres but the average clast size is between 4 and 8 metres. The breccias contain fragments of vesicular basalt, red clastic sediments and minor rhyolite tuffs. The basal unit is overlain by approximately 25 metres of immature volcaniclastic conglomerates and poorly-sorted volcaniclastic breccias and associated agglomerates containing a variety of felsic and mafic blocks ranging in size from 1 to 30 centimetres. These epiclastic rocks are interpreted to represent, in part, mudflow or landslide deposits of laharic origin. In the northern parts of the Complex, these breccias are intercalated with welded tuffs of an associated ash flow sheet.

Near Famine Back Cove, the base of the Grand Beach Complex is represented by approximately 3 metres of agglomerate and volcaniclastic conglomerate which directly overlie massive and vesicular basalts of the Calmer Formation (Plate 4:22). The agglomerates contain blocks and bombs of vesicular basalt and lesser amounts of rhyolitic tuffaceous rocks in an epidotized tuffaceous matrix. The lower agglomerates are overlain by approximately 1 metre of porphyritic rhyolite tuffs and welded ash-flow tuffs which grade upwards into a coarse mafic breccia. Approximately 10 metres of felsic ash-flow tuffs overlie

Plate 4:23:

Ash-flow tuffs conformably overlying mafic breccias, Grand Beach Complex, west of Grouse Point.

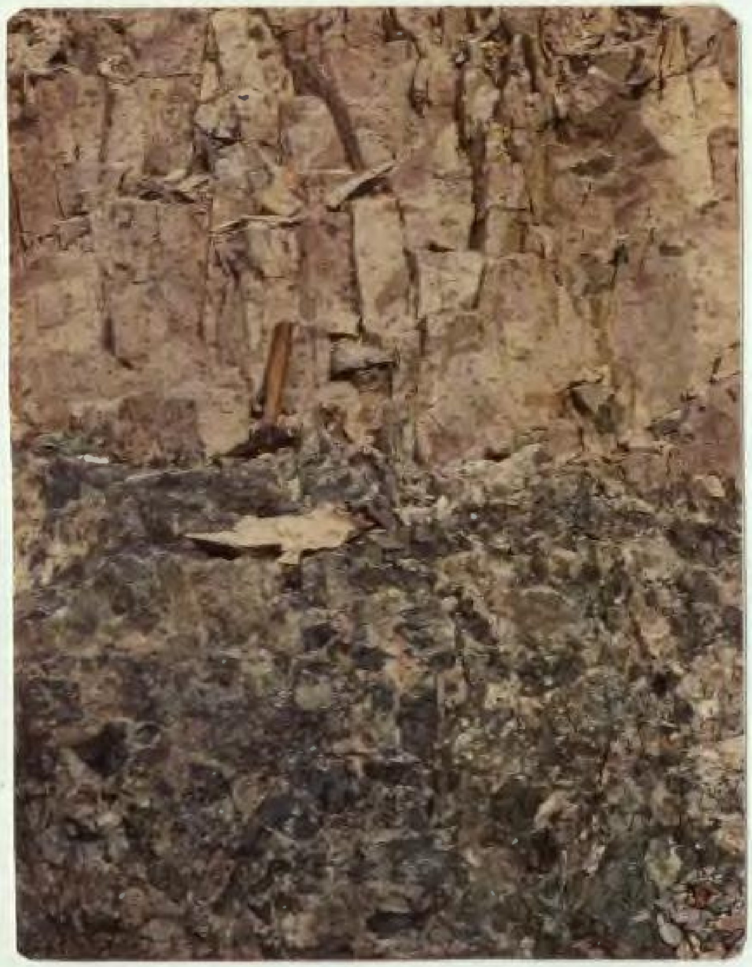


Plate 4:24 Welded tuffs of the Grand Beach Complex, west of Grouse Point.

these mafic breccias (Plate 4:23). The ash-flow can be divided into a lower unit rich in flattened pumice fragments and an upper unit of lithic tuffs showing moderate degrees of welding and little or no flattening (Plates 4:24 and 4:25). The ash-flow unit grades upwards into a series of devitrified rhyolites, massive crystal tuffs, crystal lithic tuffs and welded and unwelded lithic tuffs. A two metre thick unit of mafic agglomerate (Plate 4:26) separates these lithologies from an unknown thickness of undivided ash-flow tuffs which grade into massive rhyolite porphyry. Coarse porphyritic phases of the rhyolite locally show an intrusive relationship with the ash-flows and the rhyolite porphyry. However, most of the porphyry contains isolated flattened lithic fragments suggesting that it is dominantly extrusive in origin.

Rapid facies variations within the Grand Beach Complex, suggested by variations along strike in the basal parts of the sequence have been confirmed by recent diamond drilling throughout the Complex (personal communication, British Petroleum Minerals staff).

4.8.3 Contact Relationships and Correlation

The Grand Beach Complex directly overlies mafic volcanic rocks of the Calmer Formation. Basal relationships exposed near Famine Back Cove suggest no angular discordance at the contact with the underlying basaltic rocks. It is not possible to establish whether the contact is disconformable or conformable.

Plate 4:25:

Grey, welded tuffs overlying yellow lithic tuffs of the Grand Beach Complex.

Plate 4:26 Agglomerate containing mafic blocks in a felsic tuffaceous matrix, Grand Beach Complex at Grouse Point.

Similarly, in the Famine Brook section, no angular discordance between the Grand Beach Complex and the Calmer Formation can be recognized. However, the presence of breccias containing fragments of underlying vesicular basalt, can be interpreted as representing an erosional hiatus between the deposition of these two units. An alternate hypothesis involves the incorporation of the mafic blocks in laharic flows associated with the later Grand Beach volcanism. Such relationships could be observed in a conformable sequence, without incorporating any extensive hiatus in the volcanic activity.

An $^{40}Ar/^{39}Ar$ age date from a plagioclase concentrate from the Grand Beach Complex of 326 ± 5 Ma. was obtained by Stukas (1978). This Carboniferous age would necessitate a 300 million year break in the stratigraphic succession. However, Stukas (1978) interprets this date as being erroneous, and the result of complete resetting of the plagioclase by a strong thermal event (i.e. the intrusion of the nearby Carboniferous St. Lawrence Granite).

It is not possible at present, with the information available, to state for certain whether the Grand Beach Complex is Carboniferous or Late Precambrian in age. If the latter were the case, then the Grand Beach Complex would represent the uppermost unit of the Marystown Group, correlative of the Barasway Complex and the Hare Hills and Mount Saint Anne Formation. This suggestion is supported by the striking lithological similarities that these various units display, but it is not in accordance with some of the geochemical data (see Chapter 7).

4.9 Lithology and Depositional Environments: A Summary

Subaerial volcanic activity on the southern Burin Peninsula can be divided into three lithologically and stratigraphically distinctive periods represented by: (1) the Taylor's Bay Formation, (2) the Garnish and Calmer Formations, and (3) the Hare Hills and Mount Lucy Anne Formations and the Barasway and Grand Beach Complexes.

The subaerial, dominantly silicic volcanic deposits of the Taylor's Bay Formation represent the earliest period of volcanism in the Marystown Group. The lithology of this Formation is diverse and includes tuffaceous volcanic rocks of felsic and lesser amounts of mafic and intermediate composition. Mafic flows and tuffs are also present, but in lesser proportions than the felsic rocks. The deformation of these rocks causes difficulty in distinguishing between pyroclastic and epiclastic rocks, however, cross-stratification in some of the tuffs suggests that part of the sequence was deposited (or reworked) in a subaqeous environment. Many of the tuffaceous deposits of the Taylor's Bay Formation are characteristically nonwelded and in places display poorly developed graded bedding, suggesting that they were the result of ash-fall rather than ash-flow deposition. However, the effect of the regional deformation has masked many of the megascopic or microscopic features which could otherwise be utilized in making this distinction. Welded tuffaceous deposits occur sporadically throughout the Formation, but constitute only a minor proportion of it. Poor exposure throughout most of the area underlain by the Taylor's Bay Formation makes it difficult to establish if these deposits are related to the unwelded tuffaceous rocks; i.e. forming the lower welded portion of an ash-flow. The difficulties encountered in recognizing texturally distinct zones of individual ash flows within the Taylor's Bay Formation may be in part due to poor exposure and deformation. However, if volcanism at this time resulted in the deposition of compound flows rather than single flows, it is conceivable that a variety of seemingly unrelated, texturally unique deposits could be produced. Such occurrences are common in many of the recent, large subaerial volcanic fields (see Section 3.2.1).

Much of the Taylor's Bay Formation consists of fine-to coarse-grained tuffs and tuff breccias. Coarser-grained pyroclastic and epiclastic deposits, common in the upper parts of the Marystown Group, are notably rare at this stratigraphic level. The dominantly fine-grained nature of these rocks may indicate that they represent distal facies of a much larger volcanic field. The lack of coarse-grained deposits such as vent agglomerates, monolithologic breccias or co-ignimbrite lag deposits within the sequence supports this possibility.

In the central and northern parts of the Burin Peninsula, equivalents of the Taylor's Bay Formation are interbedded with and conformably overlain by epiclastic volcanic and sedimentary rocks (see Section 4.3.3). The upper contacts of the Taylor's Bay Formation are poorly exposed in the southern Burin Peninsula, but are locally marked by a sequence of fluviatile sediments, indicating a cessation of volcanism and erosion of the volcanic paleotopography. This period of sedimentation is represented by the clastic sedimentary rocks of the Garnish

Formation. The lithology of the Garnish Formation is characterized by oxidized red conglomerates and coarse-grained sandstones which commonly display large scale cross-stratification features. These rocks fine upwards into thinly-bedded red siltstone and mudstone, locally containing dessication features. These sediments in the upper parts of the Garnish Formation are, in places, interbedded with oxidized basaltic flows and tuffs. The above features are indicative of a terrestrial - fluviatile depositional environment.

Fluviatile systems are typified by fining-upwards sequences of which are characterized by thinly-bedded deposits in their stratigraphically highest parts (Allan, 1970; Walker, 1976). The fining-upwards nature of the Garnish Formation may be the result of the gradual maturing of a fluviatile system accompanied by a decrease in the energy within it. The coarse-grained sediments in the lower parts of the Garnish Formation may be in part the result of erosion of fault scarps and steep-sloped volcanic highlands. Continued erosion would result in the retreat of the source area, producing a lowering of the river gradient and gradual energy loss of the system, which may have resulted in the formation of overbank deposits in a braided or meandering stream environment.

The latest stages of sedimentation of the Garnish Formation were contemporaneous with the initiation of subaerial basaltic volcanism. This period of basaltic volcanic activity is represented by the Calmer Formation and its equivalents throughout the western Avalon Zone (see Section 4.4.3). On the southern Burin Peninsula, the Calmer Formation consists of basaltic flows and subordinate mafic pyroclastic rocks. The presence of ropy flow surfaces, oxidized flow tops, pipe vesicles, coarse, coalescing amygdules and the intercalations of red sedimentary rocks throughout the Calmer Formation, combined with the absence of pillowed flows indicate that most of these rocks were deposited in a dominantly subaerial environment. The localized occurrence of graded and cross-stratified mafic tuffaceous sediments suggests that some of these rocks, however, were deposited or reworked in subaqueous conditions.

The basaltic rocks of the Calmer Formation are lithologically and petrologically uniform in nature, a common feature in many plateau basalt fields (see Section 3.2.3). Fossil fissure vents within the Calmer Formation may have been concealed by the resulting volcanism, however the area of coarse mafic breccias and plagiophyric sills in the Tilt Hills area may represent the site of an eruptive centre. The duration of this period of mafic volcanism is unknown, but the limited thickness of the Calmer Formation may indicate that it represents only a small part of the tectonic evolution of the area.

Contact relationships amongst the Calmer Formation and the overlying felsic volcanic sequences of the upper Marystown Group suggest that no extensive erosional period preceded the renewal of felsic volcanism in the area. These late felsic volcanic rocks may have been widespread throughout the southern Burin Peninsula but are presently exposed only on the eastern and western flanks of the "Burin Anticlinorium" (Williams, 1979 a). This late period of volcanism resulted in the deposition of approximately 300 metres of silicic, dominantly subaerial pyroclastic and epiclastic volcanic rocks.

The stratigraphic units which overlie the Calmer Formation are characterized by ash-flow tuffs, agglomerates, volcanic and epiclastic breccias, rhyolite flows and fine grained epiclastic rocks. Ash-flow tuffs constitute a significant proportion of all these units. The ash flows are commonly moderately to densely welded and in places show non-welded, partially welded and densely welded zones. The pumice-rich ash flow deposits of the Barasway Complex are in places underlain by pyroclastic flow deposits. Coarse volcanic breccias, texturally similar to co-ignimbrite lag deposits (Wright and Walker, 1977) are spatially associated with the ash-flows in the central parts of the Barasway Complex. Coarse grained lahars and agglomerates are common in the Barasway Complex and to a lesser extent in the Grand Beach Complex. The presence of these deposits has been interpreted by some authors (see Section 3.2.2) to reflect proximity to an eruptive centre, and it appears that the lithology of the Barasway Complex is consistent with such an environment.

The lahars and polylithologic breccias of the Barasway Complex show marked facies variations along strike. Near Garnish, the breccias are chaotic, with no evidence of sorting preserved in these rocks. Over a distance of several hundred metres north and south of this area, the breccias show a limited degree of sorting and thin, discontinuous lenses of tuffaceous epiclastic rocks become intercalated with the lahars. These deposits become increasingly well sorted towards the north. Epiclastic rocks are more restricted in the area between Garnish and Grand Beach where massive rhyolite flows are spatially associated with heterolithologic and subordinate monolithologic breccias.

Coarse-grained epiclastic and pyroclastic deposits are not as extensive elsewhere in the upper volcanic cycle of the Marystown Group. Devitrified rhyolite flows are common in all the upper volcanics but are most extensive in the northern parts of the Mount Saint Anne Formation and parts of the Grand Beach Complex (personal communication, British Petroleum Minerals staff). Air-fall tuffs are recognizable only in the Grand Beach and Barasway Complex.

Subaqueous pyroclastic and epiclastic rocks are not widespread, and have been recognized mainly in the Hare Hills Formation and southern parts of the Mount Saint Anne Formation. The cross-stratification and soft sediment deformation features reflect the subaqueous deposition of these rocks. The vesiculated tuffs of the Hare Hills Formation are also consistent with such a depositional environment.

The areal distribution of facies within these lithostratigraphic units is generally consistent with a facies model in which a major volcanic centre is located within or to the northwest of the present exposure of the Barasway Complex.

5. PETROGRAPHY

5.1 Early Volcanism: Taylor's Bay Formation

5.1.1 Mafic Flows and Volcaniclastic Rocks

The basaltic flows of the Taylor's Bay Formation are typically fine grained, containing little olivine and substantial amounts of highly altered interstitial glass and primary and secondary magnetite. Although the rocks rarely appear porphyritic in the field, microphenocrysts of plagioclase are common in many of the very fine grained rocks which may possibly represent chilled flow bases. The massive portions of the flows contain groundmass plagioclases up to 1 mm in diameter, which may mask microporphyritic textures. Highly altered pyroxene is present in subordinate amounts in the flows.

Plagioclase is the most common mineral in these basalts, occurring as sparse albite microphenocrysts up to 2 mm in length and locally displaying glomeroporphyritic textures. Zoning is present in both the phenocryst and groundmass plagioclases. Intense sericitization and epidotization of the plagioclases is widespread. In the groundmass, albite forms small ($\leq$ 1 mm) subhedral laths in an intergranular to intersertal matrix of highly altered clinopyroxene, magnetite and hematitized basaltic glass (P. 1).*

In places, the mafic flows contain up to 10% highly altered clinopyroxene. Low 2V measurements (20-25°) on one relatively fresh pyroxene suggests a pigeonitic composition. Small (~ 1 mm) euhedral aggregates and crystals of chlorite and serpentine with relict polygonal outline may represent completely altered olivine, occurring in an intergranular matrix with epidotized and sericitized plagioclase. No

* P = photomicrograph

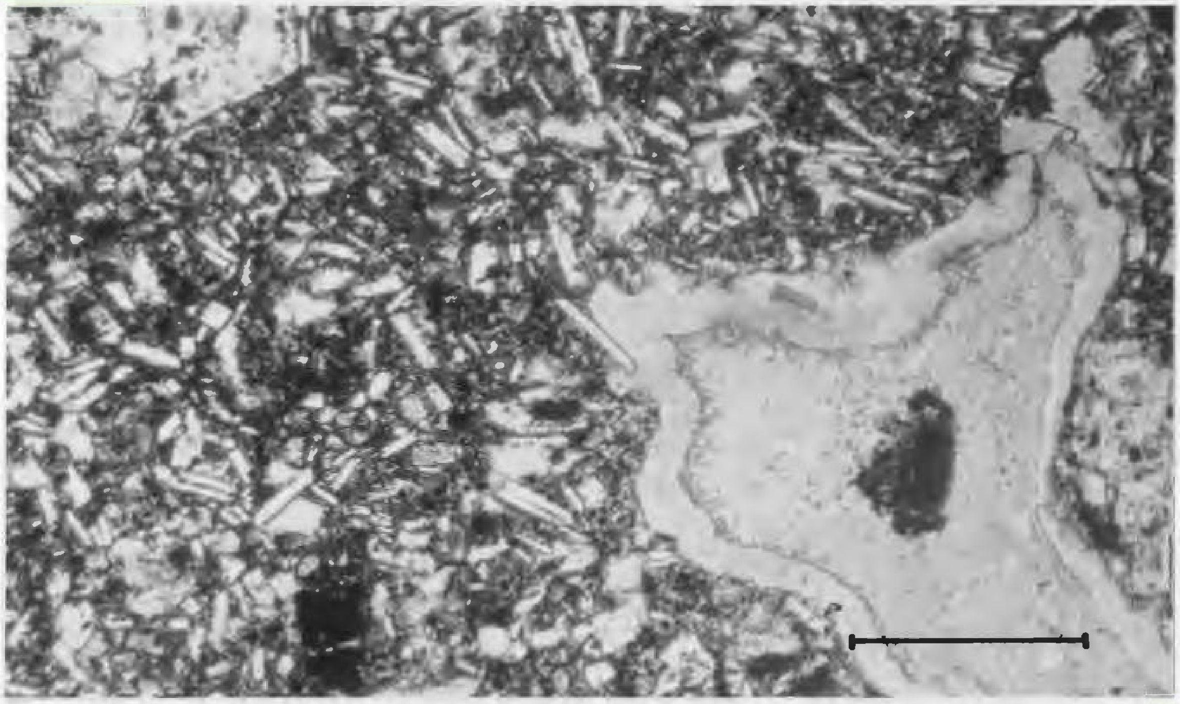
Note added in proof: Mineral identifications were done by examination of thin sections on a flat stage only.

unaltered olivine was identified in these rocks. Subhedral to anhedral magnetite porphyroblasts, ranging in diameter from 1 to 5 mm, are developed in mafic flows and tuffs adjacent to the St. Lawrence Granite.

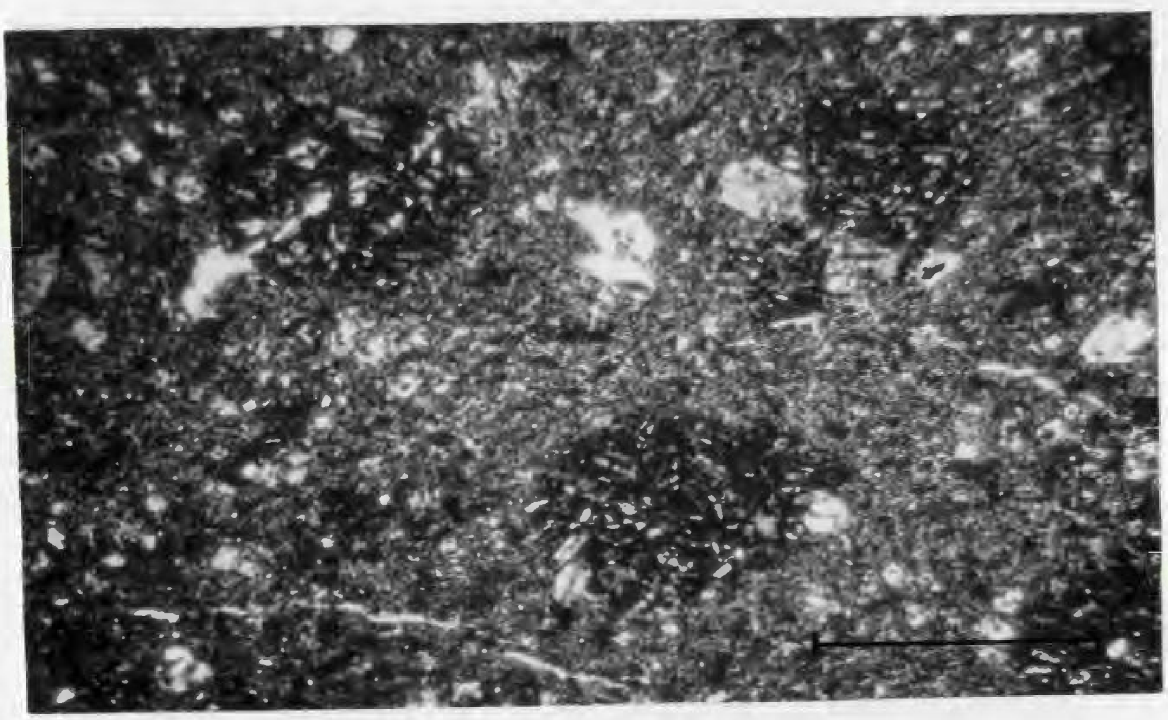
The mafic flows are only rarely amygdaloidal, with chlorite occurring in small (1-10 mm) amygdules which rarely comprise more than 1% of the rock. Chlorite is an important metamorphic phase in these rocks and in places it defines a schistosity in the more deformed tuffs and flows. Epidote, magnetite and subordinate sphene represent the other main metamorphic phases in these rocks. Narrow (1 mm) veinlets of quartz and prehnite are present locally.

The mineralogy of the mafic tuffaceous rocks is, for the most part, similar to the mafic flows described above; the only exception being the more widespread alteration which is characteristic of the volcaniclastic rocks. The most common lithic fragments in the tuffs are aphyric to very fine-grained plagiophyric basalts which occur as angular to rounded lapilli and ash sized fragments which range from <1 mm to 5 mm in diameter (P. 2). Locally the tuffs are crystal-rich and contain angular to subrounded crystals and crystal fragments of clinopyroxene and magnetite which together constitute up to 40% of the rocks. It is difficult to distinguish between primary and metamorphic fine grained magnetite in many of these rocks. Fine lapilli of plagiophyric basalt, hematitized mafic scoria and dark brown basaltic glass constitute up to 50% of these tuffaceous rocks.

Both the mafic flows and tuffaceous rocks have been locally metamorphosed to chlorite schist. Chlorite defines the main foliation of these rocks. The other recognizable metamorphic phases are epidote and



Photomicrograph 1: Vesicular basalt of the Taylor's Bay Formation. Intersertal to intergranular matrix of albite, untwinned plagioclase, magnetite, altered basaltic glass with minor clinopyroxene. Note chlorite and epidote filling of vesicle. (Plane polarized light; bar scale = .6 mm).



Photomicrograph 2: Mafic lithic tuff of the Taylor's Bay Formation. (Crossed nicols , bar scale = .75 mm).

magnetite with subordinate amounts of sericite, calcite, sphene and quartz.

5.1.2 Silicic pyroclastic and epiclastic rocks

The unwelded tuffaceous rocks of the Taylor's Bay Formation are dominantly lithic- and lithic-crystal-lapilli tuffs and fine grained tuff breccias of rhyolitic and rhyodacitic to dacitic composition (P. 3). The lithic tuffs consist primarily of subangular to rounded lapilli of sericitized felsite displaying well developed felsitic textures, micro-spherulitic rhyolite and orthoclase-phyric rhyolite. Lapilli of mafic composition constitute only a minor proportion of these rocks. In places, however, fragments of plagioclase-pyroxene porphyritic basalts constitute up to 25% of the rock. Intense alteration of the lapilli prevents determination of the composition of the pyroxene, however, one specimen displayed a weak pink-green pleochroism, suggesting the presence of minor orthopyroxene in some of the tuffs. Carbonate-quartz-sericite alteration, commonly in the form of network veins, is widespread in the unwelded tuffaceous rocks.

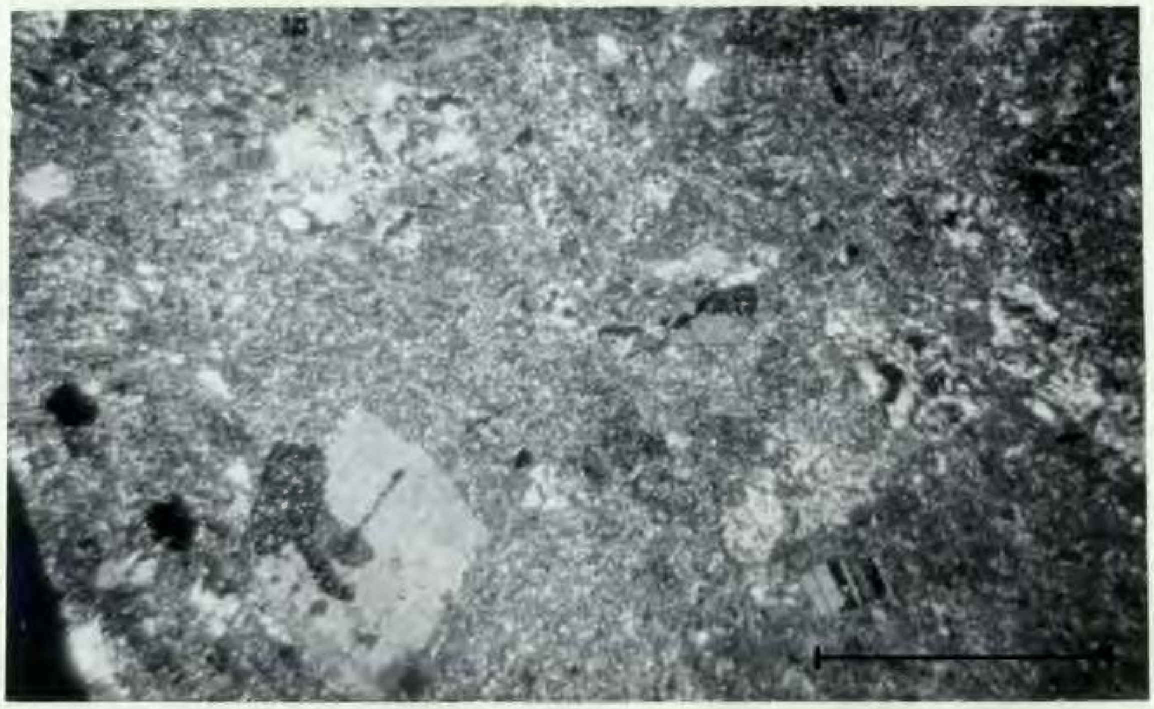
Twinned orthoclase and euhedral to embayed crystals and fragments of quartz are common components of the crystal-lithic tuffs of the Taylor's Bay Formation. Epidotized plagioclase (An_{10-20}) crystals are present but rarely constitute more than 20% of the crystal component of the rock.

The intermediate tuffs typically contain rounded to subrounded lapilli (up to 10 mm in diameter) of dacite with subordinate amounts of rounded and broken quartz and albite crystals in a locally devitrified and highly sericitized quartzo-feldspathic matrix, in places containing very minor biotite.

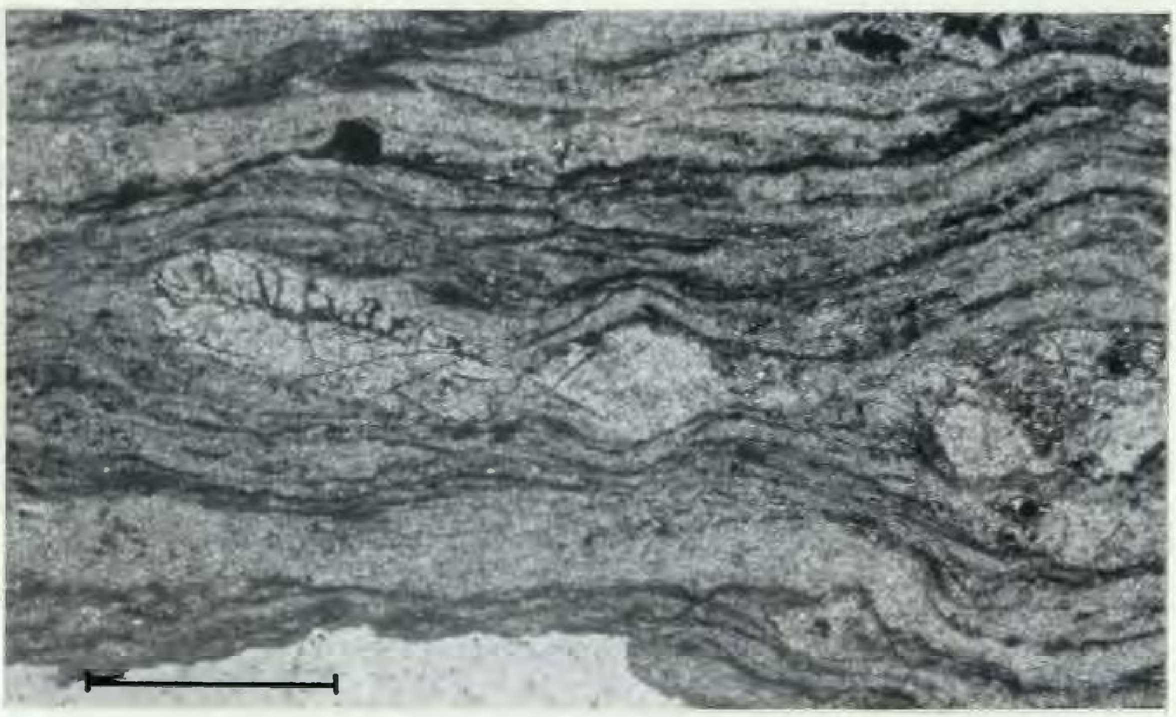
Apart from characteristic differences in grain size, there are no significant petrographic differences between the tuff breccias and volcanic breccias and the finer grained tuffaceous rocks of the Taylor's Bay Formation.

Both the felsic and intermediate volcaniclastic rocks of the Taylor's Bay Formation have been metamorphosed to sericite schist in many places. These rocks are typified by the growth of secondary sericite, which defines the main foliation in the rocks, and by varying degrees of recrystallization of the quartzo-feldspathic groundmass. Feldspar and quartz are present as strained, embayed and broken crystals up to 3 mm in diameter which form augen within fine grained platy and minutely crystalline to submicroscopic sericite and opaques (P. 4). Chlorite and very minor brown biotite are locally intergrown with sericite, defining the main foliation in the rock. The matrix of the sericite schists typically consists of highly sericitized and epidotized plagioclase (locally up to 30% of the rock), hematitized and saussuritized potash feldspars (20-40%), recrystallized quartz (10-20%) and fine sericitic aggregates. Apatite, epidote and unidentified opaque minerals occur in places as fine grained (≤ 0.5 mm) euhedral to subhedral crystals in the groundmass. Locally the matrix of the sericite schists has been granoblastically recrystallized.

Tuffaceous sedimentary and epiclastic volcanic rocks of the Taylor's Bay Formation are characterized by widespread calcite and sericite alteration and usually contain subrounded to subangular pebble and sand



Photomicrograph 3: Unwelded lithic/crystal tuff of the Taylor's Bay Formation. (Crossed nicols , bar scale = .75 mm).



Photomicrograph 4: Sericite schist in the Taylor's Bay Formation along a reverse fault near Lawn. Note feldspar crystals are broken along shear planes which form a 45° angle with main sericitic schistosity. (Plane polarized light; bar scale = .6 mm).

sized fragments of unwelded felsic pyroclastic and mafic rocks which are petrographically similar to the mafic flows and volcaniclastic rocks described above. Massive and flow-banded rhyolitic detritus constitutes a minor proportion of these rocks.

5.1.3 Rhyolite Flows

Flow-banded rhyolites of the Taylor's Bay Formation are characterized by continuous individual flowage bands which range in thickness from ≤ 0.1 mm to approximately 5 mm. The coarser bands display microspherulitic and paecilitic textures (cf. Haworth, 1888) (P. 5). In areas where devitrification features are not widespread, fine grained crystalline aggregates of quartz and hematitized potash feldspar define the individual flowage bands which both abut and enclose augen of quartz, albite and orthoclase subhedra. Thin lenses of rhyolite displaying discontinuous banding are locally interlayered with the flow banded rhyolite. Megascopically, these features resemble strongly flattened pumice fragments, although no microscopic evidence of primary welding or flattening was recognized.

Massive rhyolites are rare in the Taylor's Bay Formation, and when present, are often devitrified. The spherulitic rhyolites generally display a finely comminuted siliceous matrix. Quartz, albite and orthoclase are recognizable in samples where the matrix is coarser grained. Fine grained aggregates of sericite and carbonate are the main groundmass alteration phases. Spherulites are not widely developed in these rocks and do not show a wide variation in size, with individual spherulites rarely exceeding 0.5 cm in diameter. The larger spherulites consist of radially disposed, fibrous crystals of quartz and hematitized potash feldspar.

5.1.4

Intermediate compositions: dacite and quartz andesite

Rocks which are petrographically and chemically (see Chapter 7) classified as dacite are present as flows only within the Taylor's Bay Formation where they represent only a small proportion of the formation. The rocks are quartz normative reflecting the abundance of locally embayed quartz phenocrysts. Sericitized albite locally comprises 40% of the phenocryst assemblage. Subhedral potash feldspar, strongly saussuritized and locally hematitized, is subordinate to plagioclase. Locally the rocks contain up to 50% altered plagioclase phenocrysts and may be more properly termed quartz-andesite. Subhedral groundmass ferromagnesian phases in these rocks are pseudomorphed by chlorite and amphibole.

5.2 Continental sedimentation and mafic volcanism: Garnish and Calmer Formations

5.2.1 Sedimentary rocks

The fine grained clastic sedimentary rocks of the Garnish Formation contain sand-and silt-sized rock and crystal fragments in a clay matrix composed of calcite, minor sericite and unidentified clay minerals. The rock fragments are subrounded to angular and are poorly to moderately sorted. Flow-banded, spherulitic and perlitic rhyolites together with fragments of quartz- and quartz-potash feldspar porphyries and porphyritic rhyolites are the main constituents of the detrital assemblage. Fine-grained fragments of unwelded felsic pyroclastic rocks are common in some of the sandstones.

Fragments of mafic volcanic rocks are a subordinate component of the detrital assemblage. The only mafic volcanic lithologies recognized in the detrital assemblage are fine-grained to aphanitic, locally amygdaloidal and scoriaceous basalt and clinopyroxene-bearing, plagiophyric, quartz-andesite. Rare fragments of porphyritic diabase and metadiabase were also noted.

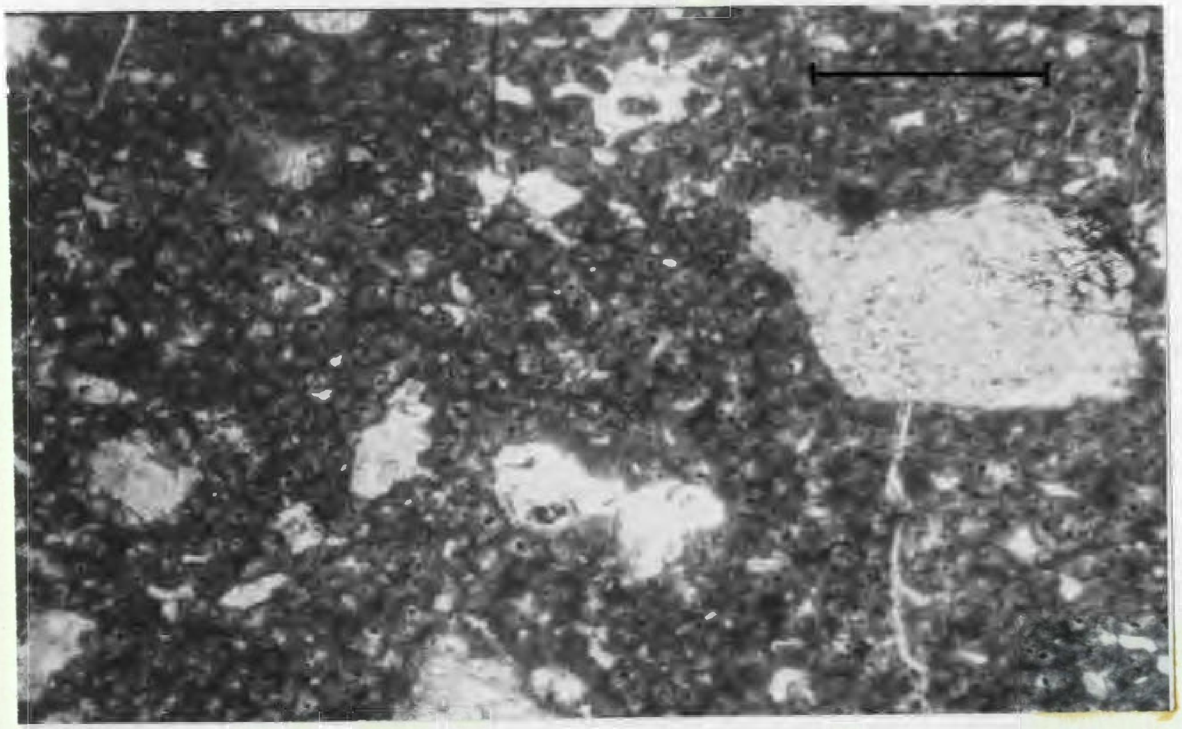
Whole and broken crystal fragments are an important detrital constituent. Crystals and fragments of vein quartz, embayed volcanic quartz and strained quartz constitute up to 20% of some of the sandstones. Albite is the main feldspar phase. Lesser amounts of hematitized potash feldspar are present. Epidote, altered clinopyroxene and magnetite are subordiante components of the detrital assemblage of the fine grained sandstones and are rare in the coarser-grained clastic rocks of the Garnish Formation. The cobbles and boulders of the conglomerates are mostly of felsic volcanic origin and are petrographically similar to the felsic volcanic and unwelded felsic pyroclastic and epiclastic volcanic rocks, present in the sandstones and siltstones of the Formation, are notably rare in the coarser-grained sedimentary rocks. The sedimentary rocks constitute a very minor proportion of the Calmer Formation and are generally petrographically similar to the sediments of the Garnish Formation with the only difference being the greater amount (up to 20% of the rock) of mafic detritus in the Calmer Formation sediments.

5.2.2 Mafic Flows

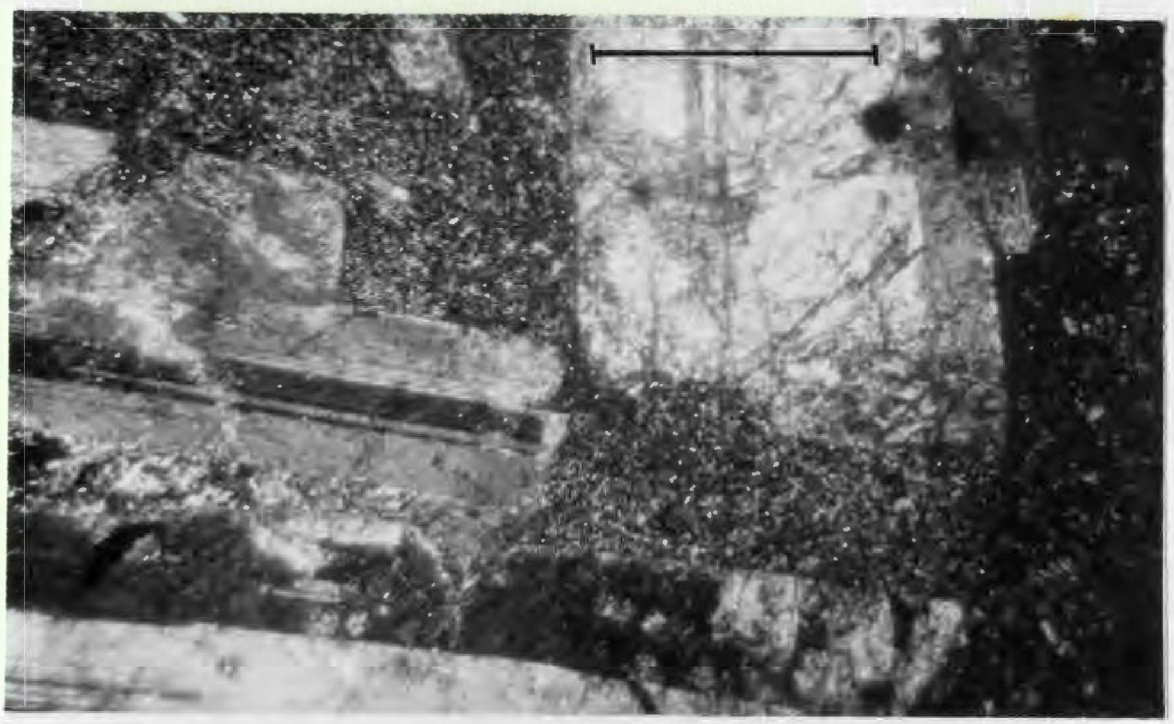
The uniformity of the basaltic flows of the Calmer Formation is little less striking in thin section than it is in the field. A typical mafic flow is vesicular to amygdaloidal, locally microporphyritic, fine- to medium-grained basalt. The chilled bases of the flows are aphanitic or aphyric. Medium to coarsely porphyritic basalt occurs in the south-central and eastern parts of the Calmer Formation. The microporphyritic and porphyritic flows contain phenocrysts of plagioclase and subordinate olivine micro-phenocrysts. Olivine also occurs in the matrix, together with clinopyroxene and plagioclase. The latter two phases display ophitic to subophitic relationships in the coarser-grained basalts. The matrices of the baslats are dominantly diabasic and show mainly intersertal, intergranular and locally holocrystalline textures.

Albite is the major plagioclase phase and it occurs as both stubby and elongate, euhedral to subhedral crystals which range in length from $\leq$ 0.1 mm to a maximum of 7.0 mm (P. 6). The palgioclases are in places highly altered, with epidote and carbonate. Albite is most common in the groundmass of the amygdaloidal flows where it displays intersertal and locally ophitic to subophitic relationships with altered clinopyroxene.

In the lithologically distinctive coarse-grained palgiophyric basalts, which are tentatively correlated with the Calmer Formation



Photomicrograph 5: Microspherulitic growths in hematitized devitrified band in flow banded rhyolite of the Taylor's Bay Formation. (Plane polarized light; bar scale = .6 mm).



Photomicrograph 6: Coarse grained albite phenocrysts in a fine grained matrix of plagioclase, epidote and opaques; Calmer Formation basalt. (Crossed nicols : bar scale = .75 mm).

(see Section 4. 4), albite occurs as subhedral to anhedral phenocrysts ranging in length from 1.0 mm to 1.0 cm. The plagioclase phenocryst are, in places, completely altered to subhedral metadomains (cf. Jolly, 1974) of epidote, carbonate and sericite. Plagioclase (An_{10}) is also present in these rocks as fine grained (< 1.0 mm) euhedral laths in an intergranular groundmass of chlorite, epidote, altered pyroxene (actinolite), sphene and leucoxene. The matrix of these rocks is fluidized in places and well developed trachytic textures are locally preserved. Apatite needles are present in the groundmass glass of the porphyritic flows.

In the majority of the basalts examined, small pseudomorphs (after olivine) make up 2-3% of the rock (P. 7). Some of the larger (2-3 mm) phenocrysts consist of a core of readily identifiable olivine, rimmed by dark brown iddingsite. In some of the more altered basalts it is difficult to distinguish fine grained altered olivine from magnetite and altered basaltic glass in the matrix and the original presence of olivine cannot always be substantiated. This is typical of many of the coarser grained plagiophyric flows.

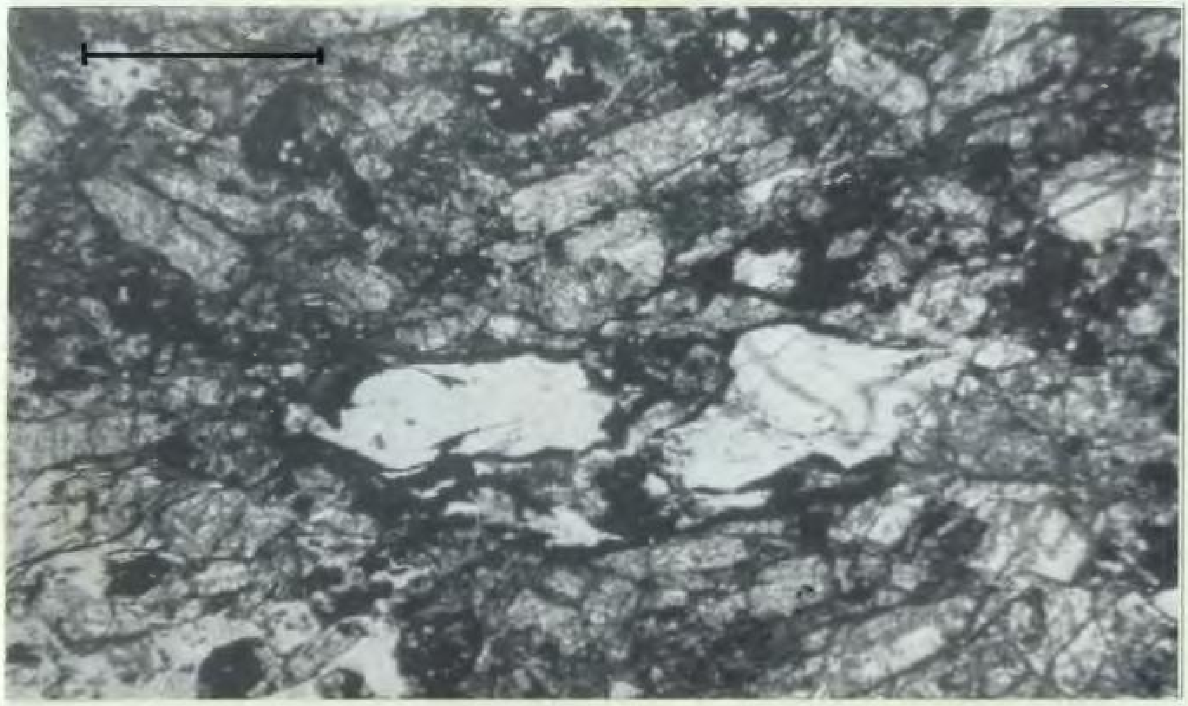
Clinopyroxene is common in the aphyric, microporphyritic and vesicular flows. It is typically altered to actinolite, but in places, relatively fresh clinopyroxene is present as subophitic intergrowths with albite. Augite is identifiable in several of the basaltic flows.

Subhedral actinolite occurs mainly in the groundmass of the basalts. although small (< 1 mm) microphenocrysts are locally present in some of the finer grained parts of the flows. In the groundmass, actinolite locally replaces dark brown amphibole which itself may pseudomorph a pyroxene phase. Ca-poor pyroxenes are not present in these rocks.

Epidote, chlorite and hematite are the main secondary minerals and together they often constitute up to 10% of the rock. Magnetite occurs as skeletal and euhedral octahedral forms. Leucoxene and sphene are present in subordinate amounts.

The amygdaloidal flows are characterized by spherical to irregular amygdules which range in diameter from 1-2 mm to a maximum of 7.5 cm and locally comprise up to 50% of the rock (P. 8). Chlorite and calcite are the main phases present in the amygdules and quartz, prehnite and pumpellyite are present in subordinate amounts. A zeolite phase, tentatively identified optically as laumontite, occurs as an amygdule-filling phase in two samples. Both the amygdaloidal and aphyric flows contain cross-cutting veinlets of calcite, chlorite, epidote and quartz which range from $<$ 1 mm to $\doteq$ 10 cm in diameter.

Only one of the studied samples from the Calmer Formation could possibly be petrographically classified as andesite. The rock contains microphenocrysts of plagioclase which are locally zoned and often highly sericitized. The clinopyroxenes are altered to actinolite, but the moderate 2V angle (50-55°) attained from one relatively fresh sample suggests an augitic composition. The highly altered (epidote actinolite and chlorite) groundmass contains very small anhedral crystals which display a very weak pink to pale green pleochroism, however, the original presence of orthopyroxene in these rocks cannot be definitely substantiated. Olivine was not recognized in this sample. Plagioclase, magnetite and pyroxene are the main primary minerals in the fluxionally textured groundmass.



Photomicrograph 7: Coarse grained clinopyroxene and olivine-bearing basalt of the Calmer Formation. Large crystal altered to chlorite, serpentine and opaques may represent pseudomorphed olivine. (Bar scale = .6 mm).

Photomicrograph 8: Chlorite rim and epidote core of vesicle in Calmer Formation basalt. (Plane polarized light; bar scale = .75 mm).

Pyroclastic Rocks

The mafic tuffs of the Calmer Formation are typically altered and comprise mostly lithic lapilli and coarse ash in a highly altered matrix. The most common lithic fragment is altered plagiophyric basalt, containing phenocrysts of plagioclase, actinolite and iddingsitized olivine in an intergranular matrix of magnetite, chlorite and actinolite. Fragments of basaltic scoria, consisting of highly altered plagioclase in an opaque matrix, are less common. Fragments of fine grained, altered mafic tuffaceous rock are also present in the tuffs, but the intense alteration inhibits identification of any primary phases. Felsic lithic fragments comprise a very minor proportion of the tuffs and are typically sericitized rhyolitic lithic tuffs, containing whole and broken crystals of quartz, hematitized potash feldspar and plagioclase, plus rhyolitic and mafic scoriaceous lapilli in a hematitized, glassy and locally recrystallized matrix.

5.3 Late Silicic Volcanism

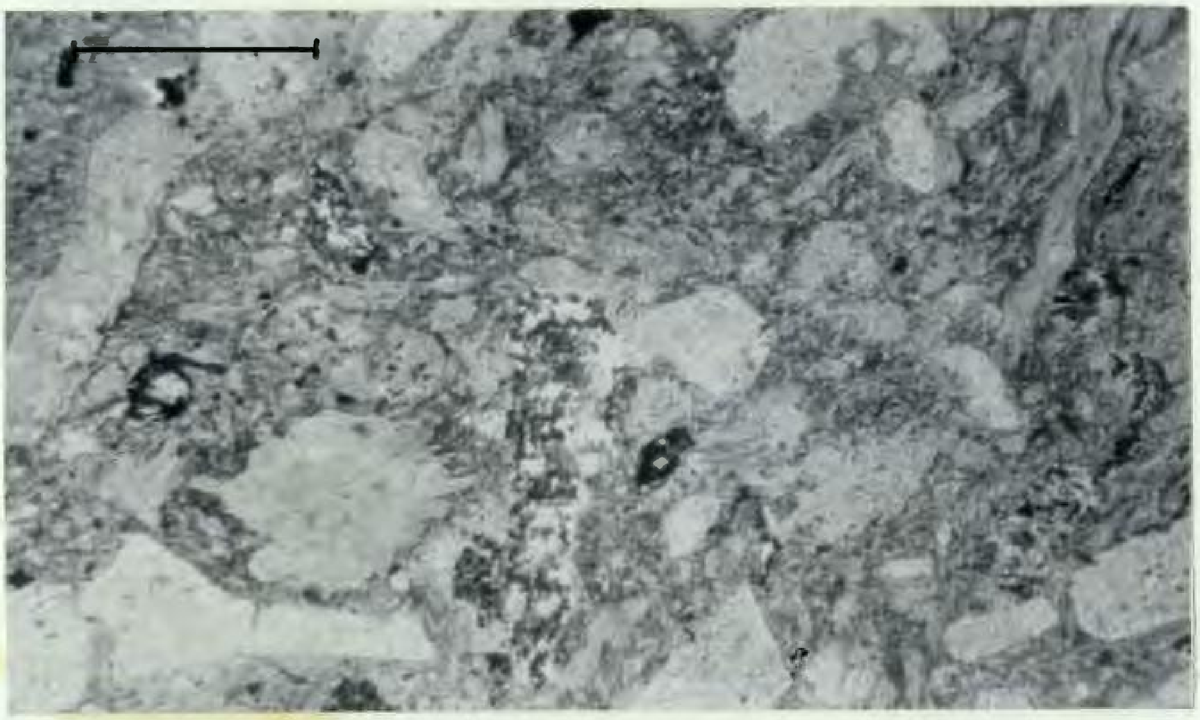
5.3.1 Barasway Complex

The slightly to moderately welded ash-flow tuffs of the Barasway Complex are typified by fine grained (< .1 mm) acicular and platy shards in a strongly hematitized cryptocrystalline matrix. Highly altered pumice fragments locally constitute approximately 20% of the rock. Flattening of the pumice fragments varies in intensity (P. 9). The pumice fragments are generally disc shaped and, for the most part, are randomly oriented. Some stretching of the pumice fragments was observed, but this may be the result of tectonic deformation rather than a primary welding feature.

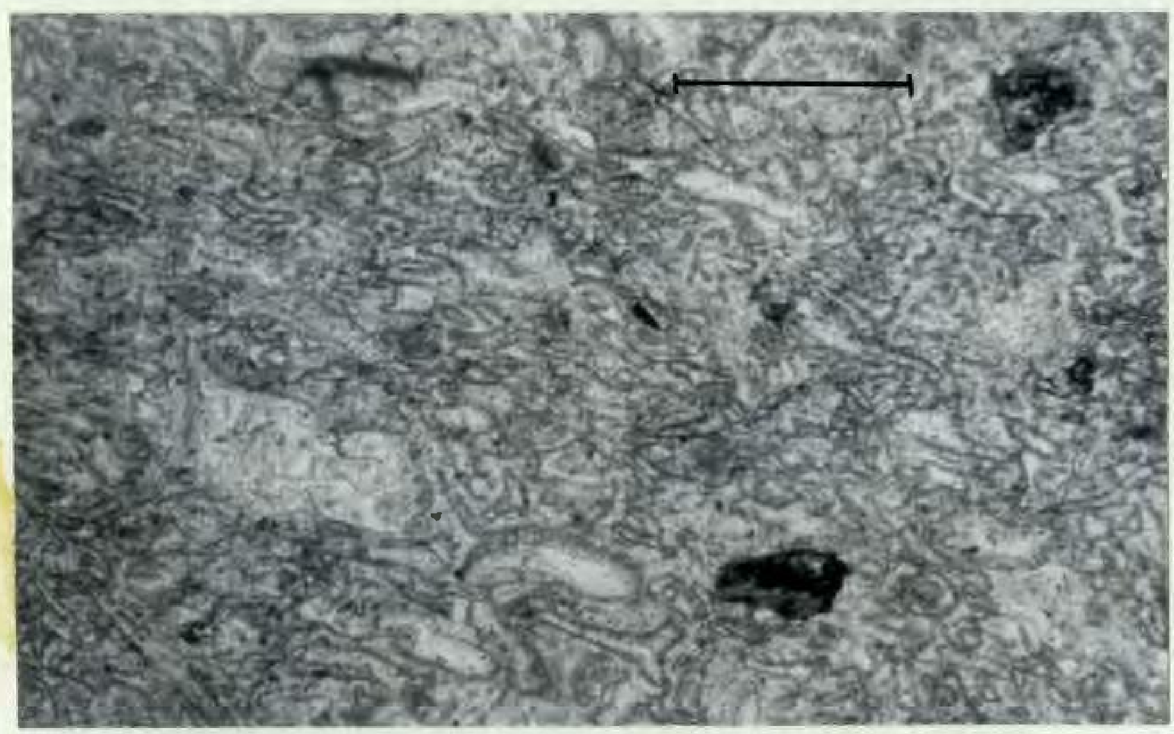
The strongly welded tuffs contain highly altered, stretched (length/width ratio ≤ 20:1) shards and pumice, in places enclosing anhedral to subhedral phenocrysts of albite and microcline. Locally the shards display fork shaped outlines. In areas of strong welding the shards are flattened and define a eutaxitic foliation (P. 10). Fiamme (.1-3 mm in diameter) commonly display microspherulitic textures and show delicately serrated margins. Strongly flattened fiamme are locally preserved in these rocks. The matrix of the strongly welded tuffs is typically red, highly oxidized and cryptocrystalline and locally shows devitrification features such as microspherulites.

The pumice-rich ash flows contain both eutaxitic and unflattened, altered pumice lapilli (P. 11). The pumice commonly shows serrated margins, granophyric patches and locally displays ruled structures (P. 12 + P. 13). Cuspate and platy, highly oxidized shards can be recognized in the vitroclastic matrix. In some of the more deformed pumice-rich ash flows, the flattening is parallel to a weak sericitic fabric. In such cases it becomes difficult to establish how much of the flattening is tectonic, rather than primary in origin.

Crystals and fragments of albite and quartz are common in all the ash flow tuffs and locally constitute up to 30% of the rock. Crystals of albite are generally subhedral, rarely exceed 3 mm in diameter and often show either lamellar or Carlsbad twinning. Quartz usually forms euhedral crystals which locally are strongly embayed. Altered augite is present as small (1-2 mm), subhedral to rounded crystals in the welded ash-flow tuffs. Fine grained patches of chlorite and magnetite



Photomicrograph 9: Variation in degrees of flattening of pumice lapilli in eutaxitic matrix of ash flow tuff of the Barasway Complex. (Plane polarized light; bar scale = .6 mm).



Photomicrograph 10: Weak eutaxitic texture defined by glass shards in vitric-crystal tuff of the Barasway Complex. (Plane polarized light; bar scale = .75 mm).

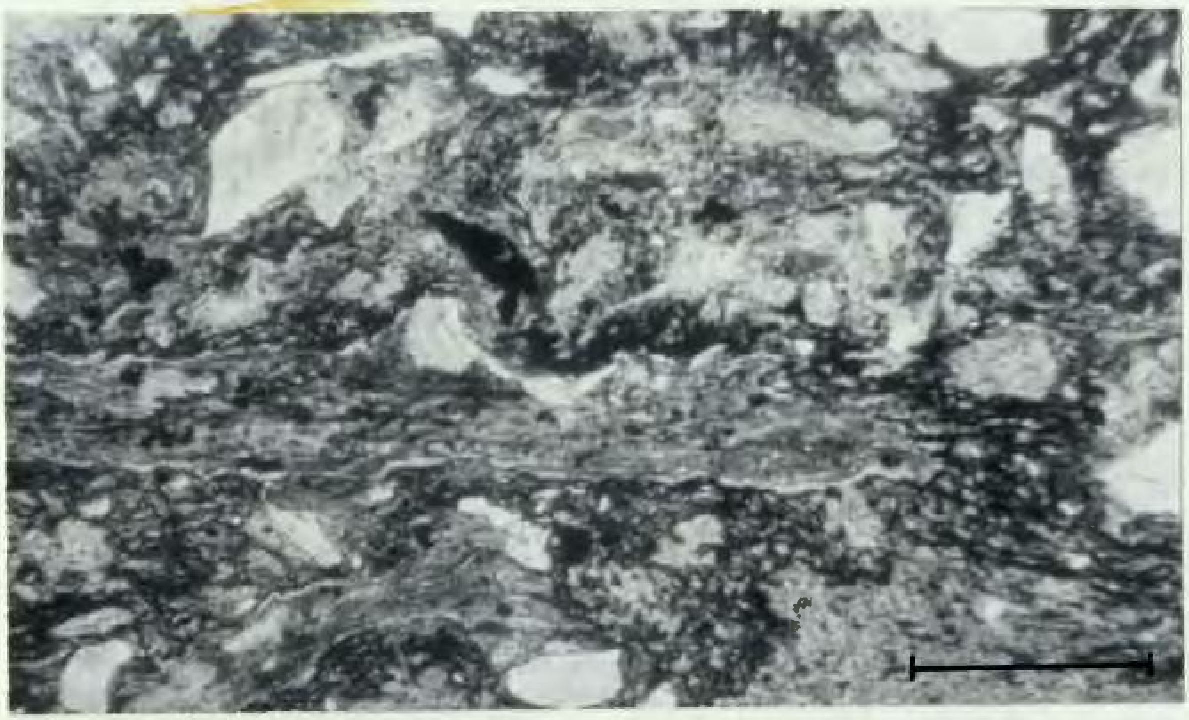
are present locally, possibly pseudomorphing olivine. Minor (≤ 1%) biotite flakes, locally oxidized (≤ 1 mm), were identified in the welded tuffs of the Complex.

The massive rhyolitic flows of the Barasway Formation are gray, aphanitic to fine grained (.05-1 mm) and locally quartz and/or plagioclase porphyritic. Hematitized oligoclase is rare as a phenocryst phase. The groundmass of the rhyolite flows is commonly microspherulitic and comprises fine grained (≤ 1 mm) quartz and potash feldspar with lesser amounts of lamellar twinned plagioclase. In places the groundmass is very fine grained, almost cryptocrystalline, and displays partially developed perlitic textures.

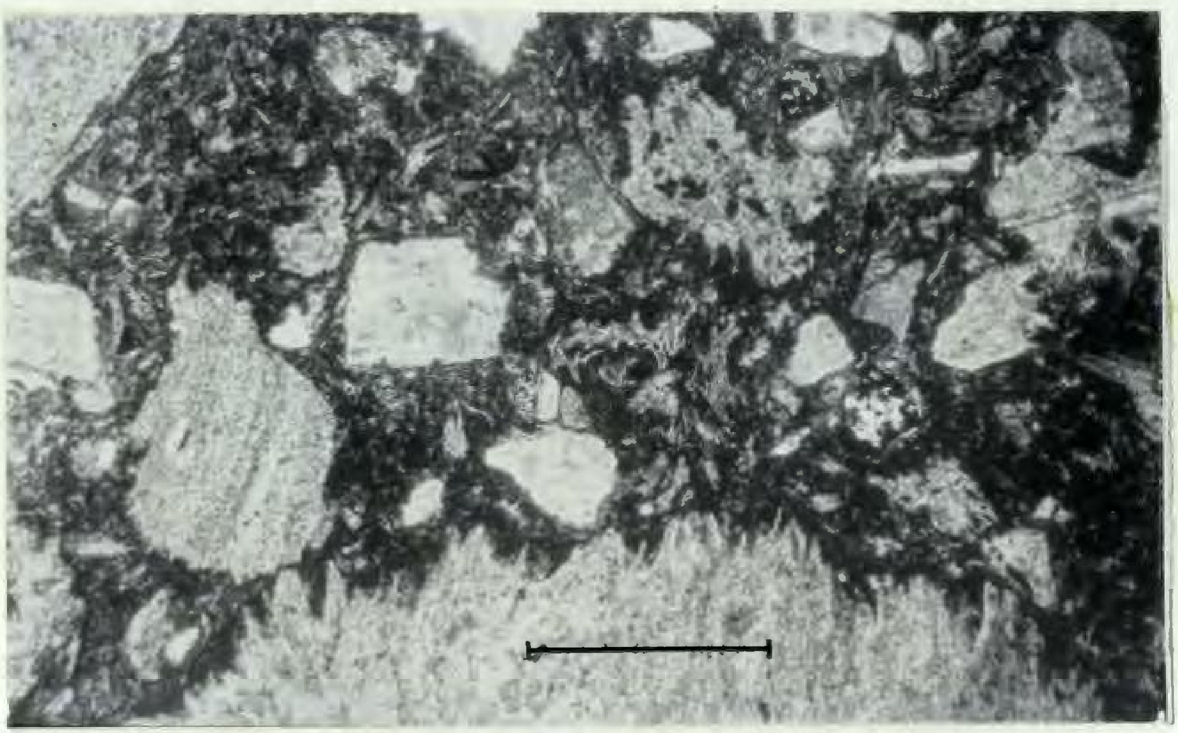
The flow banded rhyolites often display coarse flowage bands, up to 3 cm in width, defined by microspherulitic intergrowths of quartz and feldspar. They are petrographically similar to the massive flows but are often more pervasively devitrified. The finer (≤ .1 mm) flowage bands are usually defined by flow-oriented, acicular opaques.

The autobrecciated flows are monolithologic, containing angular to subrounded fragments of massive, banded and porphyritic rhyolites which are petrographically identical to the rhyolite flows described above. The intersertal matrix of the autobrecciated flows comprises mainly a highly sericitized, carbonatized and devitrified glass.

The unwelded pyroclastic deposits in the Barasway Complex are mainly highly altered rhyolite breccias and rhyolitic to intermediate tuffs. A typical rhyolite breccia of the Complex consists of subhedral and broken crystal and glomeroporphyritic aggregates of albite (0.05-2 mm), euhedral quartz (.1-1 mm) and minor hematitized potash feldspar. Ferromagnesian phases are notably rare and appear to be represented



Photomicrograph 11: Moderately flattened pumice fragments in eutaxitic matrix of squashed pumice and oxidized shards. (Plane polarized light; bar scale = .6 mm).



Photomicrograph 12: Ruled structure and serrated margins in pumice lapilli of pumice rich ash-flow tuffs of the Barasway Complex. (Plane polarized light; bar scale = .6 mm).

only by chlorite and serpentine.

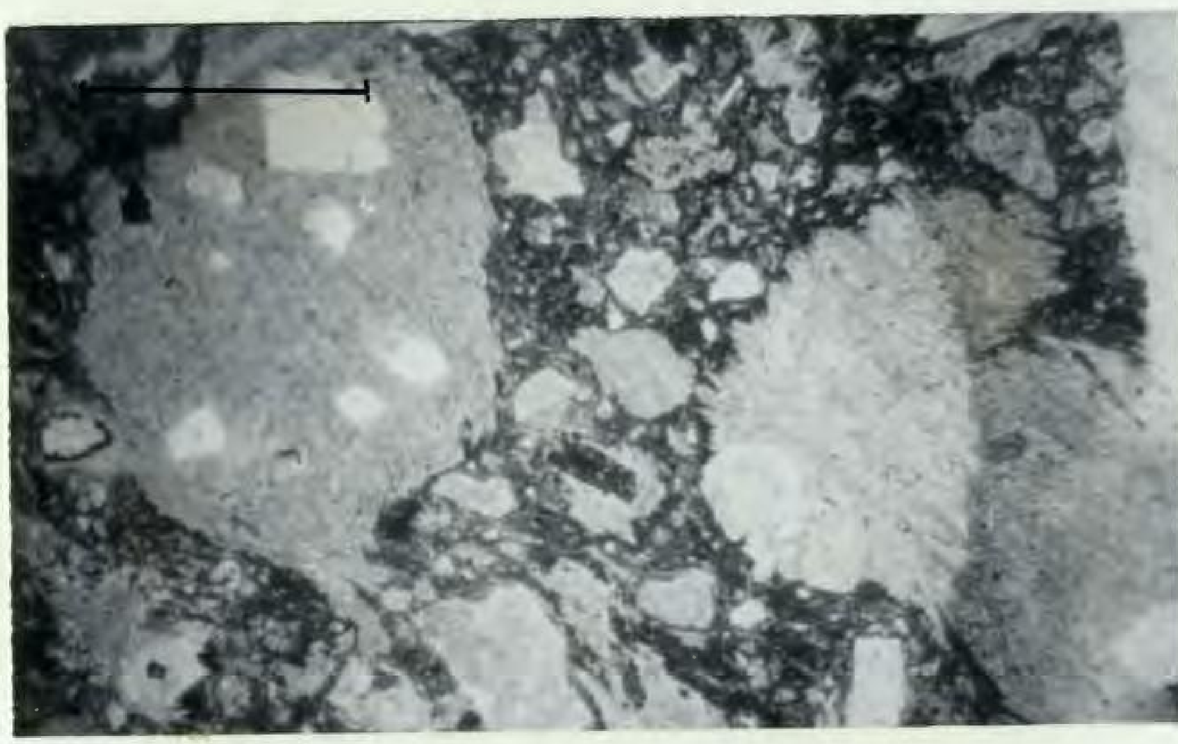
The most common lithic fragments in the breccias are highly sericitized potash feldspar-quartz porphyritic rhyolites and fine grained, magnetite-rich, plagiophyric (albite) basalt ; the latter locally displaying fluidized matrix.

The matrix of the rhyolite breccias is commonly a very fine grained (≤ .1 mm) cryptocrystalline aggregate of quartz, potash feldspar, and/or plagioclase. Sericitization and carbonatization of the matrix is widespread. Magnetite and apatite are locally present as groundmass phases.

Epiclastic volcanic and tuffaceous sedimentary rocks of the Barasway Complex are petrographically similar to the same rock types which occur elsewhere in the Marystown Group. They are typically highly altered, with sericite, carbonate and chlorite being the main alteration phases. The detrital assemblage is characterized by a wide variety of dominantly felsic and lesser amounts of intermediate massive and pyroclastic volcanic rocks, similar to those found elsewhere in the Complex.

The agglomerates and coarse grained breccias of the Barasway Complex are dominantly intermediate in composition but contain blocks and bombs of felsic to mafic composition. The matrices of the agglomerates are commonly highly sericitized and contain fine grained subhedral laths of altered plagioclase and resorbed quartz. In the less altered samples, the matrix locally displays a vitroclastic texture, with fine-grained (≤ .1 mm), slightly flattened, altered glass shards preserved in places. Locally, the matrix consists mainly of devitrified glass, represented by a very fine grained, microspherulitic, in places

Photomicrograph 13: Granophyric patches in unflattened pumice-lapilli of pumice-rich ash-flow tuffs of the Barasway Complex. (Plane polarized light; bar scale = .6 mm).



Photomicrograph 14: Unflattened pumice-lapilli with feldspar phenocrysts in ash-flow tuff of the Hare Hills Formation. (Plane polarized light; bar scale = .75 mm).

cryptocrystalline quartz -feldspathic groundmass.

The rhyolitic blocks in the agglomerates and breccias are petrographically similar to rhyolites elsewhere in the Complex. In the breccias, blocks show neither megascopic nor microscopic indication of post-eruptive cooling; e.g. alteration rims, plastic deformation features, etc.

A typical andesitic bomb in these agglomerates consists of subhedral laths of plagioclase as phenocrysts in a fine grained, sericitized, locally fluidized matrix of epidote, chlorite, altered pyroxene, hematite, minor quartz and/or potash feldspar.

Rare mafic blocks and bombs are either aphyric, plagiophyric and/or microvesicular basalt. They locally contain eudedral phenocrysts of epidotized albite (1-3 mm) and actinolitized clinopyroxene. The matrices show fluidal to intergranular textures and typically contain euhedral plagioclase (An_{10}), altered pyroxene and opaques.

A felsic plutonic block taken from the agglomerates displays well developed graphic intergrowths. Subhedral to anhedral, locally rounded quartz phenocrysts show embayed and corroded crystal shapes. Minor alkali feldspar poikilitically encloses zoned and locally twinned plagioclase.

The blocks in the coarse-grained laharic breccias are petrographically similar to the blocks and bombs in the above agglomerates and pyroclastic breccias. The matrix of these breccias is predominantly sedimentary and does not display the vitroclastic textures which are locally preserved in the matrix of the agglomerates.

5.3.2 Hare Hills Formation

The non-welded felsic crystal-vitric tuffs of the Hare Hills Formation contain up to 50% xenocrysts of plagioclase (An_{10}) and subhedral, rounded and embayed quartz in subequal proportions. Saussuritized potash feldspar in places comprises up to 10% of the crystal content of some of these tuffs. Oxidized biotite, hematite, magnetite and actinolite are only present in subordinate amounts in the groundmass.

These rocks very locally contain altered glass shards which are typically coated with fine hematite dust. The shards are broken and rarely display any effect of flattening or welding.

Lithic lapilli locally constitute approximately 20% of any one thin section of the tuffs. The lapilli assemblage consists of roughly equal amounts of mafic and felsic volcanic rocks. The lithology of the felsic lapilli is typified by subangular to angular fragments (1.0-6.0 mm in average maximum dimension) of equigranular aphyric and quartz-porphyritic rhyolite. Fragments of epidotized aphanitic and albite-porphyritic basalt rarely constitute more than 10% of the tuffs.

Mafic tuffs of the Hare Hills Formation consist of up to 90% subrounded fragments of mafic volcanic rocks in a highly chloritized, in places sericitized, matrix. Felsic volcanic detritus is notably rare in these rocks and rarely constitute greater than 5% of the total lithic proportion of the tuffs. Olivine-bearing, plagiophyric basalt and altered basaltic scoriae are the most common mafic lithic fragments in these rocks. Agglomerates which are intercalated with the mafic tuffs contain blocks and bombs of petrographically similar rock types.

The grey lithic tuffs of the lower portion of the Hare Hills Formation locally consist of up to 80% felsic and minor mafic lapilli. In places, the tuffs contain ≤ 10% altered and unflattened pumice-lapilli. Crystal fragments (subrounded quartz and albite subhedra) rarely comprise more than 10% of the tuffs. The lack of flattening or welding features may indicate air fall deposition.

The non-welded ash-flow tuffs contain irregularly shaped lithic and pumice-lapilli with maximum dimensions from .01 mm to ca .20 cm. The lithic-lapilli and blocks are generally felsic in composition and are typically highly sericitized and locally epidotized. The pumice-lapilli are disc-shaped, showing little or no evidence of flattening (P. 14). Fine grained, acicular shards are locally preserved in the hematitized, cryptocrystalline matrix. Accidental crystals rarely constitute more than 20% of these tuffs. The major xenocrystic phase is albite, with hematitized potash feldspar and rounded quartz being abundant. Phenocrysts of euhedral plagioclase (An_{10}) are locally present in the tuffs.

The felsic volcanic breccias are usually non-welded and contain blocks of sericitized porphyritic rhyolite, red densely welded and unwelded ash flow tuffs and lesser amounts of highly epidotized, plagiophyric and aphyric basalt. Subangular to rounded crystal fragments of epidotized plagioclase and quartz occur in the sericitized and epidotized quartzo-feldspathic matrix of the breccias.

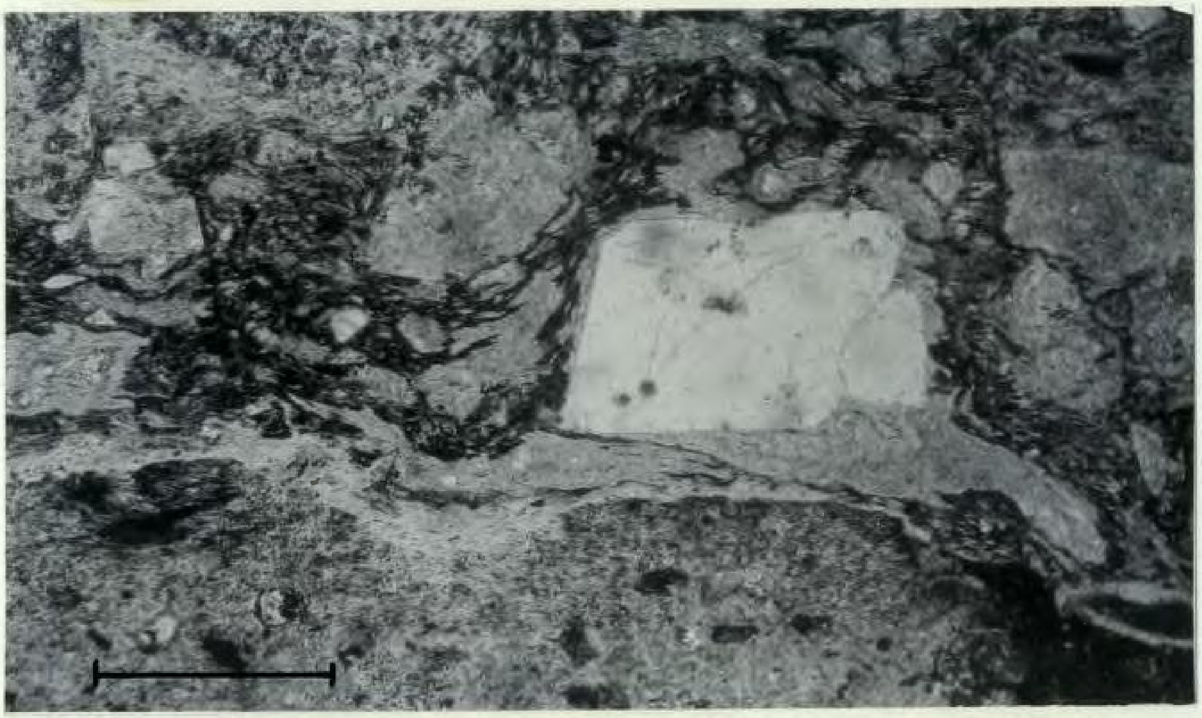
The densely-welded ash-flow tuffs contain highly altered, flattened shards which, in places, define a strong eutaxitic foliation in a hematitized, cryptocrystalline, locally spherulitic matrix. Flattened fiamme (≤ 5 mm in length) are only very rarely preserved. Albite and lesser amounts of potash feldspar are xenocrystic phases. Flattened and altered pumice lapilli and minor fiamme enclose augen of the xenocrysts (P. 15).

Unwelded tuffs of intermediate (e.g. mixed mafic and felsic lapilli) composition are characterized by widespread epidotization and lesser sericitization. Subrounded fragments of porphyritic basalt are the main constituent of the tuffs. The basalts contain epidotized albite phenocrysts (.01-2.5 mm) in an intergranular matrix of plagioclase and altered clinopyroxene. Fragments of sericitized unwelded felsic tuffs rarely comprise more than 20% of the lithic component of the tuffs.

The epiclastic tuffaceous rocks of the Hare Hills Tuff are petrographically similar to the epiclastic rocks of the Barasway and Grand Beach Complexes (Sections 5.3.1 and 5.3.4) and require no further description.

Crystal-rich, felsic tuffaceous sedimentary rocks are unique to the Hare Hills Formation. The rocks are petrographically similar to the crystal-rich tuffs of the Barasway Complex but contain fewer lithic fragments. Locally, the tuffs contain up to 70% euhedral to rounded, whole and broken crystal fragments and aggregates of epidotized albite, embayed and subhedral quartz and saussuritized potash feldspar. The crystals vary from ≤ .01 mm to 4.5 mm. The tuffaceous rocks are well sorted and locally graded. Thin (1.0-3.25 mm), discontinuous bands of non-oriented opaque oxides are locally finely cross-bedded, indicating the subaqueous deposition of these epiclastic rocks.

The massive rhyolite flows are pink to white and aphyric to microphyritic. The groundmass of the flows consists of a finely crystalline



Photomicrograph 15: Flattened pumice lapilli enclosing augen of quartz crystals. Note flattening of pumice between quartz crystal and adjacent lithic fragment. (Plane polarized light; bar scale = .6 mm).

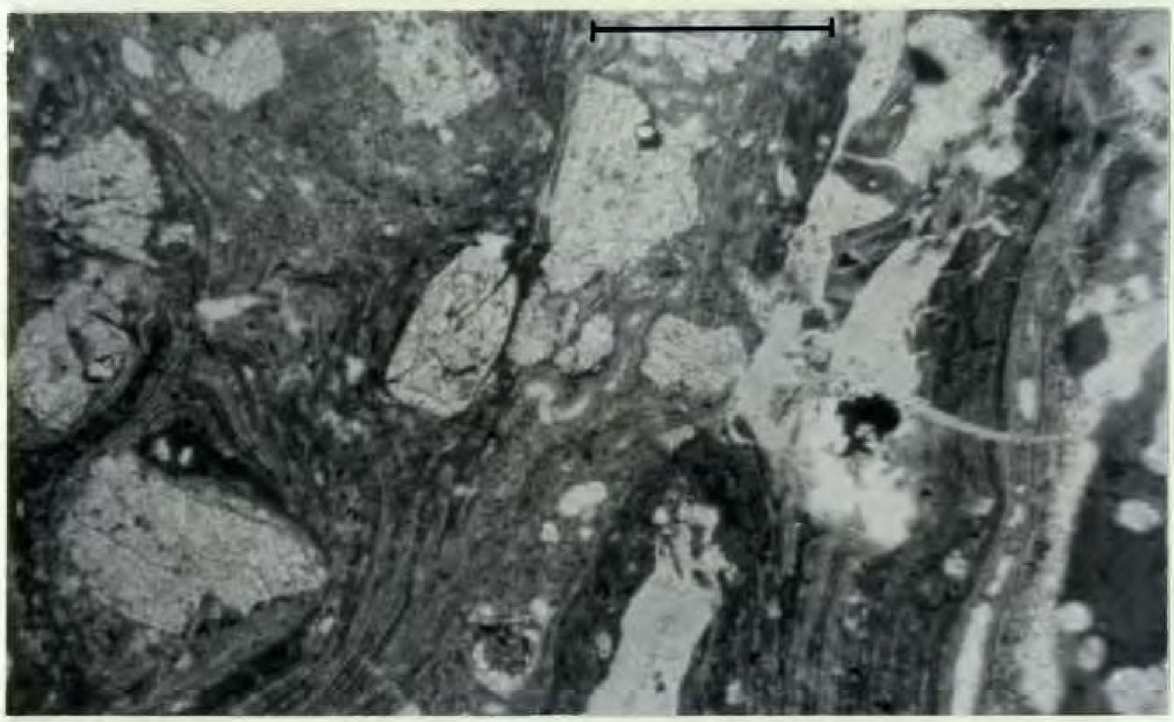
aggregate of subhedral to anhedral quartz, potash feldspar and minor albite. Pink to orange anhedra of piemontite (0.01 mm - 0.1 mm) occur in the groundmass and also as small (≤ .1 mm) phenocrysts in the micro-porphyritic flows. Devitrification features are rare in these rocks, although microspherulitic textures were recognized in one specimen from the Fortune Tolt area. Locally, the rhyolites display well developed felsitic textures.

The rhyolitic vitric tuffs consist of embayed quartz phenocrysts, saussuritized potash feldspar and albite in a fine grained, locally devitrified, vitroclastic groundmass. Shards, ranging in diameter from ≤ .01 mm to 1 mm, show varying degrees of flattening and stretching. Both axiolitic and eutaxitic textures are recognizable in these rocks. The vitric groundmass is locally devitrified, resulting in sporadic growth of spherulites.

5.3.3 Mount Saint Anne Formation

The petrography of the felsic volcanic rocks of the Mount Saint Anne Formation is similar to those of the Barasway Complex (Section 4.5.3) and will not be discussed in detail here.

The flow-banded rhyolites are characterized by sub-millimeter scale, highly irregular to straight flow bands defined by very fine grained, microspherulitic aggregates of quartz and potash feldspar and hematite which enclose augen of and abut against quartz and alkali feldspar phenocrysts (P. 16 + P. 17). The flows are locally porphyritic, containing phenocrysts of embayed quartz (2.5-4.5 mm), subhedral, epidotized plagioclase (An_{10}) (~ 2.5 mm) and hematized potash feldspar (1.5-2 mm).



Photomicrographs 16 and 17: Flow-banded rhyolite of the Mount Saint Anne Formation. Thin flow laminae forming augen of quartz and alkali feldspar crystals. (Plane polarized light; bar scale = .6 mm).

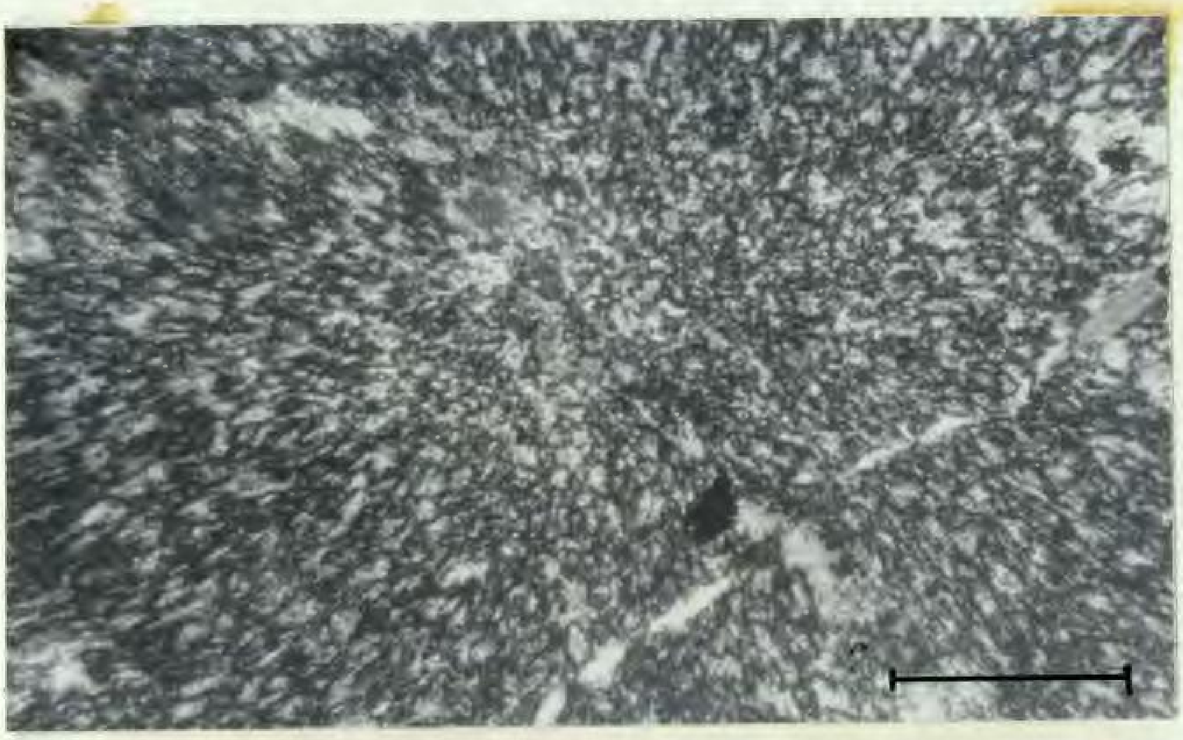
The matrix of the flows commonly displays microspherulitic devritification features. Intense epidotization is locally seen in the rhyolites.

The flows become in places autobrecciated and petrographically resemble similar rock types in the Barasway Complex.

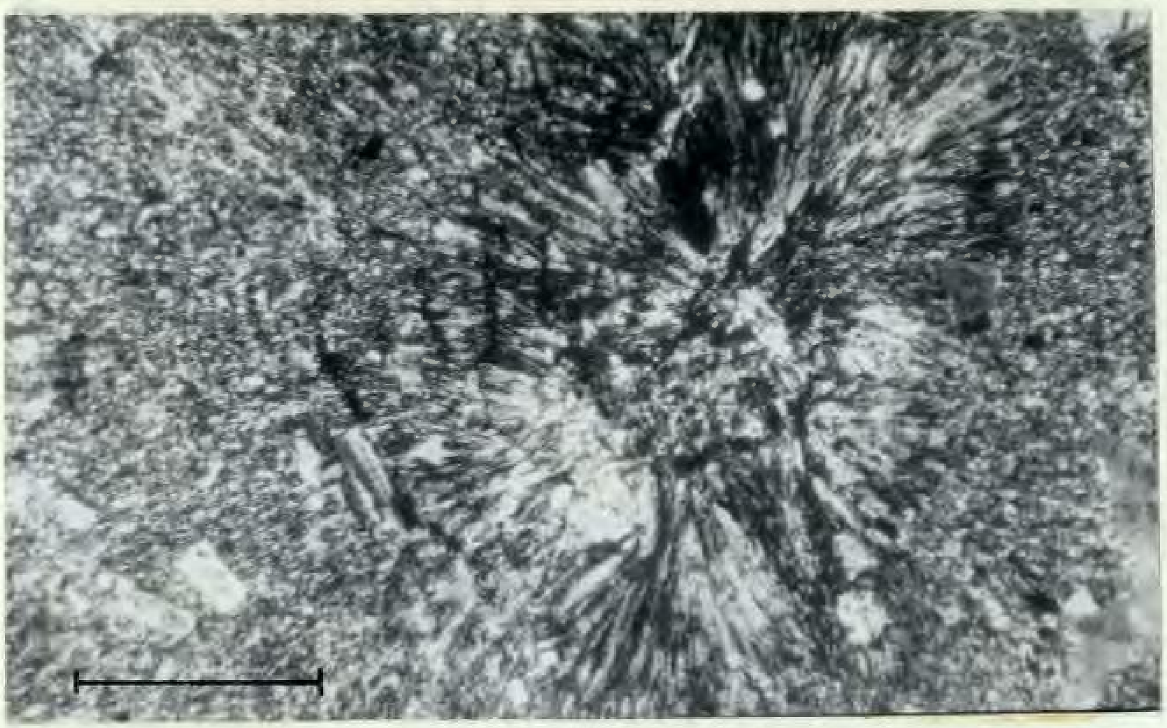
Spherulitic rhyolite flows are widely developed within the Mount Saint Anne Formation and are petrographically similar to the spherulitic lavas elsewhere in the Marystown Group. Orb, felsite and microspherulitic textures are locally preserved in these rocks (P. 18). The coarser grained (≤ 5 mm) spherulites are generally spherical in outline and consist of straight-edged, fibrous aggregates of quartz and potash feldspar (P. 19 & P. 20). The finer grained (1-2 mm) spherulites commonly display fan and sheath-like morphologies (cf. Lofgren, 1974; photomicrograph 21). At one locality, a devitrified flow consists entirely of rounded and sheath spherulites in a microspherulitic to orbicular matrix. The spherulites are locally recrystallized and have been poikilitically enclosed by anhedral quartz. The pervasive devitrification of this lithology might suggest that the rock was originally an obsidian flow.

The ash flow-tuffs of the Mount Saint Anne Formation are characteristically moderately to densely welded, locally flattened lithic and crystal-lithic tuffs. Neither pumice-rich nor vitric tuffs have been identified in this formation. With this exception, the ash-flow tuffs are petrographically similar to those of the Barasway Complex, and therefore, are not described here.

Mafic lithic tuffs are rare and occur only in the eastern exposures of the formation. The tuffs are rich (up to 50%) in irregular-shaped



Photomicrograph 18: Orb and felsitic texture in spherulitic rhyolite of Mount Saint Anne Formation. (Plane polarized light; bar scale = .6 mm).



Photomicrograph 19: Spherulitic growth in rhyolite flow of the Mount Saint Anne Formation. (Plane polarized light; bar scale = .6 mm).

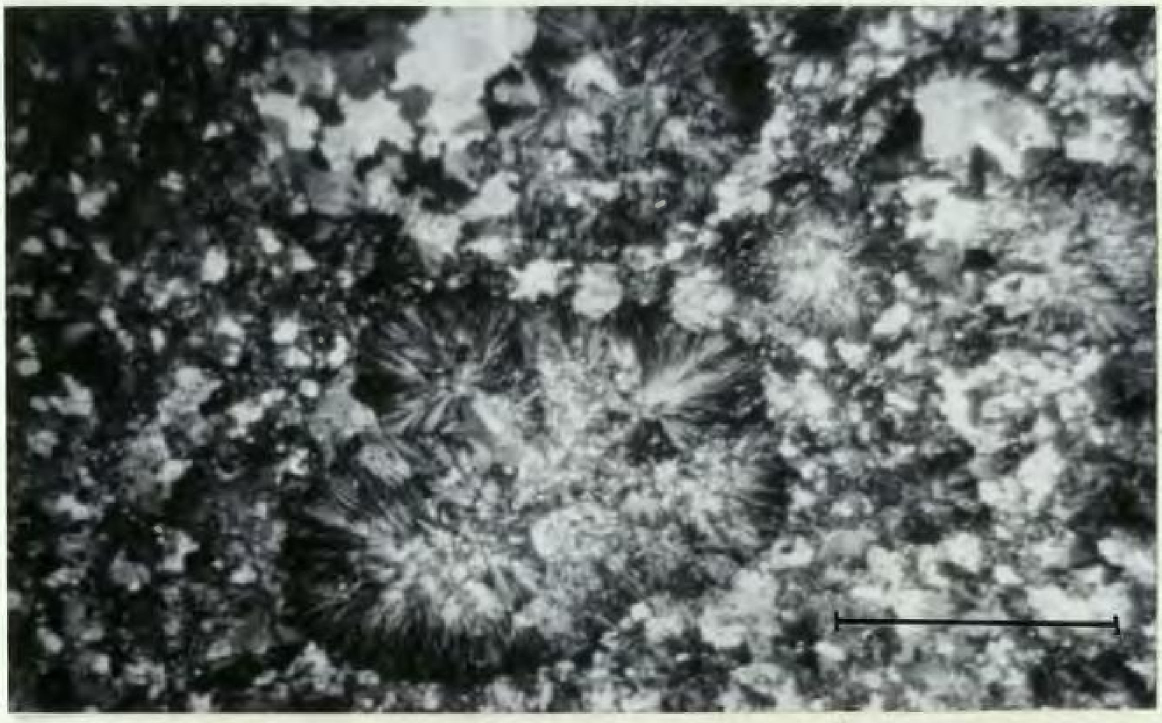
plagiophyric basalt fragments (≤ 1 cm in diameter). Highly epidotized anhedra of albite (and minor andesine) occur as phenocrysts (1-3 mm) and also as a groundmass phase, where it shows intersertal textures with altered clinopyroxene. Rhyolitic fragments in the tuffs are typically highly sericitized quartz and potash feldspar porphyritic rhyolite. Fragments of andesitic or dacitic composition were not recognized in these tuffs.

The unwelded rhyolite tuffs of the Formation contain subangular to subrounded lapilli (5 mm - ≤ 1 cm) in highly sericitized, locally crystal rich quartzo-feldspathic, in places tuffaceous, matrix. The dominant lapilli lithology is quartz-orthoclase porphyritic rhyolite tuff. Densely welded, eutaxitic rhyolite tuff fragments were recognized in places. These tuffaceous rocks are characteristically sericite and epidote rich, the former phases often defining a weak foliation in the more schistose tuffs.

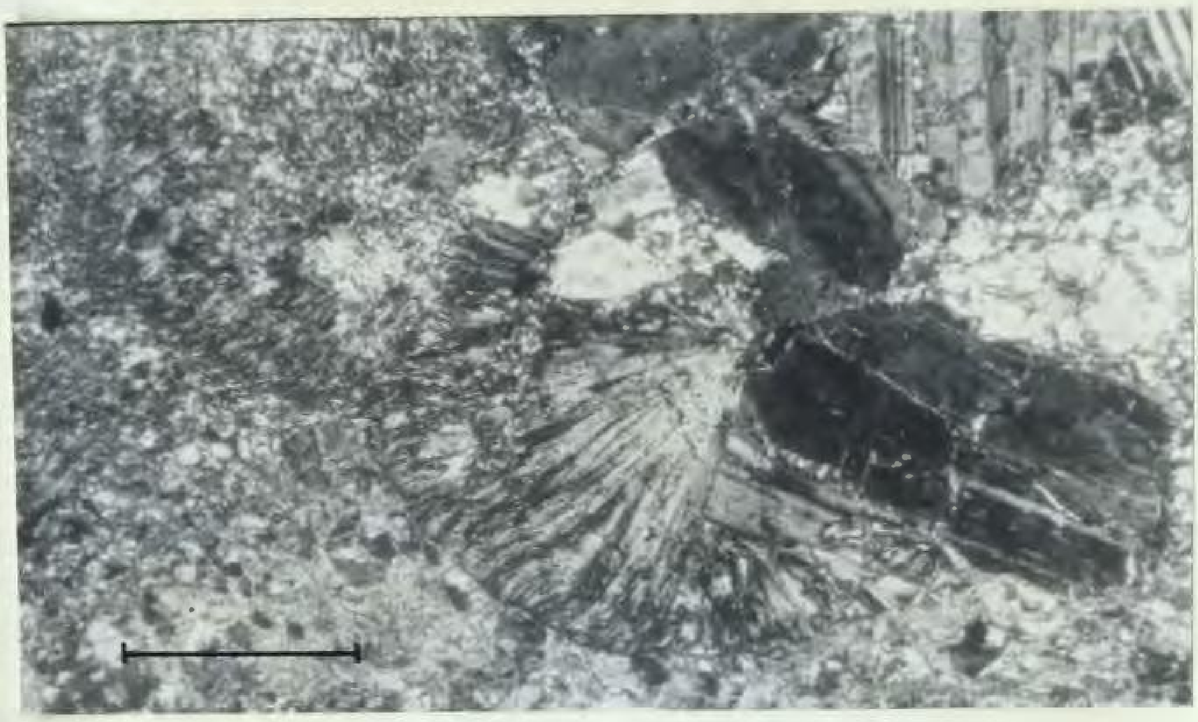
The sericite schists constitute a minor proportion of the Mount Saint Anne Formation. The main foliation, defined by cryptocrystalline aggregates of sericite, encloses augen of embayed and locally strained quartz crystals in a sericitized, locally granoblastically recrystallized matrix of plagioclase, potash feldspar and quartz.

5.3.4 Grand Beach Complex

The volcaniclastic and epiclastic breccias of the Grand Beach Complex consist of a variety of mafic and felsic volcanic and sedimentary fragments in a fine to medium grained, hematitized and carbonatized, dominantly quartzofeldspathic clastic matrix. The mafic fragments



Photomicrograph 20: Spherulitic growth in rhyolite flow of the Mount Saint Anne Formation. (Plane polarized light; bar scale = .75 mm).



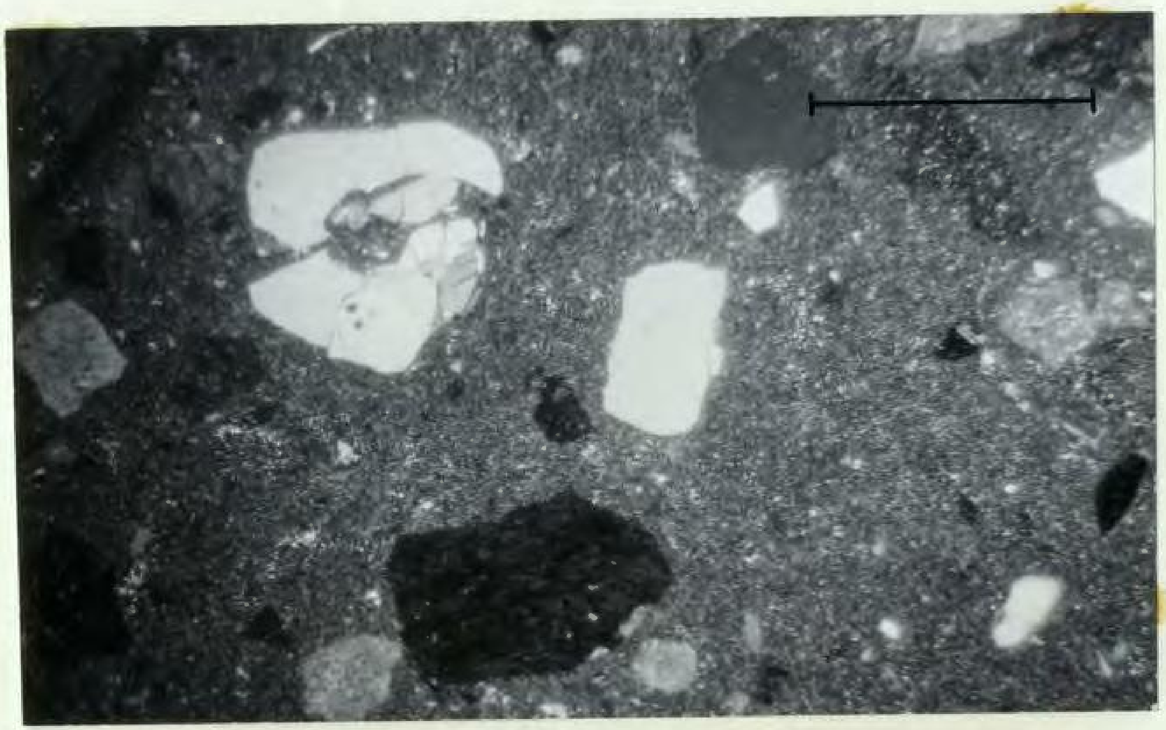
Photomicrograph 21: Fan spherulite in devitrified rhyolite flow of the Mount Saint Anne Formation. (Plane polarized light; bar scale = .6 mm).

consist of vesicular, plagiophyric and aphanitic basalts, which are petrographically similar to basaltic flows of the underlying Calmer Formation (see Section 5.2.2). The sedimentary fragments in the breccias are typical of the fine-to medium-grained clastic rocks of the Garnish Formation (see Section 5.2.1).

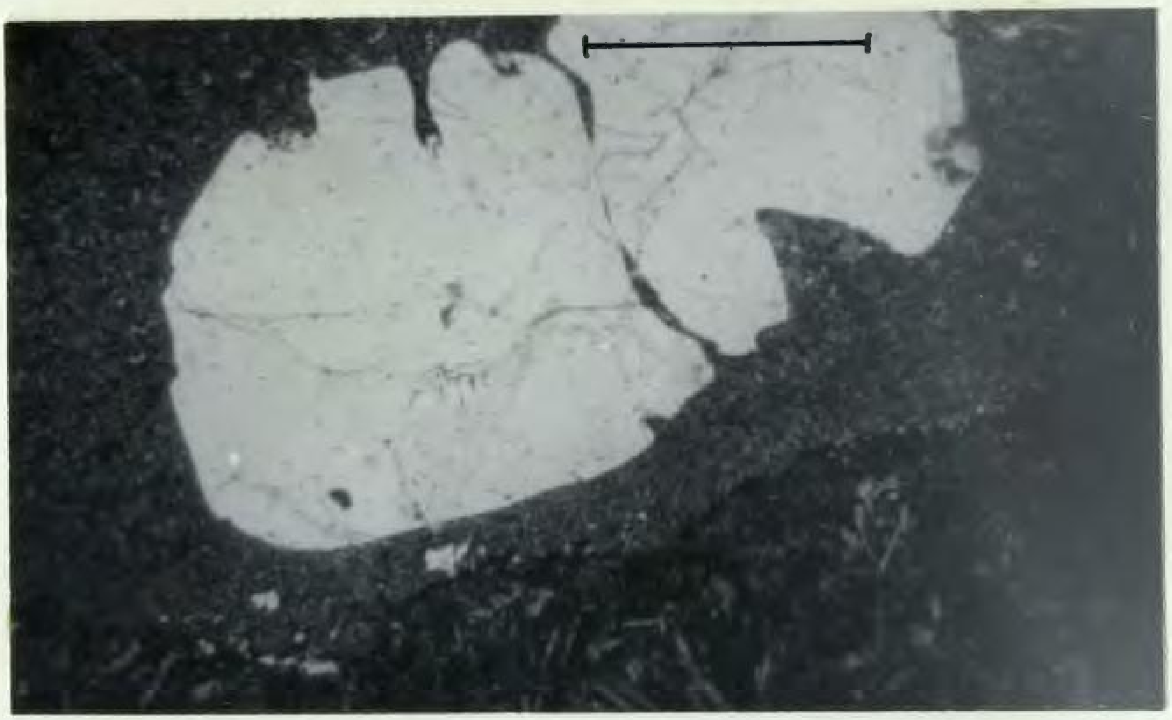
These breccias also contain fragments of nonwelded air fall tuffs and poorly to moderately welded ash flow tuffs. The nonwelded tuffs contain crystals of embayed quartz, hematitized and saussuritized potash feldspar, perthite and checkered albite in a highly hematitized, microcrystalline to felsitic quartzo-feldspathic ash matrix (P. 22). The welded tuff fragments contain xenocrysts of similar composition. Vitroclastic microspherulitic and weak eutaxitic textures are locally preserved in the matrix of the tuffs.

The air fall tuffs and nonwelded crystal-lithic ash flow tuffs of the Grand Beach Complex are typified by fine grained (≤ .1 mm) highly hematitized matrix locally displaying felsitic textures. Discontinuous flow laminae, defined by fine grained microlites of iron oxide, are recognizable in some of the tuffs. Devitrification features are uncommon in these rocks, although irregular, ameboid zones displaying microspherulitic textures are locally preserved in the matrix.

Quartz and potash feldspar are the most common xenocrystic phases in the nonwelded tuffs. Quartz is present as euhedral to rounded, in places highly embayed, xenocrysts ranging in diameter from < 1.0 to 6.5 mm (P. 23). Potash feldspar crystals (≤ 7.0 mm) comprise approximately 65% of the identifiable feldspar phases and are often completely saussuritized, hematitized and/or carbonatized. The local occurrence of



Photomicrograph 22: Broken crystals of quartz, alkali feldspar and chequered albite from rhyolite tuff of the Grand Beach Complex. (Plane polarized light; bar scale - .75 mm).



Photomicrograph 23: Rounded and embayed quartz crystal in ash flow tuff of the Grand Beach Complex. Groundmass highly altered to sericite and hematite. Note lithic fragment of chloritized basalt. (Plane polarized light; bar scale = .75 mm).

chequered albite and perthite reflects the albitization of some of the feldspars and some degree of Na- metasomatism of these rocks. Albite locally displays lamellar and Carlsbad twinning.

Mafic volcanic rocks occur as both altered and unaltered lithic inclusions within the tuffaceous rocks. Most of the fragments are between 0.5 mm and 5 cm in diameter, however, fragments up to 30 cm in diameter have been recognized.

The larger lithic fragments are locally rimmed by fluorite and barite aggregates. The basalts are aphanitic, in places microvesicular and rarely contain plagioclase phenocrysts. Albite, chlorite and opaque oxides occur in intergranular to partially fluidized matrices.

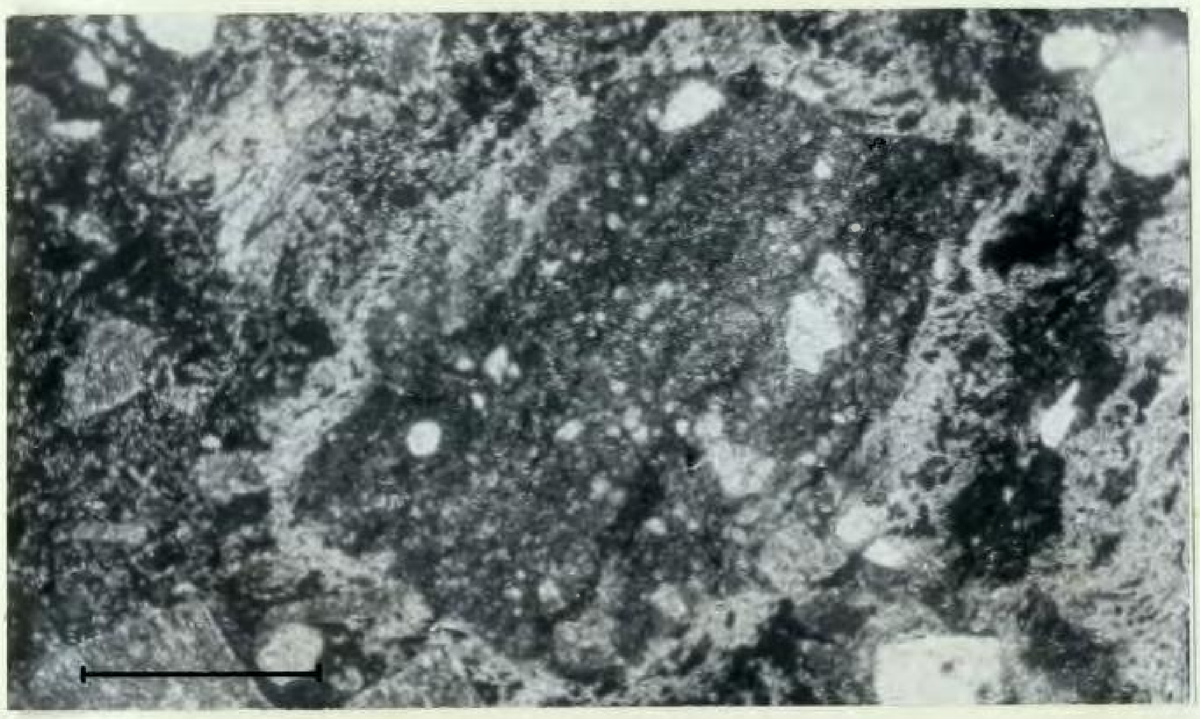
The quartz-rich crystal tuffs of the Complex contain up to 40% euhedral, rounded and highly corroded quartz phenocrysts and xenocrysts which range in diameter from < .1 mm to ~ 6.0 mm in diameter. Sausuritized and hematitized potash feldspar occurs as small (1.0-3.5 mm) subhedral crystals, locally with microcline twinning. The feldspars display perthitic texture in places. Lamellar-twinned albite locally constitutes approximately 10% of the rock. The groundmass is a microcrystalline aggregate of quartz, potash feldspar and minor plagioclase which is locally coarsened due to recrystallization. Felsitic textures are rarely preserved.

Felsic lapilli are common in the nonwelded to slightly welded ash flow tuffs and consist mainly of irregularly shaped fragments of recrystallized quartz-potash feldspar porphyritic rhyolite and devitrified, spherulitic rhyolite tuffs. The maximum dimension of the lapilli vary from 1.0 to 10.0 mm, however, isolated fragments up to 6.0 cm are present in places. The lapilli are locally stretched with length:width ratios approaching 7:1. The lack of welding textures preserved in these rocks suggest that these stretched lapilli may be the result of syn- to post-depositional flowage rather than flattening and/or welding associated with the deposition of hot ash flows. Eutaxitic textures were not recognized in these rocks. A poorly developed flow alignment, defined by coarsening of the quartzo-feldspathic matrix is locally preserved in the more crystal-rich tuffaceous beds. Pumice lapilli in these rocks show little evidence of flattening. The pumice encloses quartz and potash feldspar crystals and locally displays granophyric patches (P. 24).

The lithic tuffs contain felsic lapilli (≤ 40% of the rock) which are petrographically similar to the groundmass, with the exception of being coarser grained (≤ 0.1-1.5 mm). Quartz, hematitized potash feldspar and plagioclase are the only phenocryst phases present.

The densely welded tuffs of the Complex display vitroclastic textures in a groundmass which is commonly intensely altered and coated with a fine, pervasive, hematite dust. Shards and pumice fragments are recognizable in places and display moderate degrees of flattening. Devitrification features are not widespread in the welded tuffs, but microspherulitic textures are locally preserved. Poorly developed axiolitic texture is present in one specimen of welded tuff.

Rhyolite flows are of restricted areal extent in the Grand Beach Complex. The flows are typically devitrified and locally show recrystallization of the fine grained cryptocrystalline, often felsitic groundmsss. Euhedral to embayed quartz, hematitized oligoclase and minor



Photomicrograph 24: Unflattened pumice fragment with granophyric patches and feldspar phenocrysts. Note reaction with iron stained matrix. Ash tuff of the Grand Beach Complex. (Plane polarized light; bar scale = .6 mm).

albite are typical phenocryst phases. The upper parts of the rhyolite unit display poorly developed vitroclastic textures. Both flattened and unflattened glass shards are preserved at this level of the unit, locally forming axiolitic textures. The vitroclastic felsites grade upwards (over 0.1 m) into moderately-welded tuffs which are petrographically identical to those described above.

6. STRUCTURAL AND METAMORPHIC HISTORY

6.1 Introduction

The structural pattern of the Marystown Group is dominated by the northeast trend of most units which has been affected by later flexuring from northeast to east-west. Present structural features are interpreted to be the result of an orogenic event which post-dates the deposition of Cambrian rocks and pre-dates the intrusion of the middle Carboniferous St. Lawrence Granite. The main period of deformation resulted in a regional northwest-southeast shortening accompanied by the formation of upright to overturned folds with associated northeast-striking axial planar foliations. Continued compression resulted in the development of high angle, northwest - dipping thrust faults.

The most prominent structural features are broad, open to moderately tight, dominantly northeast-plunging anticlines and synclines with associated vertical to steeply west-dipping axial planar foliations. Two sets of faults can be recognized in the area. Northeast-trending thrust and minor normal faults are related to the main period of folding. North-south and northwest trending faults post-date these structures. Late strain-slip foliations may be related to this later period of faulting.

6.2 Structures Related To The Main Deformation Period

6.2.1 Regional Foliation

The regional foliation of the Marystown Group varies in intensity from a wide to closely spaced fracture cleavage to a penetrative foliation. It is related to both the folding and faulting resulting from the main deformational event.

The foliation is axial planar to upright and westward-overturned fold structures (e.g. Beacon Hill Anticline, Tilt Hills Syncline). Recognizable folds are uncommon in areas of relatively intense deformation. In such areas, a penetrative schistosity, commonly defined by quartz and sericite, can be demonstrated to be axial planar to locally preserved, tight isoclinal folds. The regional foliation is coplanar with respect to primary orientations in the volcanic and sedimentary rocks.

The variation in the intensity of the regional foliation is a function of several factors. Lithological control of foliation intensity is well displayed in the interbedded felsic tuffaceous rocks and rhyolite flows of the Taylor's Bay Formation (e.g. in the area north of Roundabout and in the immediate vicinity of Taylor's Bay). No tectonic fabric is developed within the more resistant rhyolites, however structurally concordant rhyolitic lithic tuffs preserve a penetrative sericitic schistosity (Plate 6:1).

Northeast-striking zones of relatively intense vertical to west-dipping schistosity which die out rapidly across strike are developed in the Marystown Group (Plate 6:2). These schistose zones are interpreted to reflect the presence of thrust faults within the sequence (Strong et al., 1978 b), but in many areas no recognizable stratigraphic marker horizons are available to document the existence of such faults. One area in which this relationship can be demonstrated is immediately south of Salmonier Hill, where the intensity of the schistosity in the Taylor's Bay Formation increases southwestwards towards its thrusted contact with the Eocambrian sedimentary outlier in that area.

The intensity of the regional foliation is, in part, related to stratigraphic level. Rocks of the Taylor's Bay Formation are generally more pervasively deformed than the overlying Calmer and Garnish Formations. The stratigraphic units which overlie the Garnish Formation rarely display any regional penetrative foliation. Most of the fracture cleavages in the Hare Hills Tuff are related to northeast-trending faults in this westward-dipping monoclinal sequence. The Grand Beach Complex is essentially undeformed. Schistosities are only locally developed, and are related to the northwest-trending faults near Grouse Point. Deformation in the Barasway Complex is variable, but appears to be mostly lithologically controlled.

In general, there is an increase in deformation from northwest to southeast throughout the map area; a feature which predates the regional flexuring of the area. No clearly systematic variation is evident, this being the result of a combination of the factors governing intensity of deformation listed above. That part of the peninsula underlain

Plate 6:1 Foliated lithic tuff breccia of the Taylor's Bay Formation in the Beacon Hill Anticline.

Plate 6:2 Schistose zone in rhyolitic Mount Saint Anne Formation near Lawn.

by the Hare Hills Tuff, Grand Beach Complex, the eastern exposures of the Barasway Complex and the exposures of the Garnish and Calmer Formations west of the Beacon Hill Anticline form a flat lying to west-

dipping monoclinal sequence (Plates 6:3 and 6:4). Penetrative foliations are very rarely developed. A coarse fracture cleavage is the major tectonic fabric preserved in these rocks. A series of northeast-striking open to tight anticlines and synclines characterizes the central part of the peninsula which is underlain by the Taylor's Bay and Calmer Formations. The eastern part of the peninsula has a structural pattern characterized by tight, locally overturned anticlines and synclines. Normal and high angle reverse faults are characteristic of this part of the belt. This northwest to southeast increase in deformation with proximity to the boundary between the Marystown Group and the Rock Harbour - Burin Group terrain is recognizable throughout the Burin Peninsula (O'Brien, 1978; O'Brien and Taylor, 1979; O'Driscoll and Hussey, 1977).

6.2.2 Folds

The major folds in the area are broad, open synclines and anticlines with wavelengths in the order of 1-4 kilometers. The upright folds have associated vertical axial planar foliations. The folds are locally overturned to the east and have steep to moderately west dipping axial planes and axial planar cleavages. Locally, the western, overturned limbs of the smaller folds have been truncated by thrusts.

Plate 6:3 Gently dipping sediments of the Garnish Formation south of L'Anse au Loup.

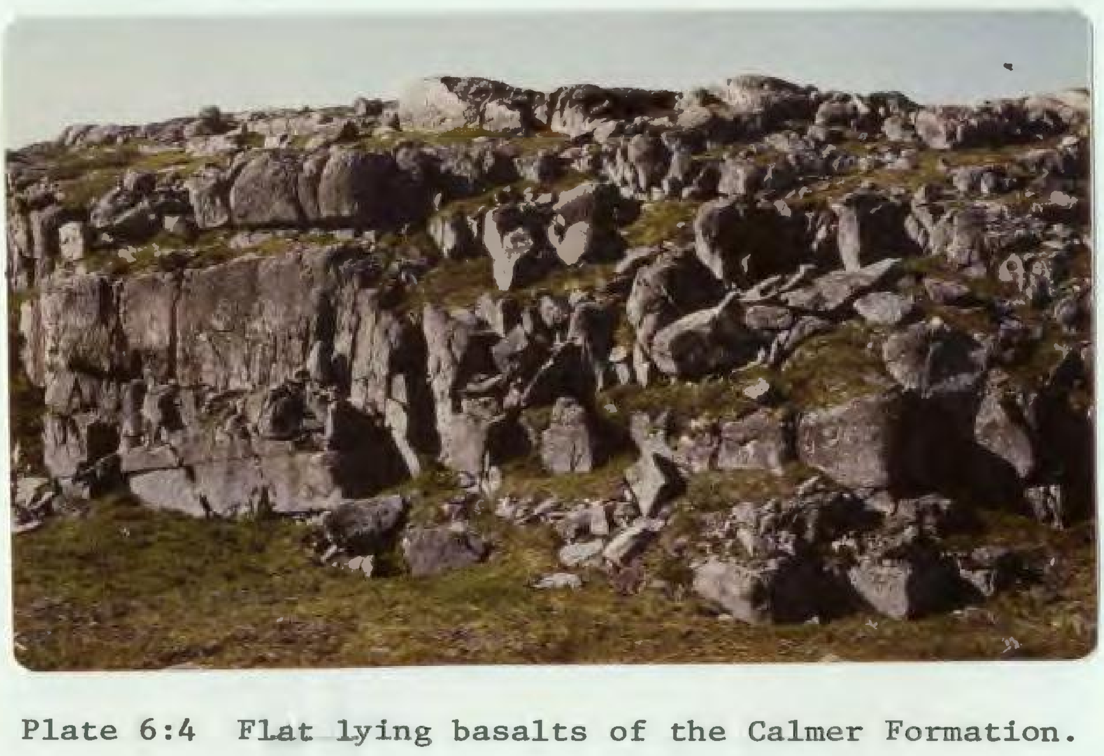


Plate 6:4 Flat lying basalts of the Calmer Formation.

This feature is present in both the Precambrian and Cambrian sequences on the peninsula (Taylor, 1976; Strong et al., 1978 a,b).

Locally preserved bedding-cleavage relationships and the regional outcrop distribution of the stratigraphic units suggest that the larger scale folds (e.g. Beacon Hill Anticline, Tilt Hills Syncline) in the central parts of the area plunge moderately to the northeast. The two anticlines in the southwestern part of the area (near Flagstaff Point) plunge to the southwest. Doubly plunging folds, such as those described by Bradley (1962) have not been recognized in this area.

Small-scale folds in the volcanic rocks of the Marystown Group are rare. This rarity may be more apparent than real, due to limited exposure and lack of lithologically unique marker horizons which can be traced across fold axes. Also, the rapid facies variations which occur along strike (e.g. in the Grand Beach, Hare Hills and Barasway Complexes) prevent correlation of lithologically heterogeneous stratigraphic units across fold hinges (see Chapter 3).

Isoclinal folds are uncommon in the area, and have only been recognized in the Taylor's Bay and Mount Saint Anne Formation adjacent to the Lawn Bay Fault (section 6.2.3). These structures are both upright and overturned to the east. A penetrative schistosity, locally coplanar with primary layering features, is axial planar to these folds.

Open folds, with shallow dipping limbs, are present in the north central part of the area. The largest of these is a syncline near Fox Hummocks. The base of this structure is underlain by rhyolite flows of the Barasway Complex. The limbs are underlain by mafic tuffaceous rocks of the Calmer Formation.

The Kennedy Hill Anticline is cut by a high angle reverse fault which roughly parallels the fold axis. The axes of many of the larger scale folds (Beacon Hill Anticline, Salmonier River Syncline) have been offset by north-south trending faults.

6.2.3 Faults

Faulting has played a major role in determining the present distribution of stratigraphic units on the southern Burin Peninsula. Four main types of faults are present in the area. Northeast to east-west trending high angle reverse and thrust faults are the most prominent features. Vertical to steep northwest dipping normal faults are developed only locally. North-south faults of unknown dip show a component of strike-slip movement. Northwest-trending faults, in places represented by shear zones, are present in the northern part of the area.

The northeast-to east-trending normal and reverse faults are related to the main period of folding, particularly in the development of the eastward overturned folds. The northwest and north-south trending faults truncate the folds and faults formed during the main period of deformation (see section 6.3.1).

The most prominent structural feature in the map area is the Lewins Cove Thrust Fault (Strong et al., 1975) (Plate 6:5). It defines the eastern and southern extent of the Marystown Group and displaces it southeastwards upon Cambrian rocks of the Inlet Group. In the area east of the St. Lawrence Granite, the fault strikes north to northeast and dips approximately 45° to the west. Westward dipping schistosities are locally developed adjacent to the fault. Stretching lineation, parallel to the direction of thrusting, is developed in rhyolite tuffs of the Mount Saint Anne Formation adjacent to the fault.

The fault plane is not exposed in the area between Mount Saint Anne and Black Hill, however, the presence of the Fault is the most reasonable explanation of the Marystown Group - Inlet Group contact relations seen in that area (Strong et al., 1978b). Indirect evidence for the existence of the Fault in this area may be present in the southward facing isoclinal folds in the Inlet Group on Ryan's Hill. These structures are preserved immediately south of the contact with the Marystown Group. The east-west trend of the fault appears to be the result of a shallowing of the thrust plane and later regional flexuring. The latter is indicated by the east-west trend of the basaltic units of the Taylor's Bay Formation which parallels the fault in this area.

Several other northeast-trending thrust faults are present in the area. At Pump Cove, on the southern coast of the peninsula, interbedded red sandstones (possible equivalents of the Bay View Formation - section 2.3.4) and maroon lithic and crystal tuffs of the Mount Saint Anne Formation are thrust over red and green sandstones, shales and orthoquartzites of the Inlet Group. The thrust plane is marked by a 30 cm wide zone of shearing and minor brecciation which strikes northeast and dips to the northwest at 45° (Plate 6:6). A schistosity of

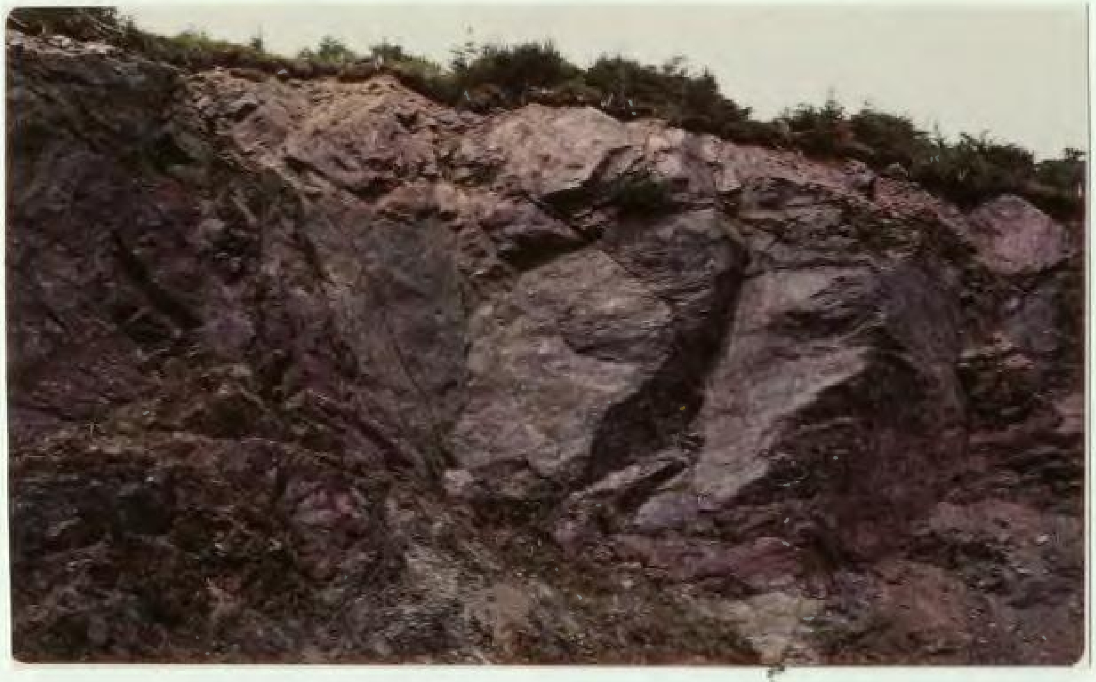


Plate 6:5 The Lewins Cove Thrust Fault at Lewins Cove; light colored volcanic rocks of the Marystown Group structurally overlying stratigraphically higher sediments of the Cambrian Inlet Group.

Plate 6:6:

Zone of shearing and brecciation marking the Pump Cove Thrust Fault.

similar orientation is locally developed adjacent to the thrust fault. Anticlines and synclines (wavelength ~ 10 m) which are present in the volcanic rocks adjacent to the thrust are overturned to the southeast (Plate 6:7).

Volcanic rocks of the Taylor's Bay Formation are in fault contact with red clastic sedimentary rocks of the Eocambrian Admiral's Cove Formation in the central part of the map area south of Salmonier Hill. The contact is marked by shearing in the volcanic rocks and southeastward overturning of folds in the adjacent Eocambrian strata.

Normal and reverse faults are present in the Marystown Group immediately northwest of the Lewins Cove and Pump Cove Thrust Faults. The contact between the Taylor's Bay and Mount Saint Anne Formations is unexposed and is marked by a topographic lineament along which schistosities in the Taylor's Bay Formation are preferentially developed. The stratigraphic position of these formations (sections 4.2 and 4.7) suggests that the fault has a high angle reverse sense of movement. Locally preserved bedding-cleavage intersections suggest the presence of tight folds within the volcanic rocks east and west of the fault trace.

The topographic lineaments and spatially associated zones of strong schistosity in the Mount Saint Anne Formation and westernmost exposures of the Taylor's Bay Formation (e.g. west of Lawn Bay) may reflect the existence of bedding plane thrusts which repeat sections of the stratigraphy in that area. A similar style of faulting has been documented within equivalents of the Taylor's Bay Formation in the central parts of the Burin Peninsula (O'Brien and Taylor, 1979).

A series of vertical to steeply dipping faults, locally with a reverse sense of movement, are exposed on the west side of Lawn Bay (Plate 6:8). The largest of these parallels the coast of the bay and is marked by a zone of intense brecciation and localized shearing. The main foliation along the fault is locally overprinted by 1 m wide, vertical shear zones (see section 6.3.2). This fault forms a structural weakness, along which a series of post-tectonic composite dykes is intruded (O'Brien et al., 1977).

6.3 Later Structures

Structures which post-date faulting, folding and the development of the regional foliation during the main deformational event are locally developed in the study area.

6.3.1 Faults

North-south faulting is evidenced by the offset of lithologic and stratigraphic units of the Marystown Group. The fault planes are not exposed but the fault traces are defined by strong geophysical and topographic expression (Figure 6:1). No cleavage or schistosity is associated with the faulting. Most of the north-south structures occur in the western part of the area where they offset the axis of the Beacon Hill Anticline and the synclinal and anticlinal axes in the area north and south of Salmonier Hill. The faults appear to have components of both strike-slip and dip-slip movement.

Plates 6:7 + 6:8 Folding adjacent to the Pump Cove Thrust Fault.

Northwest-striking faults crosscut earlier structures produced during the main deformational event. These features are locally associated with coplanar schistosities. In places, the faults display some component of transcurrent movement.

A northwest-trending fault, immediately north of Great Lawn Harbour, displaces the Lewins Cove Thrust Fault and also defines the western limit of Eocambrian rocks in that area. Primary and tectonic foliations in the Marystown Group are truncated by this fault.

A major northwest-trending lineament defines the contact of the Baraswayand Calmer Formations north of Garnish River. The lineament corresponds with a break in both the aeromagnetic and gravity patterns in this area. Regional geochemical trends established by lake sediment geochemistry (Davenport and Butler, 1978) parallel this structural break (pers. comm., P.H. Davenport). This northwest lineament parallels faults of a similar trend recognized immediately north of the present study area (O'Brien and Taylor, 1979) and is interpreted to reflect a similar structure.

Narrow (≤ 30 cm) northwest-trending shear zones cut the Grand Beach Complex in the vicinity of Grouse Point. The shearing appears related to a northwest-trending fault which has been outlined by recent diamond drilling and geophysical surveys in that area (pers. comm., British Petroleum Minerals staff). Lack of exposure prohibits the recognition of the surface extension of this feature.

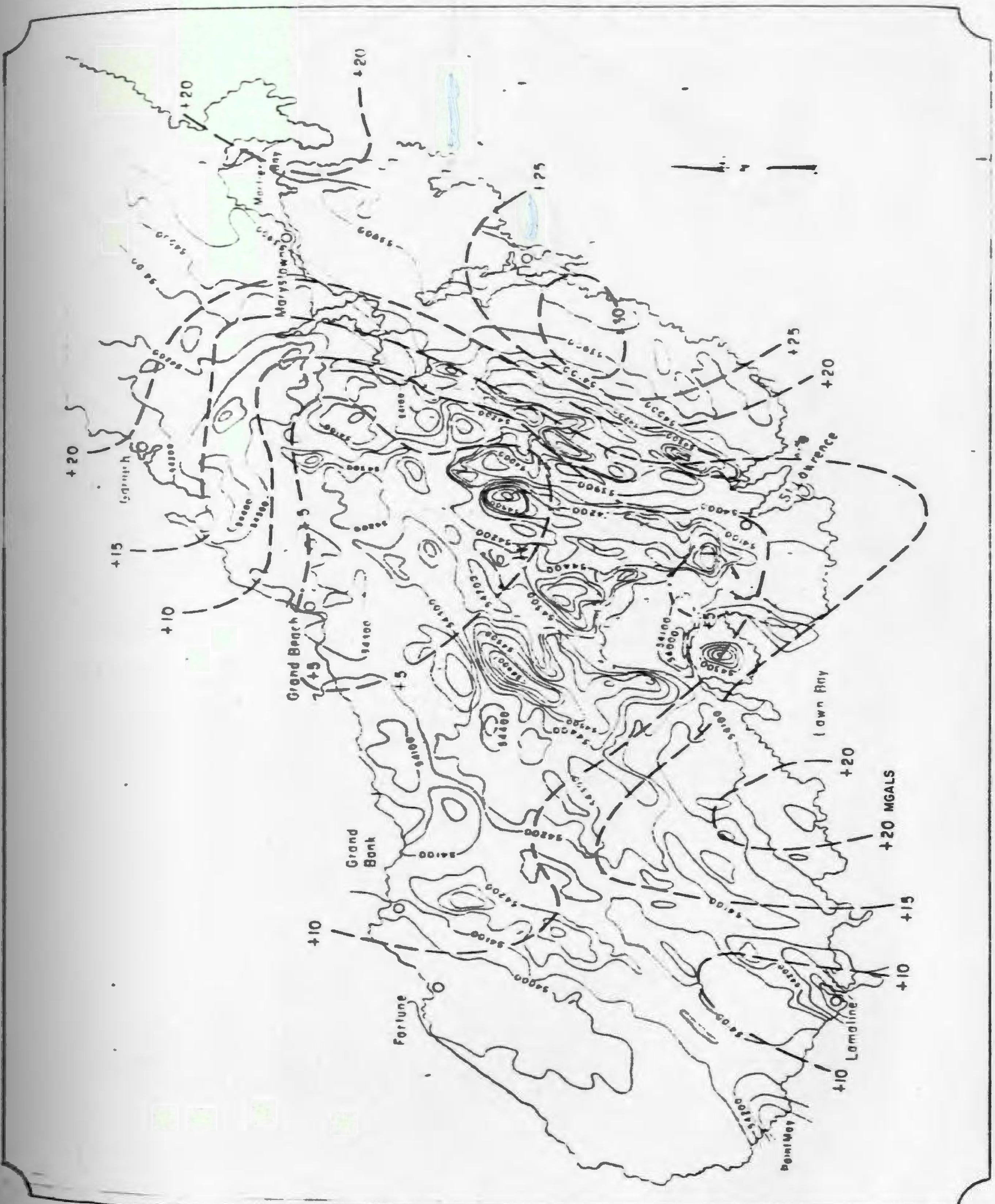


Figure 6:1 Aeromagnetic and gravity map, southern Burin Peninsula

6.3.2 Shear Zones

Late shear zones, which strike northwest and northeast are locally developed on the southern Burin Peninsula. These features are less than 30 cm wide and related to the formation of northwest-trending faults and the reactivation of the northeast-trending ones.

The shear zones near Grouse Point (section 6.3.1) are the best example of the northwest-trending structures preserved in the area. Wider and more extensive shear zones of similar orientations have been documented in the central Burin Peninsula (O'Brien, 1978) where they are interpreted to be related to the regional flexuring of the peninsula (section 6.3.4) (O'Brien and Taylor, 1979).

The major fault which parallels the west side of Lawn Bay is locally deformed by narrow (10-20 cm) shear zones which locally overprint the cataclastic foliation associated with the faulting. The late shear zones generally form at an angle of 45^{o} (or less) to the main foliation. They are parallel to the main foliation in plan but crosscut it in section. This shearing is interpreted to represent reactivation of the fault zone.

6.3.3 Crenulation Cleavage

A locally developed crenulation cleavage post-dates the formation of the regional foliation. This feature is recognizable only in the westernmost exposures of the Taylor's Bay Formation. North-northeast trending kink bands are the result of complete transposition of the earlier foliation.

Plate 6:9:

Vertical fault juxtaposing basalts of the Calmer Formation and rhyolite tuffs of the Mount Saint Anne Formation, near Roundabout.

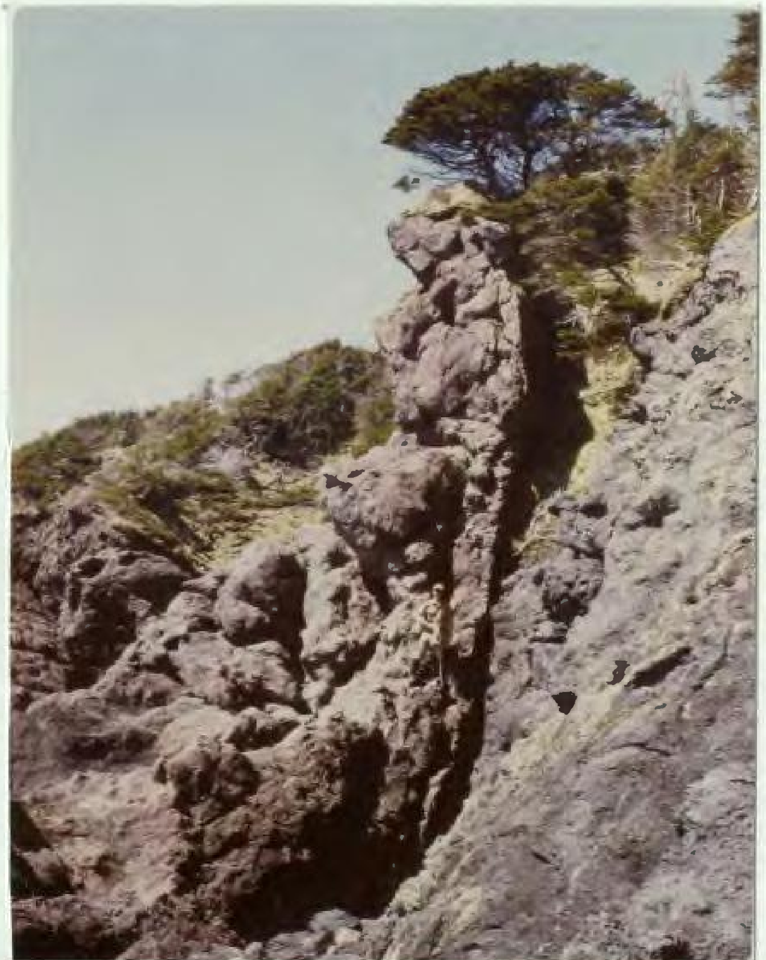


Plate 6:10 Kink bands in sericite schists near Lawn. (Mount Saint Anne Formation).

This late strain slip foliation is well developed in equivalents of the Taylor's Bay Formation in the central Burin Peninsula where it forms a well developed, closely spaced cleavage, axial planar to vertical, second phase folds.

6.3.4 Regional Flexuring

The main structural grain of the Marystown Group is northeast-trending in the western and eastern parts of the study area but is east-west in the centre of the peninsula, near the St. Lawrence Granite.

This flexuring is a regional feature which post-dates the deposition of Cambrian rocks and pre-dates the intrusion of the Carboniferous St. Lawrence Granite. The late stage structures described above may be related to this feature. The regional significance of this feature is discussed below (see section 6.5).

6.4 Metamorphism

Metamorphic facies within the Marystown Group vary from prehnite-pumpellyite to lower greenschist facies. The metamorphic grade is related to intensity of deformation and is in part a function of the stratigraphic level within the sequence. The metamorphic mineral assemblages are also related to original rock compositions.

The mafic volcanic rocks of the Taylor's Bay Formation are characteristically metamorphosed under greenschist facies conditions. A lower greenschist facies mineral assemblage of chlorite, epidote, albite, calcite actinolite and opaque oxides is typical of these rocks (see section 5.1).

Basaltic rocks of the Calmer Formation have been metamorphosed under prehnite-pumpellyite and lower greenschist facies conditions. The basaltic flows at Calmer and Famine Back Cove locally contain prehnite and pumpellyite as amygdule-filling phases. Localized zones of shearing and epidotization have a lower greenschist facies mineralogy similar to the Taylor's Bay Formation basalts.

The basaltic flows north of Lamaline have a metamorphic assemblage of chlorite, albite, hematite and epidote with minor calcite and sphene. The presence of prehnite in several sections from this area suggest that these rocks were metamorphosed under prehnite-pumpellyite facies conditions. Baslats of the Calmer Formation from the Three Hummocks area contain prehnite, epidote, calcite ahd hematite.

Most of the felsic volcanic rocks of the Taylor's Bay Formation display a typical lower greenschist facies metamorphic assemblage of sericite, quartz and epidote. The felsic volcanic rocks of the various units which overlie the Calmer Formation are only locally metamorphosed to lower greenschist facies. The ash-flow tuffs and rhyolites of the Hare Hills Tuff, Grand Beach Complex and parts of the Barasway Complex contain only minor sericite and calcite. Epidote is locally present but not as extensively developed as in the Taylor's Bay Formation. Piemontite was recognized only in rhyolites of the Hare Hills Tuff. Schistose zones within these units (e.g. northwest shear zones in the Grand Beach Complex) display a typical lower greenschist facies mineralogy of quartz and sericite.

Extensive hornfelses are developed in the Taylor's Bay and Calmer Formations adjacent to the St. Lawrence Granite. They have been described in some detail by Evans (1978).

In the northwest parts of the contact aureole, near Strouds Pond, silicic volcanic rocks have undergone intense pyrophyllitization accompanied by the development of andalusite, dumortierite, quartz and sericite.

The basalt and mafic tuff units have been metamorphosed into a series of green hornblende hornfelses, with xenoblastic magnetite crystals up to 2 cm in diameter.

6.5 Summary and Interpretation

The main period of deformation which affected the Marystown Group resulted in a regional northwest-southeast shortening, accompanied by the formation of upright to overturned folds with associated vertical to steeply west dipping axial planar foliations. Continued compression resulted in the development of high-angle reverse and thrust faults.

The main period of deformation resulted in structural features which are locally common to both Precambrian and Cambrian rocks within the map area.

The youngest rocks in the area to be affected by the regional deformation are middle Cambrian in age. The intrusion of the St. Lawrence Granite (315 ± 5 Ma., Bell and Blenkinsop, 1975) post-dates the main period of deformation, therefore the regional deformation occurred between the middle Cambrian and lower-middle Carboniferous.

The lack of a more accurate upper time limit for the deformation presents difficulties in establishing whether it occurred during the Virgilinian (Glover and Sinha, 1973), Acadian (Williams et al., 1974) or Taconic (Rodgers, 1972) orogenies.[1]

The northeasterly trends of the structures and the easterly direction of thrusting and fold overturning are similar to Acadian structures elsewhere in the Avalon Zone (e.g. Williams, 1971; Rast et al., 1976). However, the marked variation in intensity of deformation is reminiscent of the early Paleozoic Virgilinian deformation as described by Glover and Sinha (1973).

No direct evidence for a regional Precambrian orogenic event (e.g. Rodgers, 1972) is preserved in the study area.

Locally-developed late structural features post-date structures produced during the main period of deformation. The most prominent of the late structures are north-south and northwest-southeast-trending faults and the regional flexures of the early structures and stratigraphic units of the Precambrian and Cambrian sequences.

These flexures are part of a larger regional flexure of the entire Burin Peninsula (O'Brien, 1978) which parallels the Hermitage Flexure of southern and southeastern Newfoundland (Williams et al., 1970). On the Burin Peninsula, the northern recess of the flexure is the locus of northwest-trending shears and faults (O'Brien, 1978; O'Brien and Taylor, 1979) and the salient in the southern part of the flexure is marked by the intrusion of the Carboniferous St. Lawrence Granite, apparently along a north-south trending fault (Strong et al., 1978 b). The latter suggests that the flexuring and associated faulting may be either a late

[1] 6 sericite schists from this region have been dated, with ages between 382 ± 5 and 391 ± 10 MA (D. Dallmeyer, pers. comm., 1979) suggesting the deformation was Acadian.

Acadian or possibly early Hercynian feature. Other evidence within the map area (e.g. parallel flexuring of Precambrian and Cambrian strata) suggest this flexure is post-Cambrian in age.

Brown and Colman-Sadd (1976), considered the Hermitage Flexure to be an original feature of the rocks west of the Avalon Zone. They suggest that the original shape of the continental margin may have affected the initial stresses caused by the juxtaposition of the Gander and Avalon Zones.

The sigmoidal curvature in the trend of the Paleozoic folds (and related axial planar foliations) has the form of a ductile shear zone similar to smaller scale ductile shears described by Ramsay and Graham, (1970). Similar large scale flexures related to Paleozoic shear zones in Australia have been reported by Coward (1976). He showed that a regional pattern of folds on northeast-southwest axial planes was modified by a sinistral shear couple parallel to the trend of the fold isochrons, i.e. axial planar to the flexure.

Such a model of simple shear could be applied to the "Burin Flexure". The sinistral shear couple related to the flexuring may result in the formation of the northwest-southeast trending faults and shear zones which are common in the recesses of the flexure. This simple shear mechanism is also suggested by the variations in intensity of deformation. Areas where the regional foliation has been flexured from its original northeast orientation are marked by an increase in intensity of deformation (e.g. O'Brien, 1978). Similar features in the South Australian flexures have been related to structures in the underlying basement (Coward, 1976).

7. GEOCHEMISTRY

7.1 Introduction

Geochemical studies of the Marystown Group were carried out primarily to supplement the petrologic and stratigraphic observations discussed in the previous chapters and to help understand the magmatic affinities and possibly the general tectonic setting of the volcanic rocks of the southwestern Avalon Zone. In depth discussions concerning the patterns of elemental distribution in these rocks and the detailed petrogenesis of the Marystown Group volcanics are beyond the scope of this study and are, therefore, only discussed briefly in this chapter.

The 127 whole rock geochemical analyses are presented in Appendix 1 and include determinations of both major oxides (Fe_2O_3, TiO_2 P_2O_5, SiO_2, CaO, K_2O, MgO, Al_2O_3, FeO, Na_2O, MnO, H_2O) and selected trace elements, including Zr, Sr, Rb, Zn, Cu, Ba, Nb, Pb, Ni, Cr and Y. Included in this total are supplementary analytical data for 18 volcanic rocks of the Marystown Group which have been taken from Taylor (1976) and Strong et al. (1979). C.I.P.W. norms for the analysed samples are listed in Appendix 2.

Analytical methods, along with precision and accuracy data for the major and trace element analyses are presented in Appendices 3 & 4.

7.2 Sampling

Specimens for chemical analysis were collected with the aim of obtaining as representative a sampling as possible for the various stratigraphic units of the Marystown Group. However, such a distribution of sampling was hampered by several factors. Efforts were made to avoid sampling any volcanic rocks which showed obvious macroscopic evidence of metamorphic alteration. Further screening of specimens for substantial alteration was done during petrographic study of these rocks carried out prior to analyses. Nevertheless, most analysed rocks have been altered to some degree. The pyroclastic nature of many of the volcanic rocks of the Marystown Group also influenced the sampling distribution. Because ash flow tuffs represent mechanical fractionates of a parental magma source, many authors (e.g. Lipman, 1967, Spark et al., 1973, etc.) suggest that the chemical composition of ash flow tuffs often does not provide an accurate estimate of the chemical composition of the parent magma. For this reason, care was taken to avoid sampling any heterolithologic tuffs or tuff breccias. The majority of the samples collected for analysis are from massive basaltic and intermediate flows, flow-banded, autobrecciated and massive silicic flows and densely welded plagiophyric vitric tuffs. Specimens of the latter lithology were selected only where included lithic fragments represented less than 1% of the entire rock.

Despite the difficulties involved in attaining an ideal sampling, all units are represented with the following sample distribution: Taylor's Bay Formation: 17; Calmer Formation: 42; Hare Hills Formation: 5; Barasway Complex: 11; Mount Saint Anne Formation: 12 (including 6 samples from Taylor, 1976); Grand Beach Complex: 30 (including 12 samples from Strong et al., 1979). Sample locations are plotted on the geological map (in pocket).

7.3 Alteration

Most of the volcanic rocks of the Marystown Group have been subjected to metamorphism under prehnite-pumpellyite to greenschist facies conditions and have undergone varying degrees of chemical alteration. This metamorphic alteration, combined with chemical changes related to deuteric and syndepositional alteration may lead to difficulties in interpreting many of the primary chemical features of a volcanic terrain. The chemical effects of sub sea-floor metamorphism (Cann, 1969; Spooner and Fyfe, 1973) and burial metamorphism (Jolly and Smith, 1972; Wood et al., 1976) vary, but most authors consider that the composition of the metamorphic fluids is the main factor affecting the original chemistry of these rocks (Vallance, 1969, 1974; Smith, 1968; Hart et al., 1974; Kerrich et al., 1977). Metamorphism can produce variable metasomatic effects in many of the major and trace elements, particularly Na, K, Ca, Ba, Rb and Sr which locally display up to 50% variation in concentration.

The petrology of the Marystown Group volcanic rocks clearly indicates that some of the major elements have migrated during either syngenetic or metamorphic alteration. Alteration of plagioclase to albite, sericite, zoisite and calcite is widespread in the volcanic rocks (more so those metamorphosed under greenschist facies conditions) suggesting mobility of CaO and the alkalies. Chloritization of plagioclase in many of the basaltic rocks reflects leaching of CaO and addition of MgO. The diffuse albite twinning and the presence of checkered albite in the rhyolite flows may be interpreted as the alteration of alkali feldspar to albite (cf. Battey, 1955). The widespread occurrence of calcite, chlorite and epidote filled amygdules and veins, common in the Calmer Formation also reflect major element mobility. The localized occurrence of chlorite, followed by epidote and calcite reflects the sequential breakdown of Fe and Mg bearing phases such as the olivines (to iddingsite, chlorite and calcite) and clinopyroxenes (to chlorite and/or epidote) followed by the metamorphic alteration of the calcic plagioclases to sodic plagioclase and chlorite.

The presence of hematite staining, locally in the form of Liesegang banding, is common in the basaltic rocks. Similar features have been interpreted by Singer and Naurot (1970), to reflect iron mobility associated with groundwater percolation. The wide range in Fe_2O_3/FeO ratios shown in Figure 7:1 may be in part due to similar processes.

There is a widespread variation in the alkali concentration of the volcanic rocks of the Marystown Group (see Figures 7:2 and 7:13). This variation can be related to a variety of factors. Several authors consider that silicic rocks of keratophyric composition are related to metamorphism and associated metasomatism (e.g. Levi, 1969; Malpas, 1971; Hughes and Malpas, 1971 and Hughes, 1973). Syn-volcanic alkali mobilization may also result in variation in the alkali elements. Scott (1971) and Lofgren (1970) demonstrated that significant alkali exchange occurred between silicic glass and an aqueous phase during the cooling and post-eruptive devitrification of rhyolitic flows. The significance of the scatter in K_2O/Na_2O ratios is discussed in Section 7.4.4. The petrogenetic significance of the variation of alkalies in a volcanic rock is affected by metasomatic processes, although some of the alkali variation in the Marystown Group may be the result of primary magmatic

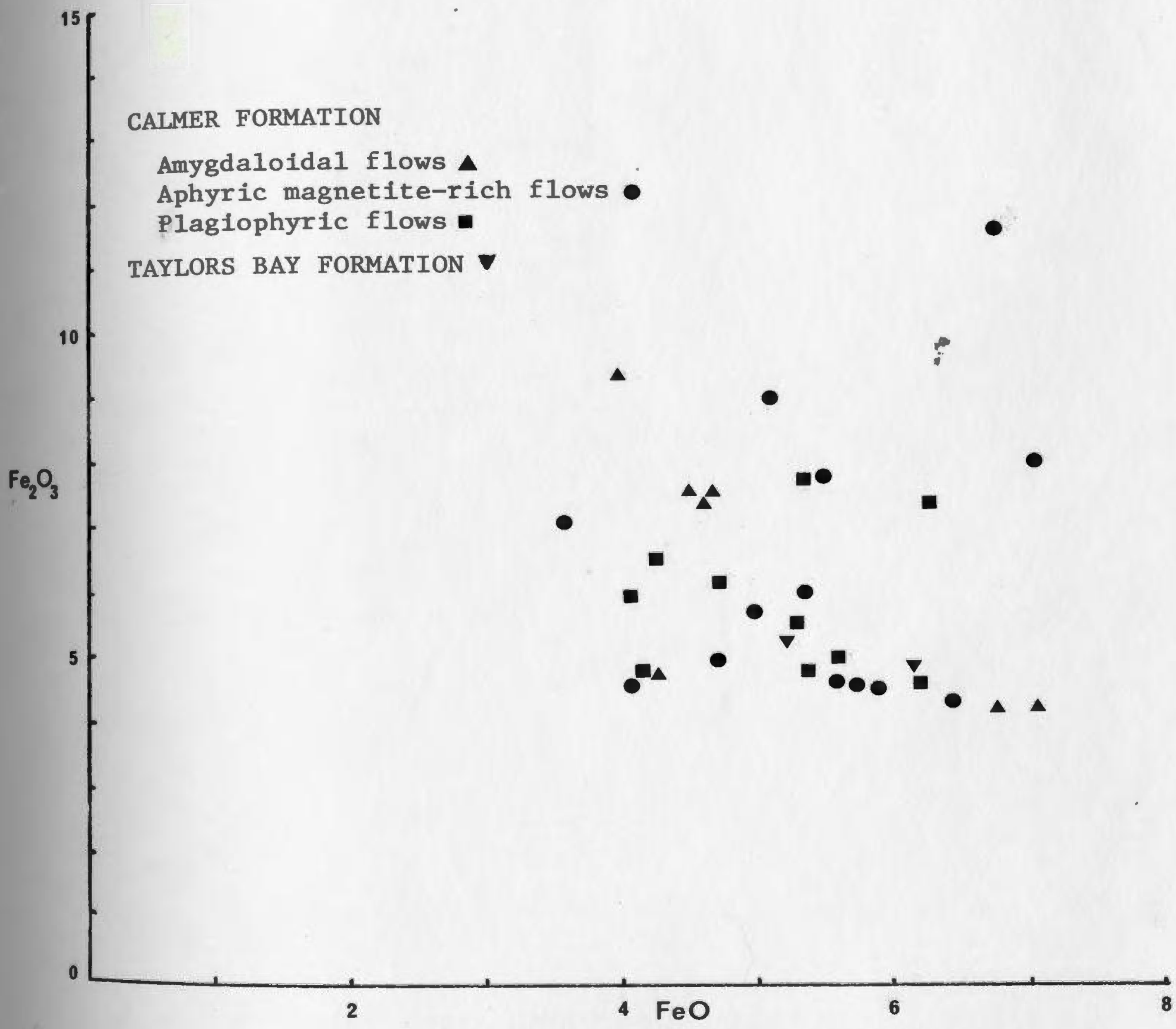


FIGURE 7:1 Fe_2O_3 vs. FeO plot of selected basaltic rocks of the Marystown Group.

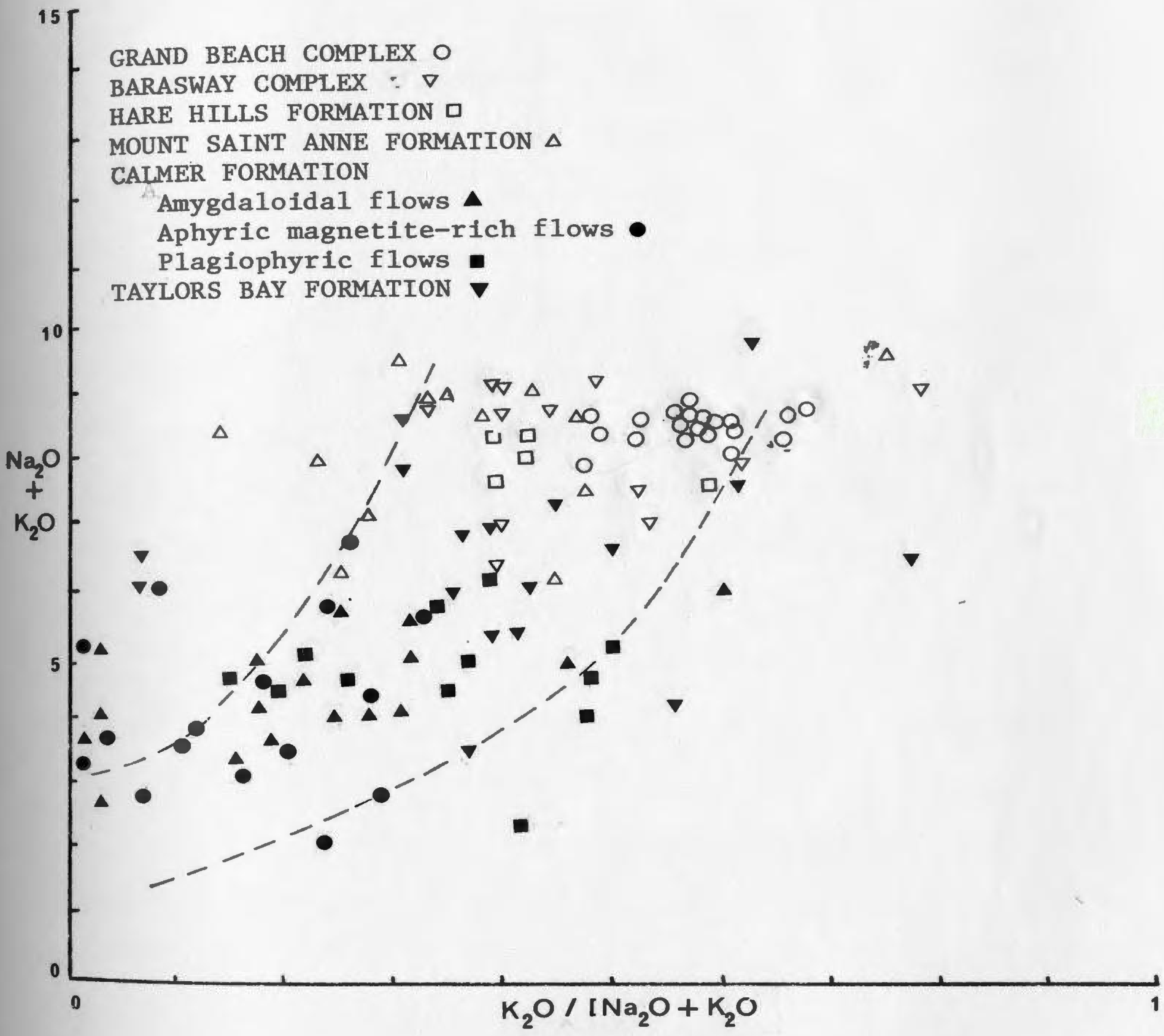


FIGURE 7:2 $Na_2O + K_2O$ vs. K_2O / $(Na_2O + K_2O)$ plot for volcanic rocks of the Marystown Group. Field of "igneous spectrum" from Hughes (1973).

variation (see Section 7.4.1.4).

The effect of metamorphic and deuteric alteration on the major and trace element concentrations of volcanic rocks must be considered when using geochemical parameters to interpret the chemical variation of a volcanic field such as the Marystown Group. The significance of standard geochemical plots which employ the variation of alkalies to illustrate trends in magmatic evolution are clearly limited by the alteration effects described above. Examples of such diagrams are the AFM diagram (Wager and Deer, 1939) and the various alkalies-silica plots (McDonald and Katsura, 1964; Kuno, 1966; Irvine and Baragar, 1971).

In metamorphosed volcanic terrains, the most significant parameters of magmatic variation are the elements Al, Ti, Zr, Nb and P, which are considered to be relatively resistant to mobilization under a variety of metamorphic conditions (Carmichael, 1969; Cann, 1970; Pearce and Cann, 1971, 1973, Hart et al., 1974; Baker and Henage, 1974). In recent years a number of authors have used the distribution and variation of these elements in volcanic rocks in differentiating tectonic environments and distinguishing magmatic affinities. Some of the more widely used plots (e.g. Floyd and Winchester, 1975; Winchester and Floyd, 1976, 1977; Pearce, Gorman and Birkett, 1975) have been adopted for use in this thesis. It should be emphasized, however, that such plots should be used with discretion and not taken as sole and distinct indicators of tectonic environment. The geochemical characteristics of the Marystown Group are used to supplement the field and petrographic studies, and are not intended to stand alone as an independent means of understanding the geological environment.

7.4 Geochemical features of the Marystown Group

The major and trace element data are given in Appendix 1. Normative compositions of these rocks (Appendix 2) were calculated from anhydrous analyses with adjusted Fe_2O_3/FeO ratios. The anhydrous major element oxides and trace elements are plotted against SiO_2 in Harker diagrams in order to outline elemental distribution throughout the Marystown Group. Standard AFM and alkali-silica diagrams are given to show the magmatic affinities of the Group as a whole based on major element data. A more detailed description of the unique trends, variations and affinities of the various Formations is given in Sections 7.4.1 to 7.4.4. The geochemical features of the Barasway Complex and the Hare Hills and Mount Saint Anne Formations display little significant variation and are discussed together and compared to the Grand Beach Complex. The Taylor's Bay and Calmer Formations are geochemically unique and are therefore discussed separately. An attempt is made to recognize relicts of magmatic affinities now obscured by a metamorphic overprint.

7.4.1

7.4.1.1 Harker diagrams: major element oxides

The variation of the major elements with concentration of SiO_2 shown in Figure 7:3 can be predicted on standard petrologic grounds. There is relatively systematic decrease in TiO_2, MnO, P_2O_5, Al_2O_3, MgO, CaO and total Fe decrease with increasing SiO_2 content while K_2O and Na_2O increase proportionally with SiO_2. Al_2O_3, MgO, TiO_2, P_2O_5, Fe_2O_3 and FeO show little variation in trends which could be related to alteration. The marked scatter of Loss on Ignition (H_2O and CO_2) suggests

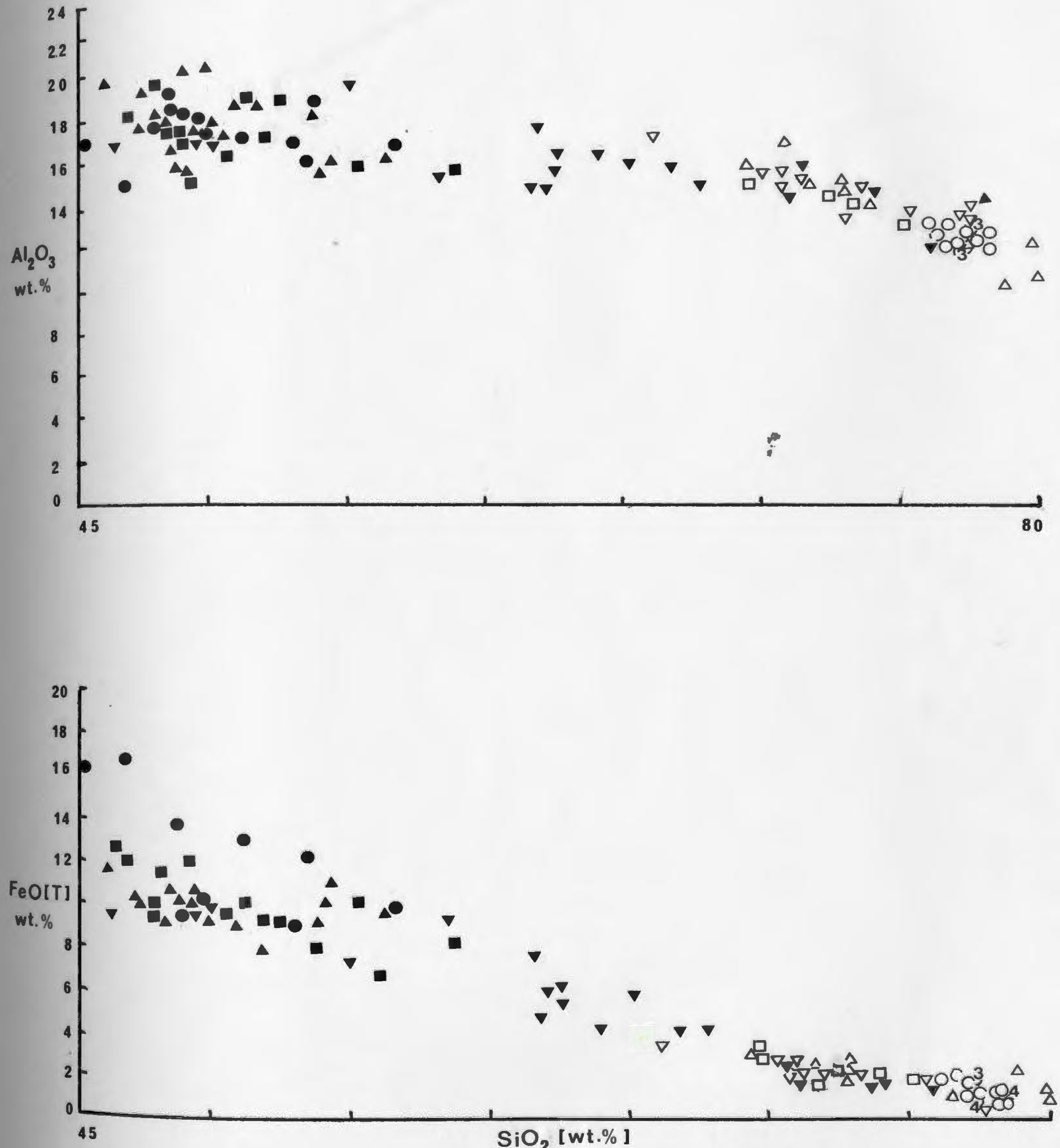


FIGURE 7:3 Harker variation diagrams: Weight percent major element oxides for all Marystown Group volcanic rocks. Symbols as in Figure 7:2

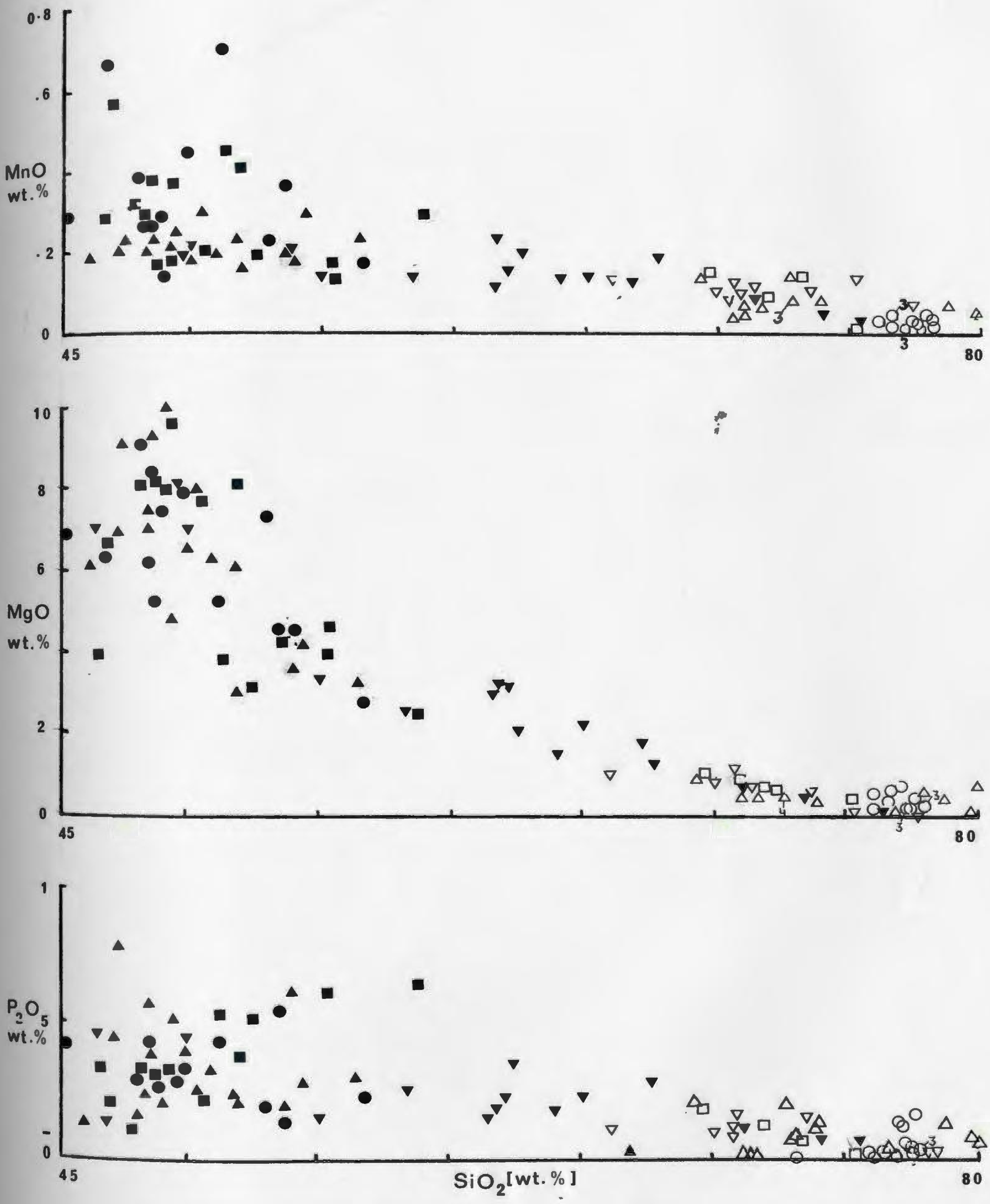


FIGURE 7:3 (Continued)

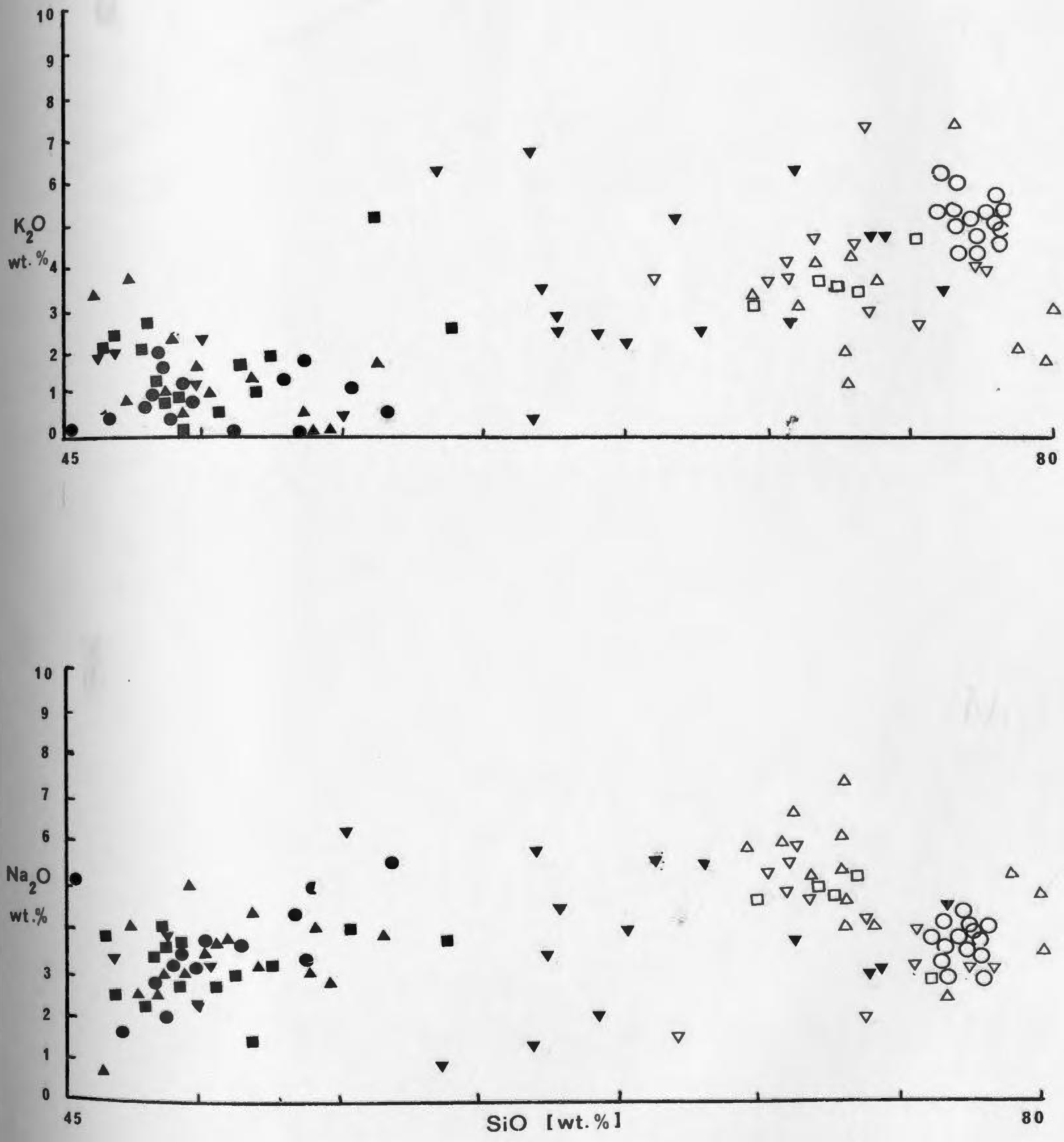


FIGURE 7:3 (Continued)

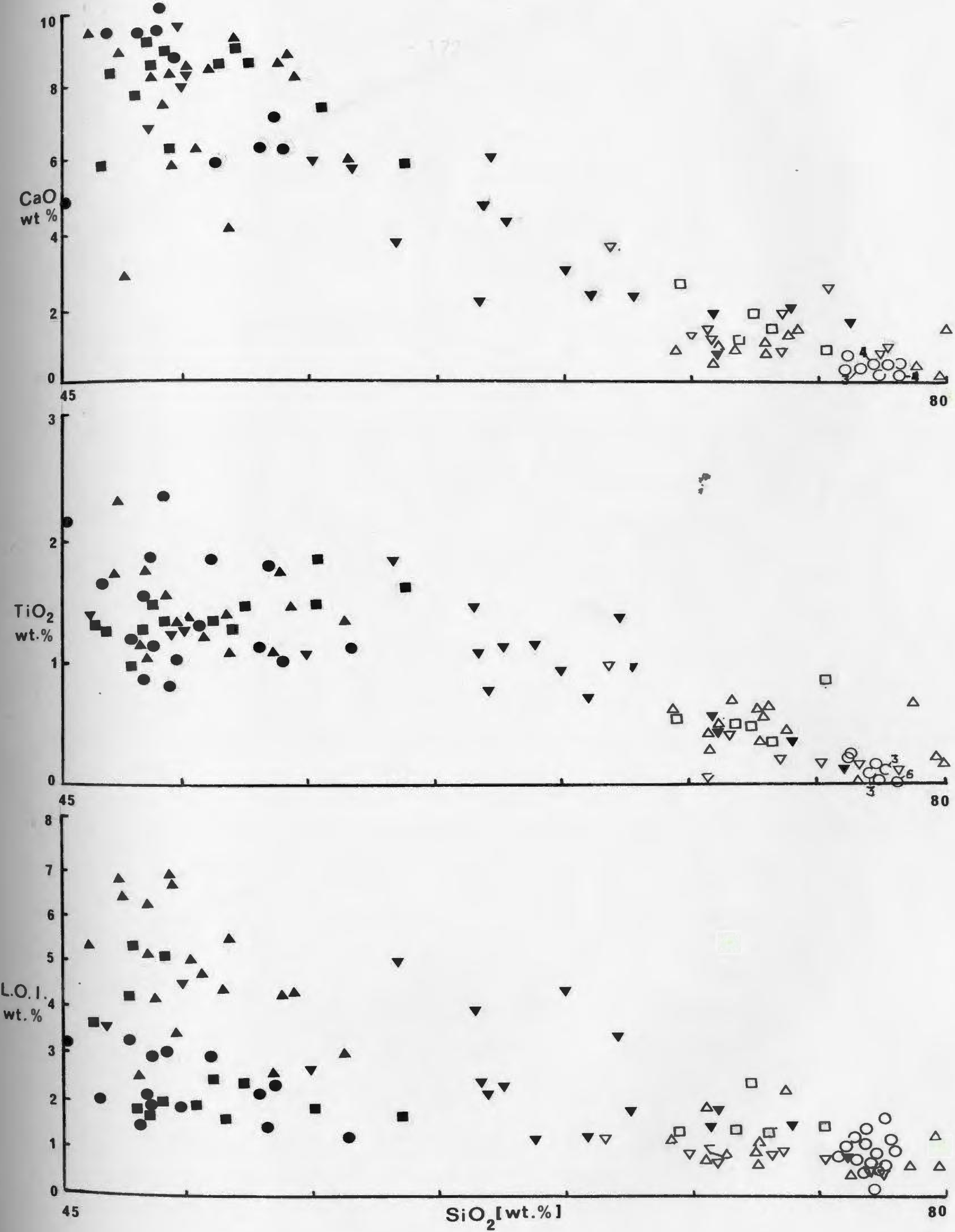


FIGURE 7:3 (Continued)

that the relatively poorly defined trends shown by the remaining major elements are in part related to element mobility during post-eruptive alteration. The variation in major element trends amongst and within the various formations is discussed in more detail in Sections 7.4.2, 7.4.3 and 7.4.4

7.4.1.2

Figure 7.4 shows the variation in concentration of trace elements with SiO_2 for the entire Marystoen Group. Cu and Zn display a wide scatter in the more mafic and intermediate compositions, but show a negative correlation with SiO_2 in the more siliceous rocks. The decrease in concentrations of Cr and Ni with increasing SiO_2 is predictable on the grounds of the similar chemical behavious of these trace elements and Mg and Fe. The wide scatter of the alkalies, particularly in the K_2O concentrations of the silicic compositions, is reflected by the considerable variation in concentrations of Sr, Ba and Rb in all rock types. Ba and Sr show slight positive trends with progressively greater scatter in the more siliceous rocks, whereas Rb shows a 50% variation in concentration in all rock types, masking any primary geochemical trends which these rocks might display. Pb displays a close geochemical correlation with SiO_2. Y and Nb and to a lesser extent Zr display a limited scatter in all rock types. The geochemical behaviour of Zr would suggest that its variation in concentration reflects some primary magmatic variation as well as alteration. The behaviour of Y and Nb is predictable since these elements are not readily accommodated in most common rock forming minerals and are concentrated in residual

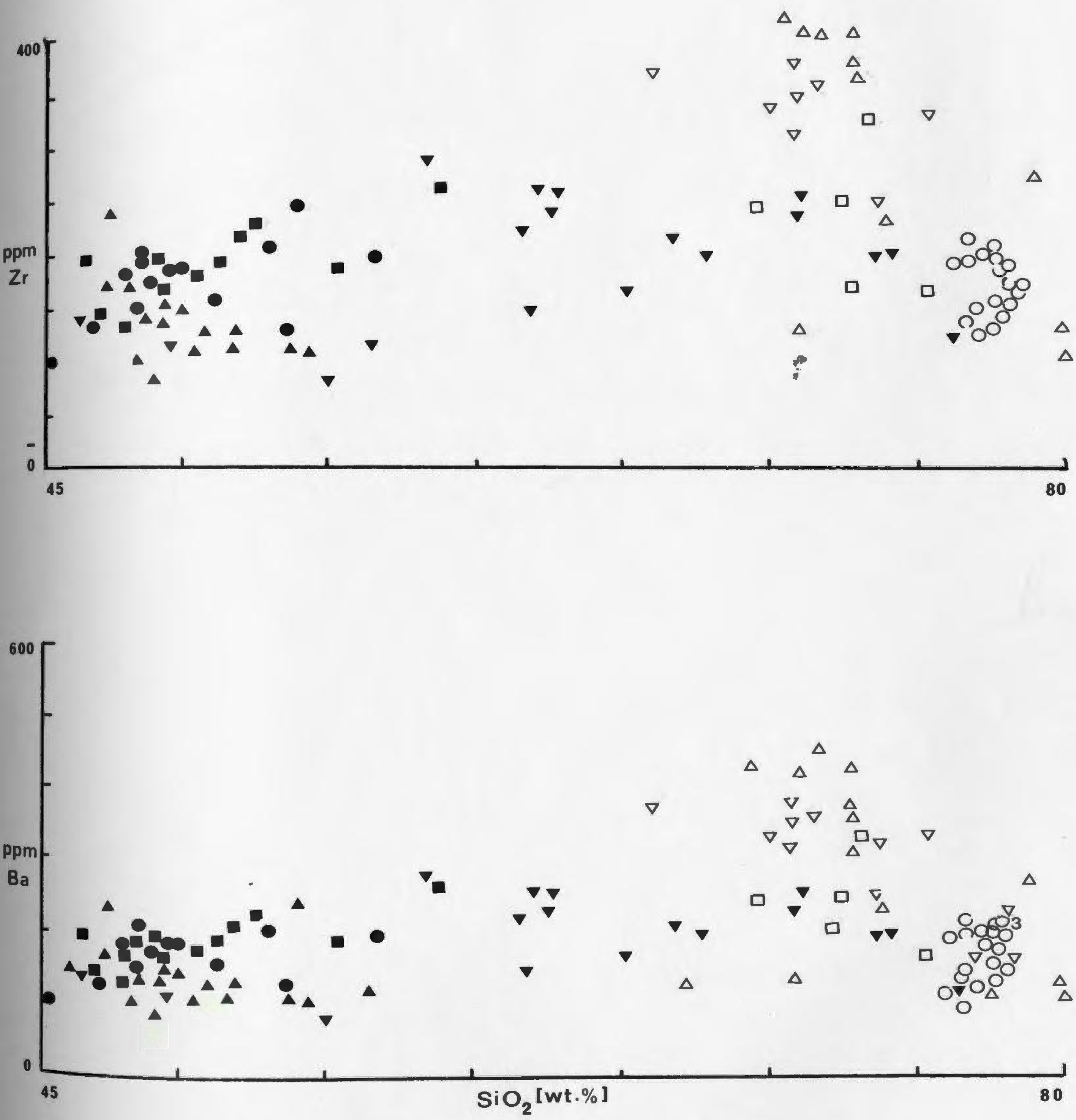


FIGURE 7:4 Harker variation diagrams : Trace element concentrations vs. SiO_2 for all Marystown Group volcanic rocks . Symbols as in Figure 7:2 .

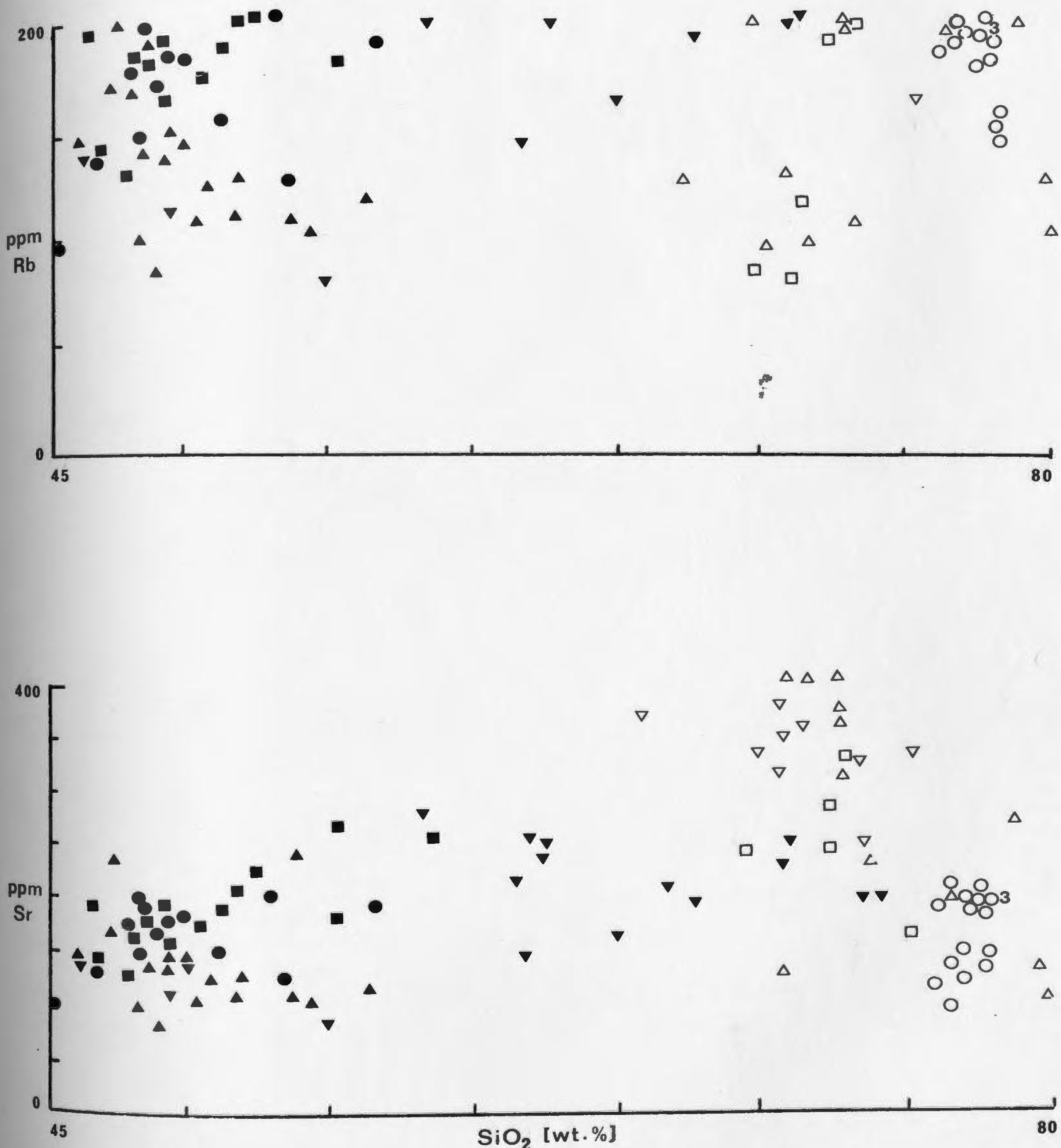


Figure 7:4 (Continued)

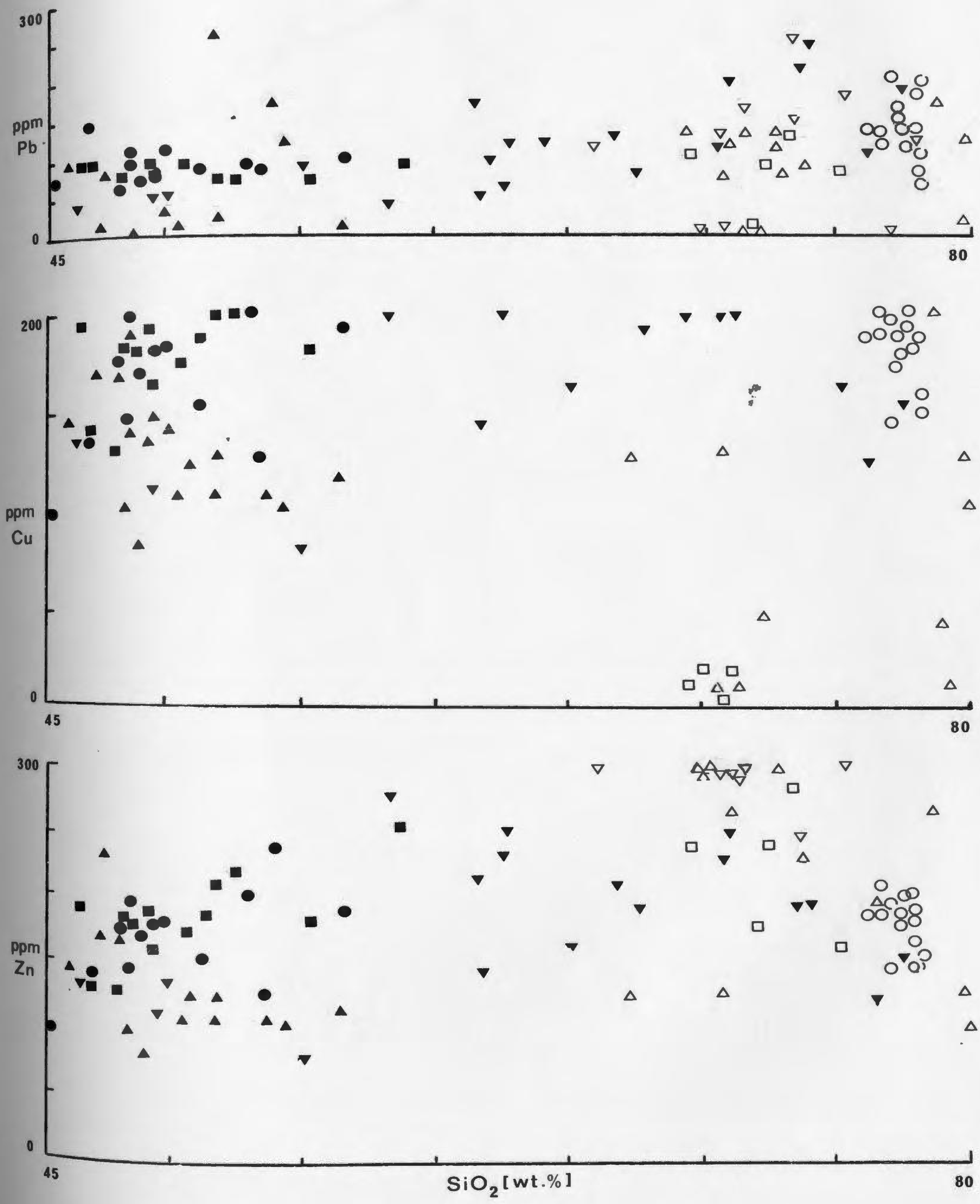
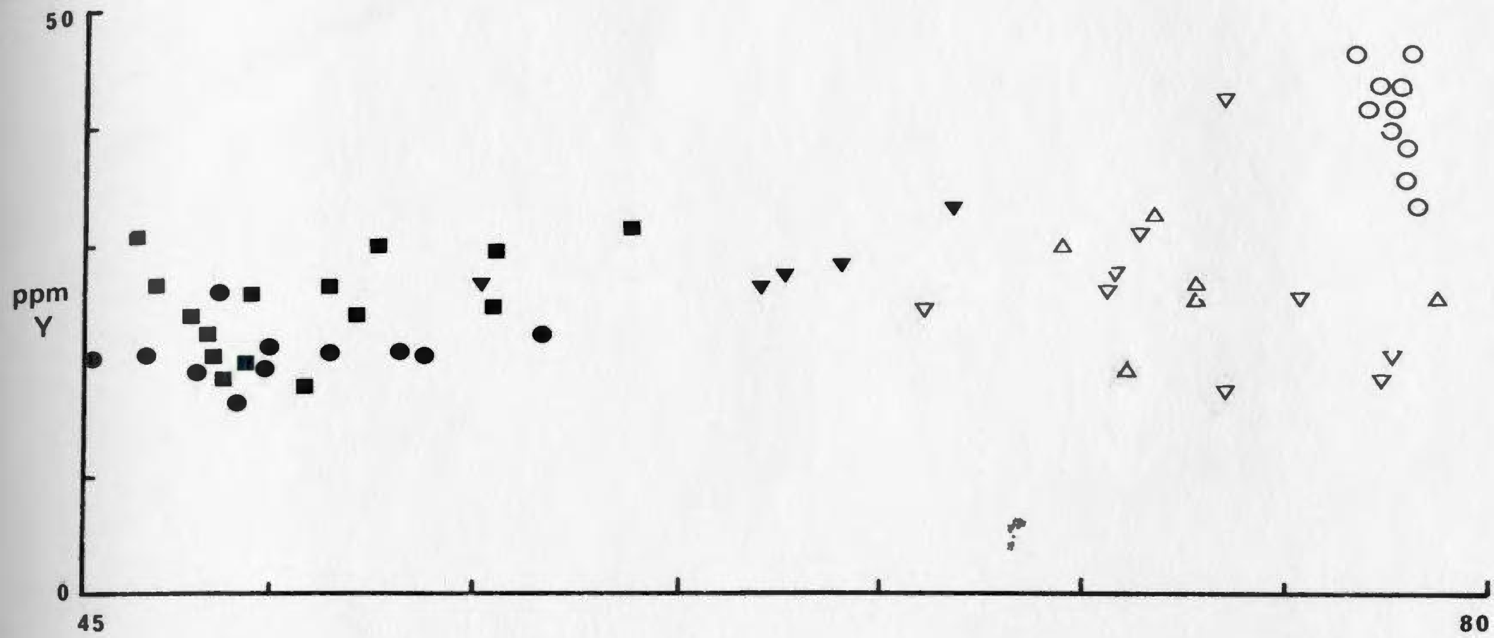


FIGURE 7:4 (Continued)



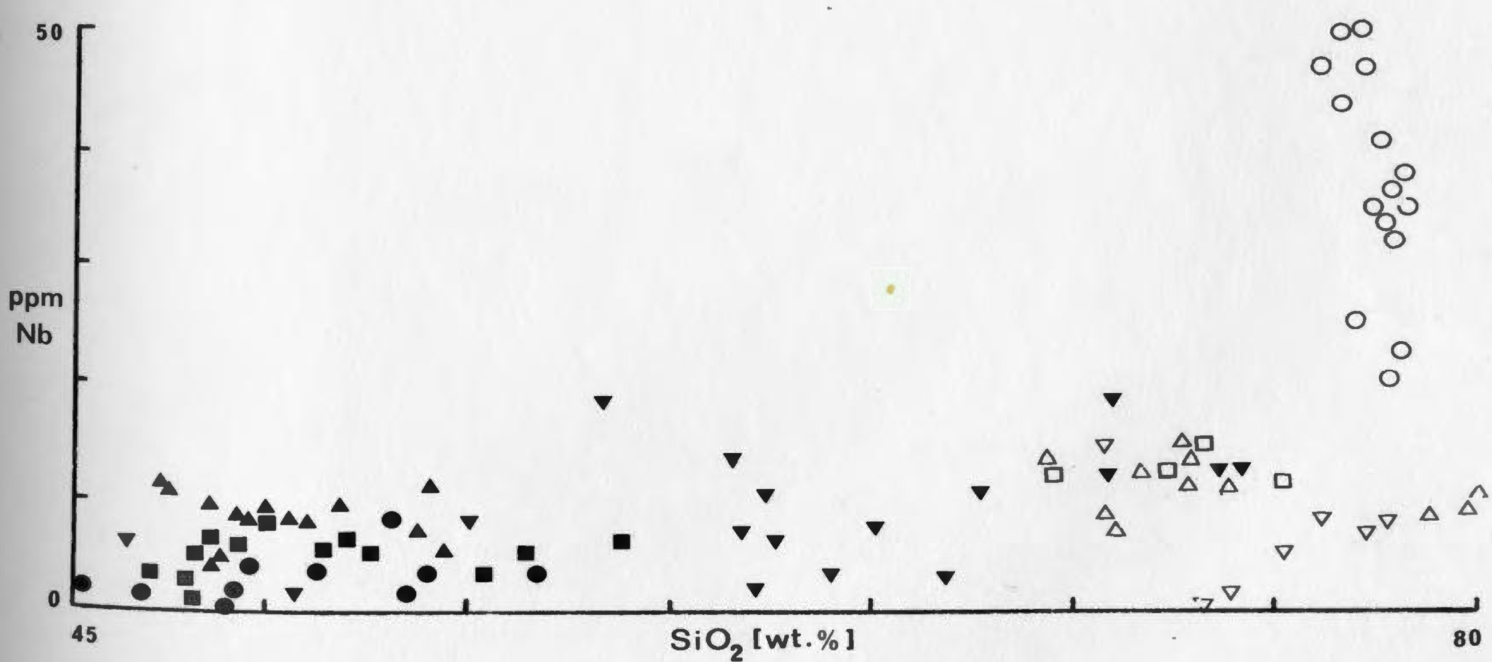
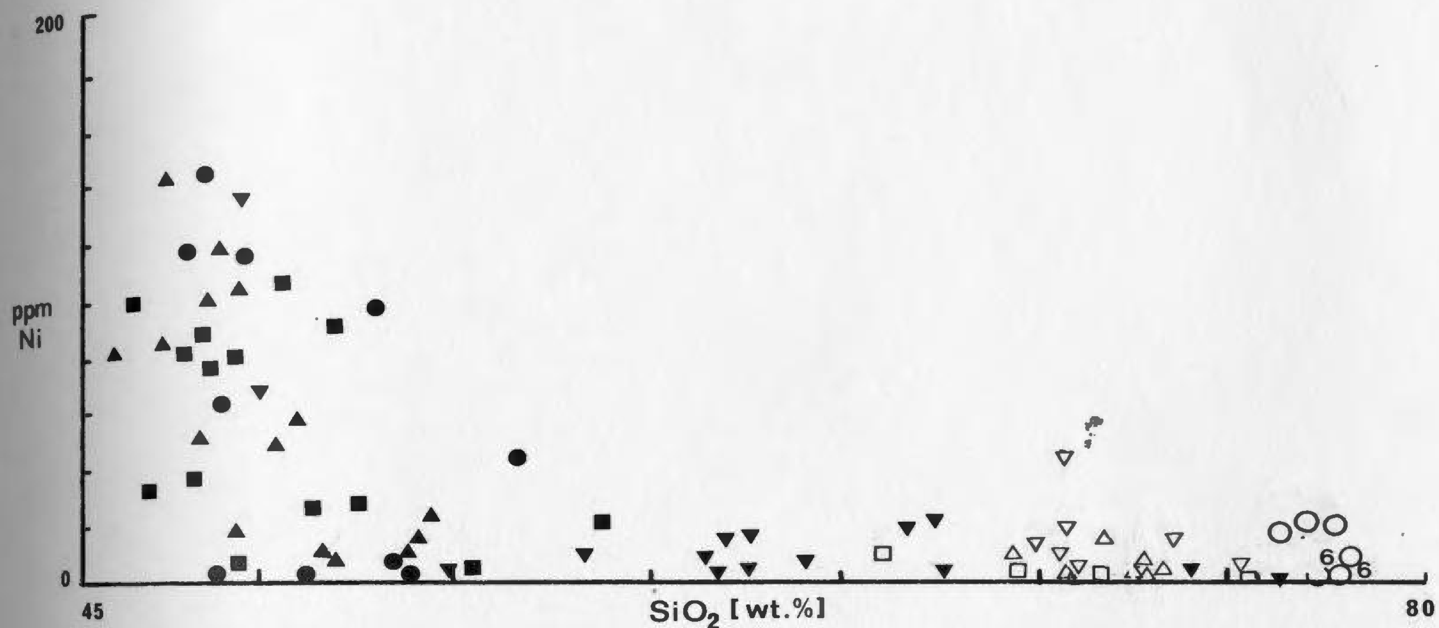


FIGURE 7:4 (Continued)



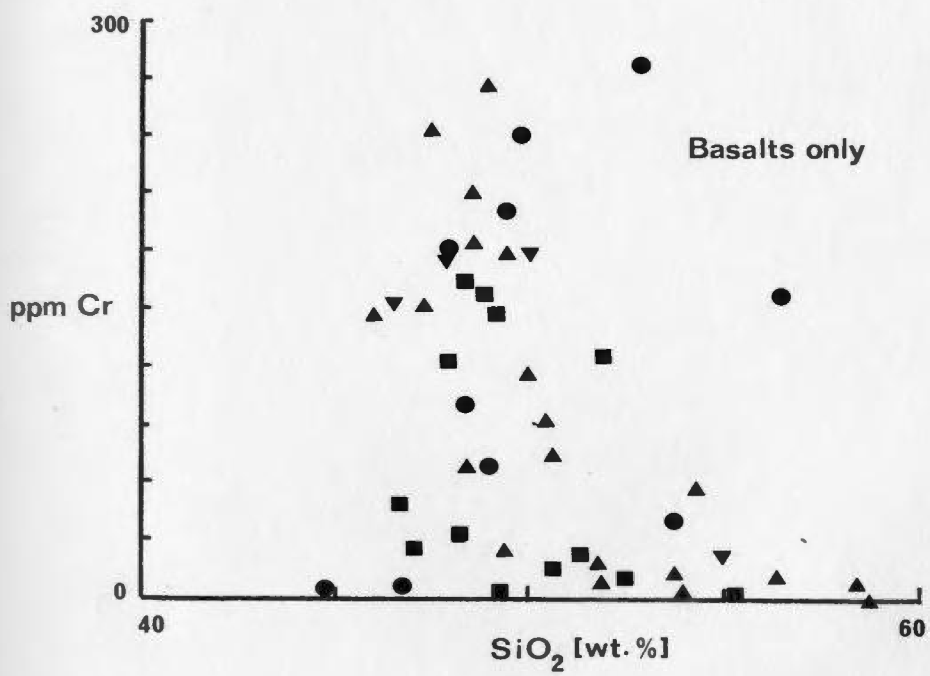
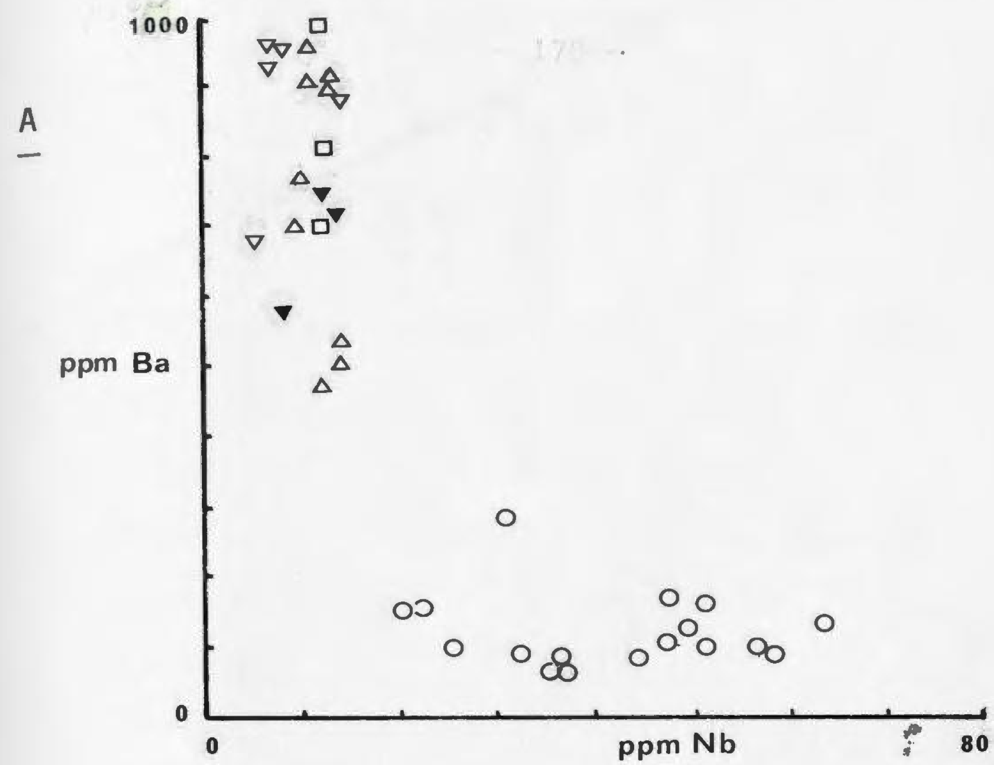


FIGURE 7:4 (Continued)



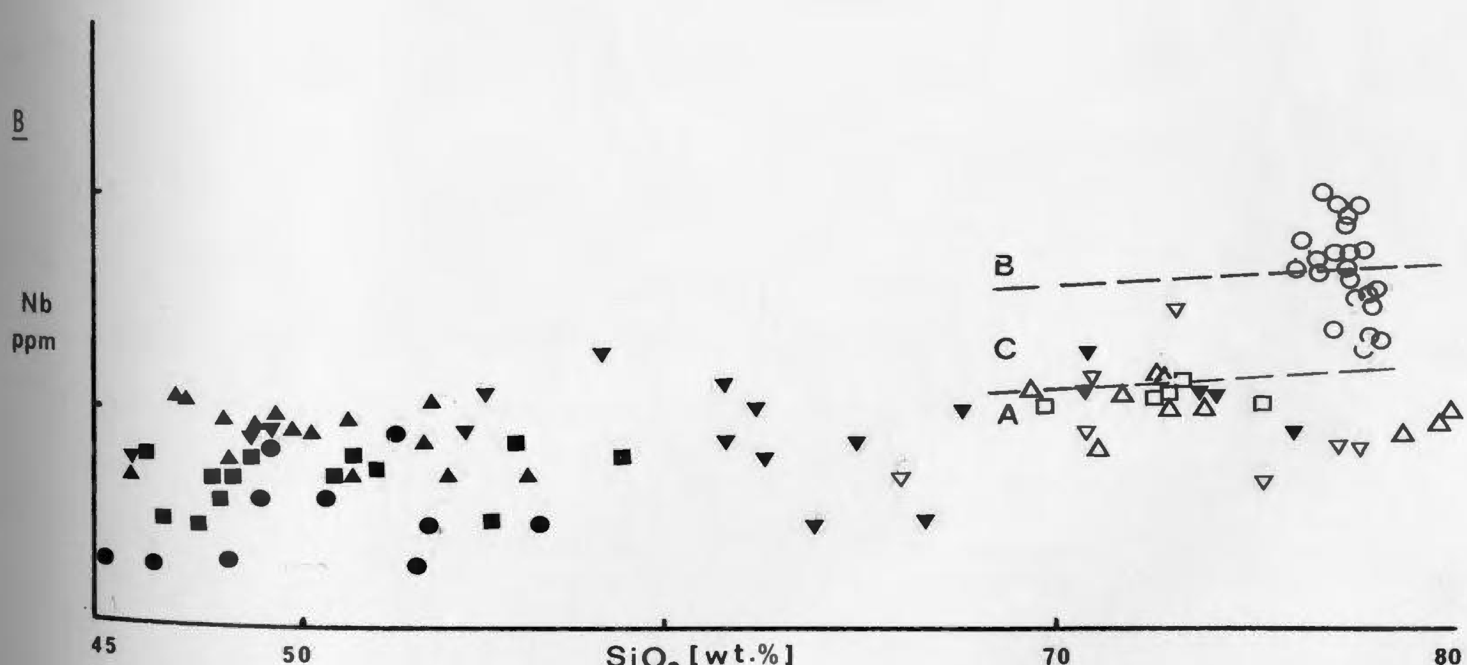


FIGURE 7:4 (A) : Ba : Nb ratios for selected Marystown Group felsic rocks

(B) : Nb vs. SiO_2 plot for Marystown Group . A=orogenic ; B= nonorogenic ; C= field of overlap (after Pearce and Gale,1978) liquids (Taylor, 1965). Thus, an increase in the concentration of these elements in residual liquids would be expected. A discussion and comparison of the significant variations in trace element distribution in the various formations of the Marystown Group is presented below.

7.4.1.3 SiO_2 vs frequency histograms

Figure 7:5 shows the frequency distribution of SiO_2 in the volcanic rocks of the Marystown Group. From Figure 7:5b it is evident that the Marystown Group as a whole contains a continuum of compositions ranging from 44% to 80% SiO_2 with the greatest concentrations of samples in the (1) 46-56% SiO_2, (2) 70-74% SiO_2 and (3) 76-80% SiO_2. Inspection of the data in Appendix 1 shows that these peaks represent the (1) Calmer Formation, (2) the Hare Hills and Mount Saint Anne Formations and the Barasway Complex and (3) the Grand Beach Complex. Figure 7:5c shows that these units form a distinctly bimodal sequence with a pronounced gap in SiO_2 values from 60 to 66% SiO_2. Figure 7:5a clearly indicates the contrast of these units with the underlying Taylor's Bay Formation which contains a significant number of analyses in the 60 to 66% SiO_2 range; however the low sample size restricts its solely statistical value.

Martin and Piwinski (1972) concluded that bimodal volcanic suites are characteristic of tensional tectonic environments. The nature of the volcanic rocks of the Marystown Group supports this conclusion. The continuum of compositions of the Taylor's Bay Formation is predictable from the petrographic studies (see Section 5.1.3). A distinction between the Taylor's Bay Formation and the rest of the Marystown Group is also suggested in several of the discrimination diagrams discussed below.

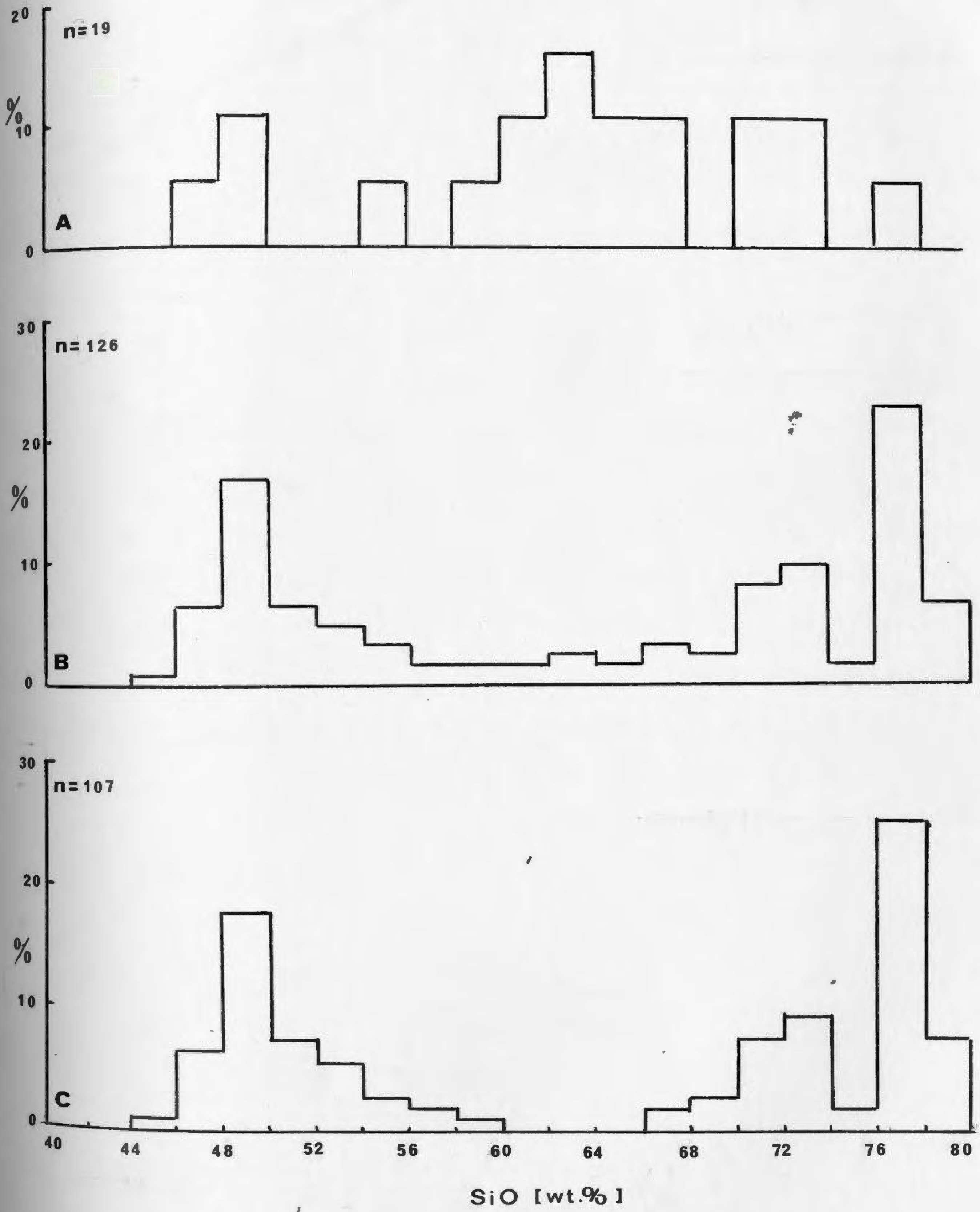


FIGURE 7:5 Frequency vs. SiO_2 histograms for (A) Taylors Bay Fm. (B) entire Marystown Gp. (C) Marystown Gp. excluding (A)

7.4.1.4 AFM and Alkalies vs SiO_2 Diagrams

The AFM diagram (Wager and Deer, 1939) and the alkalies-silica plot (MacDonale and Katsura, 1964; Kuno, 1966; Irvine and Baragar, 1971) were designed to use the variation in the alkalies along with total FeO and MgO to graphically illustrate geochemical trends in magmatic evolution. The mobility of alkalies during post-depositional alteration discussed in Section 7.3 is evident from scatter of these elements on the Harker diagrams and also on the alkalies-silica diagrams.

On the alkalies-silica diagram (Figure 7:6), the mafic rocks of the Marystown Group plot in both the alkaline and subalkaline fields of MacDonale (1968) and Irvine and Baragar (1971) and in the calc-alkaline and alkaline fields of Kuno (1966). It should be noted that approximately 80% of the mafic to intermediate rocks of the Taylor's Bay Formation lie within the subalkaline field whereas approximately 70% of the remaining Marystown Group basalts (Calmer Formation) plot in the alkaline field. Obviously, the effect of alkali mobility should be considered in interpreting such a distribution. Nevertheless, this partial distinction is consistent on many of the immobile element discrimination diagrams shown below.

The distribution of the Marystown Group volcanic rocks on the AFM diagram of Wager and Deer (1939), is shown in Figure 7:7. The field of typical alkaline suites (Irvine and Baragar, 1971) is superimposed on Figure 7:7. The alkaline affinities of the Marystown Group as a whole are evident from this diagram. The slight iron enrichment in several of the Calmer Formation Basalts reflects the presence of secondary magnetite in these rocks. The difference between the Taylor's Bay Forma-

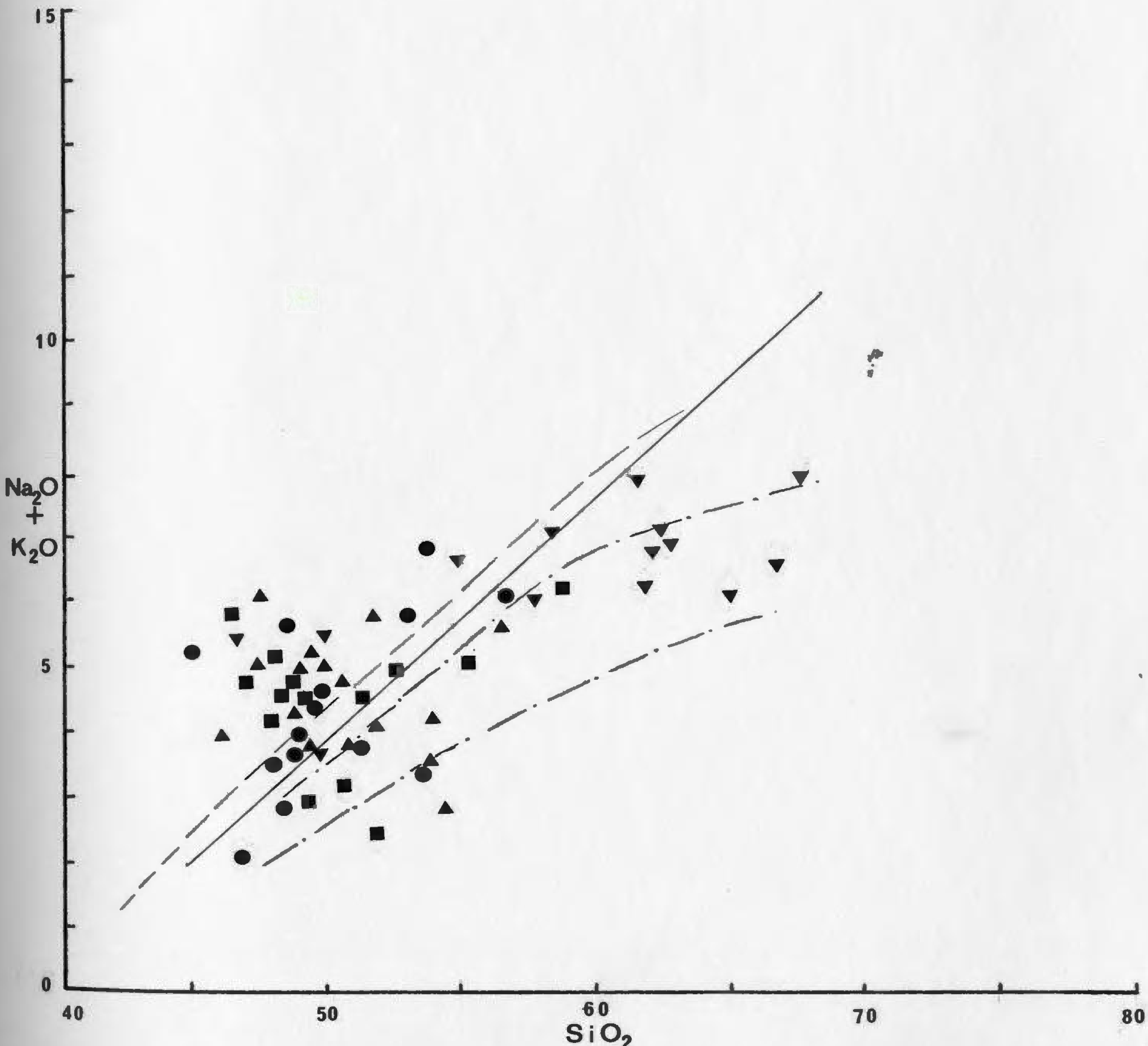


FIGURE 7:6 Total alkalies vs. SiO_2 for mafic rocks of the Marystown Group Symbols as in Figure 7:2. ——: dividing line of Irvine & Baragar 1971; ——: dividing line of MacDonald,1968; —·—·—: alkaline - high alumina - tholeiitic field dividing lines of Kuno ,1966

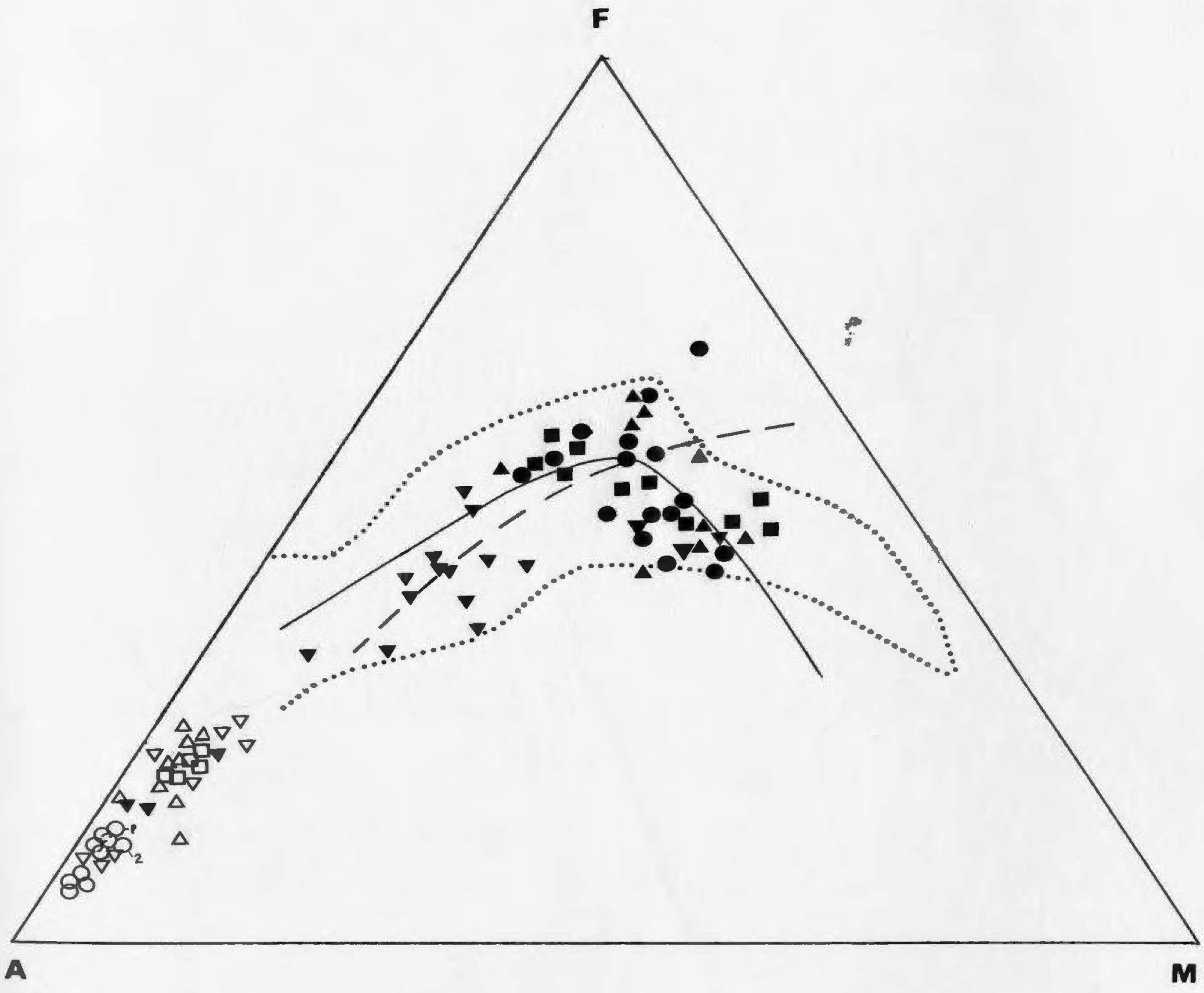


FIGURE 7:7 AFM diagram for the Marystown Group. Solid line :calc-alkaline tholeiitic dividing line of Irvine & Baragar 1971; dashed line trend of Solomon Is. and Bougainville Is. calc-alkaline suites; dotted line = field of typical alkaline suites from Irvine & Baragar, 1971 . Symbols as in Figure 7:2 .

tion and the overlying formations is also reflected in this figure.

7.4.1.5 $TiO_2 : K_2O : P_2O_5$ Diagram

As pointed out by Strong et al., 1978 a, most of the basaltic rocks of the Marystown Group (~ 95% fall within the continental basalt field of the $TiO_2:K_2O:P_2O_5$ diagram of Pearce et al. (1975) (Figure 7:8). These chemical affinities are predictable from the subaerial nature of these rocks.

7.4.2 Taylor's Bay Formation

As evidenced from the Harker diagrams (Figures 7:3 and 7:4) and frequency vs SiO_2 histograms (Figure 7:5), the Taylor's Bay Formation forms a contimuum of compositions from basic to acidic, namely basalt through andesite and dacite-rhyolite. The presence of dacite, quartz andesite and andesite flows in the Taylor's Bay Formation (see Section 5.1) is reflected by this observed chemical feature. The average analyses of rocks of the Taylor's Bay Formation compare favourably with rocks from ensialic orogenic terrains (Table 7:1).

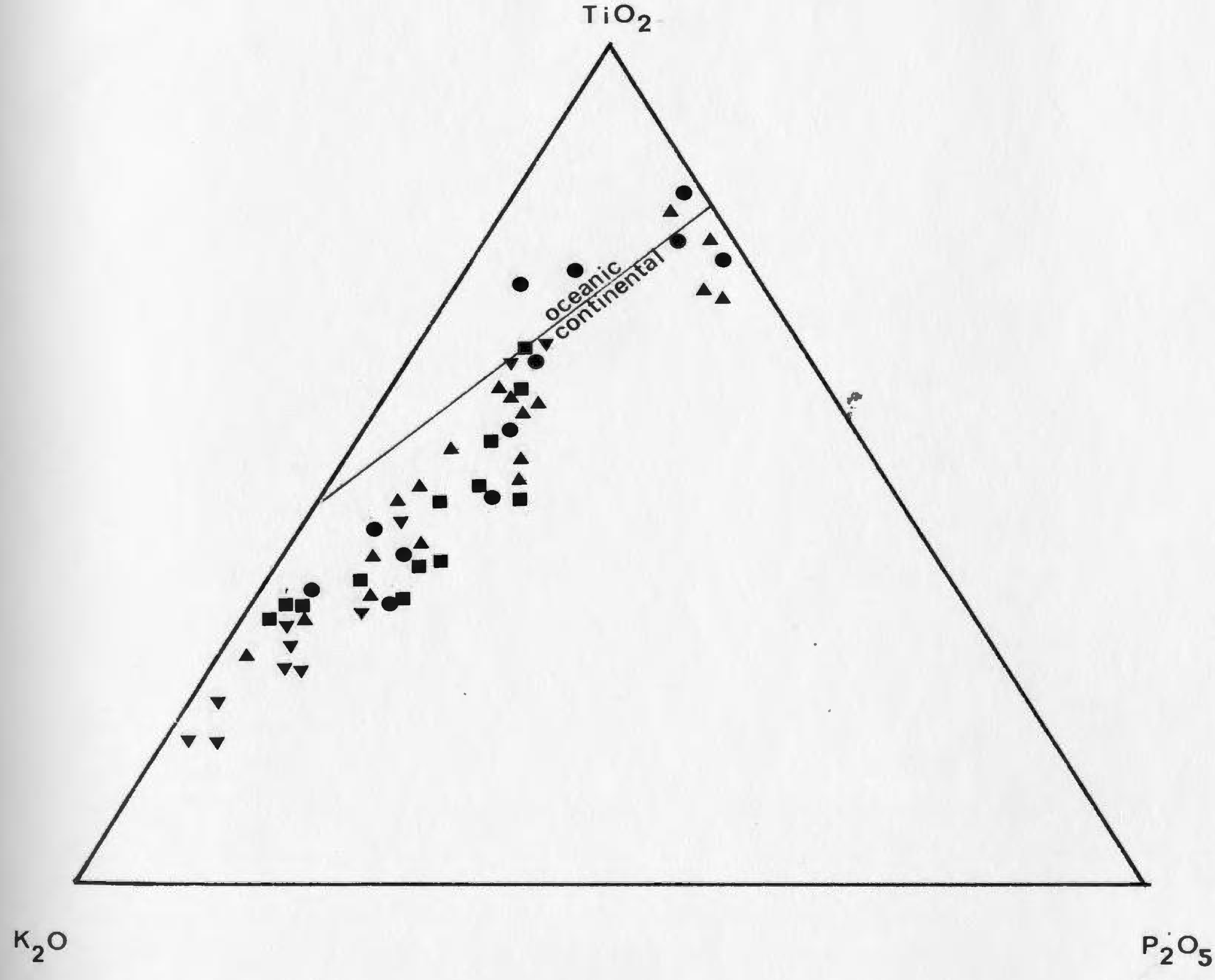


FIGURE 7:8 TiO_2-K_2O-P_2O_5 plot of mafic rocks of the Marystown Group. Oceanic-continental dividing line from Pearce et al. (1975). Symbols as in Figure 7:2 .

TABLE 7:1 AVERAGE ANALYSES (MAJOR ELEMENTS)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SiO_2	46.16	53.8	49.15	60.00	69.98	73.23	47.10	45.40	74.22	47.60	76.20	71.87	74.42	73.40	72.98	60.17	69.59
TiO_2	2.29	2.0	1.52	1.04	0.36	0.24	2.20	3.0	0.28	1.28	0.10	0.53	0.45	0.21	0.29	0.93	0.45
Al_2O_3	13.33	13.9	17.73	16.00	15.21	14.03	15.70	14.7	13.27	16.46	12.19	13.43	13.30	14.10	13.13	15.70	14.58
Fe_2O_3	9.71	9.3	7.20	6.20	1.90	1.70	7.80	9.2	0.92	3.95	0.65	0.88	0.29	0.39	0.0	3.23	0.10
FeO	1.31	2.6	2.76	1.86	1.08	0.60	3.40	4.1	0.88	8.48	0.48	1.22	1.91	1.47	1.72	2.48	2.28
MnO	0.16	0.2	0.14	0.16	0.04	0.02	0.16	0.2	0.05	0.21	0.03	0.08	0.07	0.08	0.22	0.18	0.06
MgO	0.41	4.1	6.91	3.90	0.91	0.35	7.10	7.8	0.28	6.31	0.29	0.48	0.40	0.50	0.41	2.73	0.66
CaO	10.93	7.9	9.91	5.87	2.70	1.32	10.10	10.5	1.59	7.14	0.21	1.33	0.72	1.07	1.60	4.79	1.20
Na_2O	2.15	3.0	2.88	3.85	4.47	3.94	3.30	3.0	4.24	3.18	3.57	4.21	5.06	4.06	3.27	4.36	4.76
K_2O	0.15	1.5	0.72	0.87	3.01	4.08	1.50	1.0	3.18	0.93	4.87	3.66	2.70	4.02	2.60	2.02	4.35
P_2O_5	0.16	0.4	0.26	0.23	0.10	0.05	0.47	0.4	0.05	0.32	0.88	0.03	0.08	0.05	0.08	0.28	0.11

1-6 from Irvine and Baragar, 1971: 1 = olivine tholeiite; 2 = tholeiite; 3= high-Al basalt; 4= andesite; 5 = dacite; 6 = rhyolite; 7 = average continental alkalic basalt (from Manson, 1967); 8 = "K-poor" alkali olivine basalt (Irvine and Baragar, 1971); 9 = sub-alkaline rhyolite (Ewart <u>et al</u>., 1968b); 10 = average Calmer Fm. basalt (n = 13); 11 = average for Grand Bank Complex (n = 18); 12 = average Hare Hills Fm. rhyolite (n = 3); 13 = average Mt. St. Anne Formation rhyolite (n = 9); 14 = average Barasway Complex rhyolite (n = 10); 15 = average Taylor's Bay Fm. rhyolite (n = 3); 16 = average Taylor's Bay Fm. andesite (n = 3); 17 = average Taylor's Bay Fm. dacite (n = 2).

The distribution of the major elements and their variation relative to SiO_2 content in the Taylor's Bay Formation display predictable trends, namely a well defined negative correlation of MgO, CaO, TiO_2, FeO, Fe_2O_3 and more scattered negative correlations of MnO, P_2O_5, Al_2O_3 and H_2O with increasing SiO_2 concentrations. A predictable increase in concentration of the alkalies with increasing SiO_2 is evident from the Harker diagrams.

Compared to the overlying stratigraphic units of the Marystown Group, the Taylor's Bay Formation contains a substantial proportion of rocks of intermediate SiO_2 compositions. Basalts of the Taylor's Bay Formation are characteristically lower in average concentrations of MnO, P_2O_5 and TiO_2 than the overlying units. If any other characteristic variations are present they are partially masked by a high degree of scattering of the major elements. Also the sampling distribution of basaltic rocks inhibits a more meaningful comparison as only 3 basaltic flows from the Taylor's Bay Formation were considered unaltered enough for geochemical analysis.

The variation of trace element concentrations with increasing SiO_2 in the Taylor's Bay Formation is, for the most part, similar to that of the Marystown Group as a whole (Section 7.4.1.2) and deserve no further discussion. A comparison of the trace element concentrations of these rocks with the other formations of the Marystown Group is given below.

SiO_2 Histograms

The frequency vs SiO_2 histograms (Figure 7:5) clearly indicate the relatively continuous variation in SiO_2 values for the basaltic to rhyolitic volcanic rocks of the Taylor's Bay Formation. The range in SiO_2 values from 46% to 78% SiO_2 is unique in the Taylor's Bay Formation, as the overlying units of the Marystown Group form a clearly bimodal sequence.

TiO_2-K_2O-P_2O_5 Diagram

The mafic to intermediate rocks of the Taylor's Bay Formation clearly fall in the "continental" basaltic field in the TiO_2-K_2O-P_2O_5 diagram of Pearce et al. (1975) (Figure 7:8) as do all the basaltic rocks of the Marystown Group. However, the field of the Taylor's Bay Formation is unique in that relative to the Calmer Formation, these basalts are (1) enriched in K_2O (in part due to metasomatism), (2) depleted in TiO_2, and (3) do not show the mild "oceanic affinities" (cf. Pearce et al., 1975) of some of the stratigraphically higher basalts.

P_2O_5-Zr Diagram

Winchester and Floyd (1976) compared the Zr and P_2O_5 contents of mafic volcanic rocks from a variety of environments and defined a dividing line for alkaline and tholeiitic basalts on the basis of the concentration of these elements. Figure 7:9 shows the stronger oceanic affinities (cf. Winchester and Floyd, 1976) of the mafic rocks of the Taylor's Bay Formation in comparison to the overlying basaltic rocks in the Marystown Group.

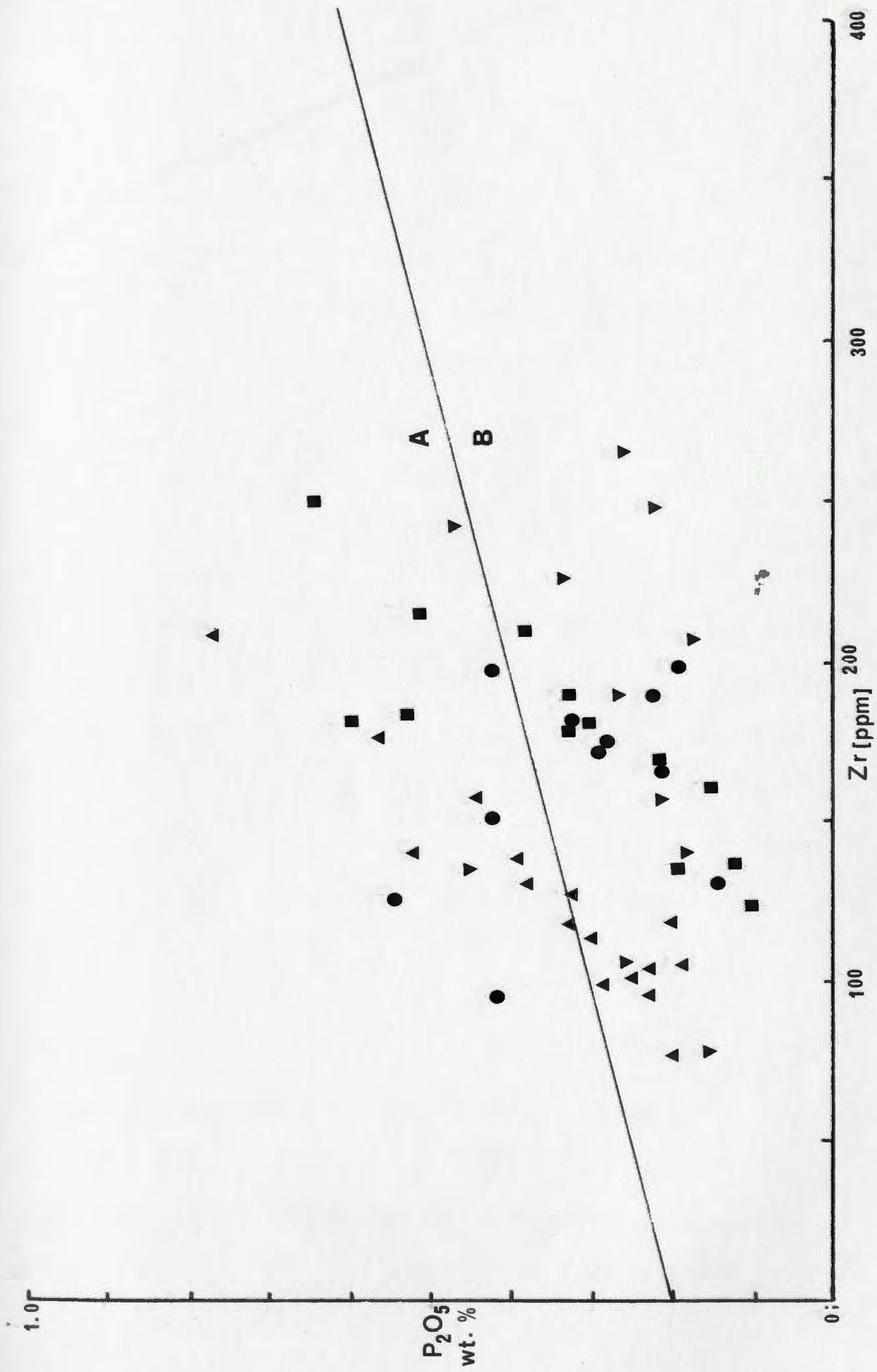


Figure 7:9: P_2O_5/Zr ratios of basaltic rocks of the Marystown Group. Dividing line between alkaline (A) and tholeiitic (B) fields after Winchester and Floyd (1976). Symbols as in Figure 7:2.

TiO_2-Zr/P_2O_5 Diagram

Winchester and Floyd (1976) showed the variation in the ratio of TiO_2 to Zr/P_2O_5 shown by alkalic and tholeiitic basalts of continental origin. The considerable variation in this ratio shown by the mafic rocks of the Taylor's Bay Formation in Figure 7:10 is characteristic of tholeiitic basalts. The majority of the analyses of the Taylor's Bay mafic rocks fall within the field of tholeiitic basalts defined by the above authors.

SiO_2-Zr/TiO_2 Diagram

The mafic volcanic rocks of the Taylor's Bay Formation plot dominantly in the field of andesite with only a few analyses in the field of subalkaline basalt on the SiO_2-Zr/TiO_2 diagram of Winchester and Floyd,(1977)(Figure 7:11). Most of the more differentiated rocks of the Taylor's Bay Formation plot in the field of rhyodacite/dacite. One basaltic rock from the Taylor's Bay Formation falls within the field of alkali basalt.

7.4.3 Calmer Formation

In general, the basaltic rocks of the Calmer Formation are characterized by higher average concentrations of TiO_2, P_2O_5 and MnO than the basalts of the underlying Taylor's Bay Formation. The Calmer Formation is also typified by lower concentrations of SiO_2 and total FeO and variable but lower average concentrations of MgO, CaO and K_2O than the stratigraphically lower mafic volcanic rocks. The Al_2O_3 concentrations of both formations show little significant variation. The

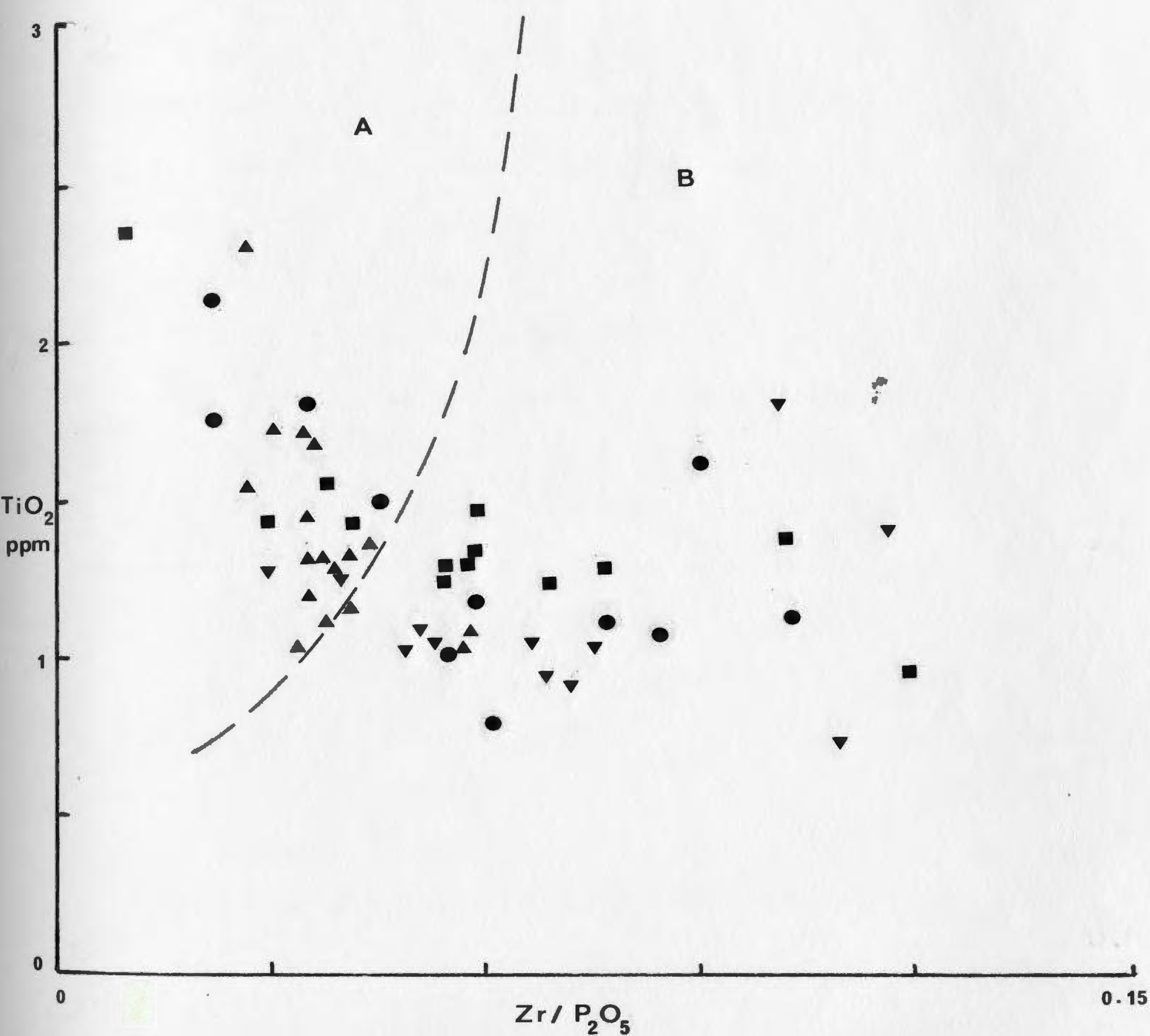


Figure 7:10: TiO_2 vs Zr/P_2O_5 plot for basaltic rocks of the Marystown Group. Dividing line between alkaline (A) and tholeiitic (B) fields after Winchester and Floyd (1976). Symbols as in Figure 7:2.

Harker variation diagrams for the Calmer Formation show scattered trends with an inverse correlation between all major elements and SiO_2, with the exception of the alkalies.

Compared to the basalts of the underlying Taylor's Bay Formation, the Calmer Formation is enriched in Zr, Rb, Ba, Zn, Pb and Nb and relatively depleted in Cr and Ni. The depletion of Cr and Ni reflects the lower concentrations of total FeO in the Calmer Formation and is strongest in the more silica-rich rocks of the Calmer Formation.

Pb, Rb and Ba display a close geochemical correlation with K (Taylor, 1965) and hence show a scattered but positive correlation with SiO_2. Sr generally follows Ca, however the mobility of both elements is evidenced by their scatter in the Harker diagrams. Similarly, the variation in Na_2O and K_2O may be more indicative of alteration affects rather than any primary petrological features. The incompatible trace elements (e.g. Zr, Nb, Y) are predictably enriched in the more differentiated mafic flows.

There are some distinct differences between the major and trace element concentrations of the Calmer Formation and the andesitic compositions of the underlying Taylor's Bay Formation. The Calmer Formation basalts are relatively depleted in K_2O, Na_2O, SiO_2, Rb, Pb, Nb, Zr and Ba compared to the andesites. The basalts are characterized by a relative enrichment in average concentrations of P_2O_5, TiO_2, $FeO_{(T)}$, MnO, Cr, Ni and to a lesser extent, CaO and Al_2O_3.

In general, the Calmer Formation is characterized by a homogenity of chemical compositions. Nevertheless, minor, albeit relatively

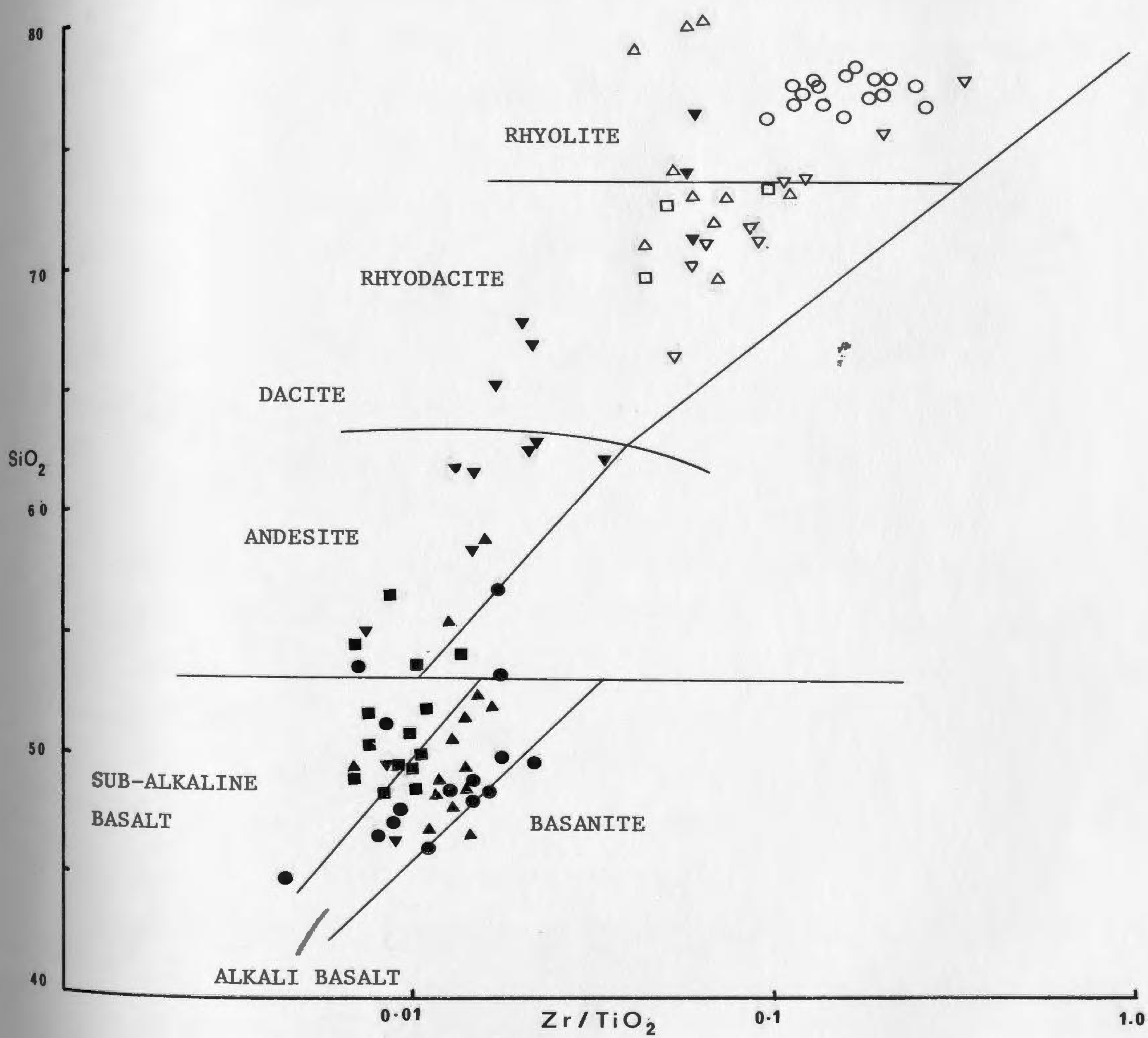


Figure 7:11: SiO_2 vs Zr/TiO_2 plot for the Marystown Group. Various fields from Winchester and Floyd (1977). Symbols as in Figure 7:2.

distinct chemical variations are present and appear related to the petrographic distinctions amongst the three major rock types in the formation, namely: amygdaloidal olivine basalt, coarse plagiophyric basalt and magnetite-rich, "aphyric" basalt. In general, the magnetite-rich and plagiophyric basalts show limited variation in major and trace element concentrations relative to each other with increased SiO_2. However, the fine grained amygdaloidal olivine basalts which are typical of the Calmer Formation show a depletion in P_2O_5, $FeO_{(T)}$, MnO, Loss on Ignition, Sr, Ba, Rb, Cu, Zn, Zr, Ni and Cr with increasing SiO_2. A clear enrichment in Nb and a scattered and only slight enrichment in the alkalies is characteristic of these rocks.

The similarities in concentration of TiO_2, CaO, MgO and Al_2O_3 suggest that any apparent differences within the Calmer Formation basalts are not necessarily the result of any fundamental chemical difference, but possibly represent only local variations in the stage of evolution in the basic magma. The trends within the amygdaloidal olivine basalts show characteristic variations with increasing fractionation. Most of the variations within the remainder of the Calmer Formation can be related to recognizable petrographic dissimilarities and the variation in the nature of the metamorphism. The lack of variation in CaO and Al_2O_3 within various rock types of the Calmer Formation suggests that no significant variation occurs in the order of crystallization of the plagioclases and pyroxenes in these rocks.

Enrichment in Nb in the olivine basalts possibly reflects the slightly more alkalic affinities of these rocks as is evidenced by the greater proportions of olivine and clinopyroxene in these rocks. The greater proportion of magnetite in the coarse plagiophyric and magnetite-rich flows may account for their slight tholeiitic affinities. These flows also contain substantial amounts of apatite in the groundmass basaltic glass (Section 5.3.2). This distinction is evidenced by the increased concentrations of P_2O_5 in these rocks relative to the finer grained amygdaloidal flows.

The magnetite-rich basalts contain higher concentrations of Zr, possibly reflecting the substitution of Zr^{+4} for Fe^{+3} in the magnetite (Fe^{+2} Fe_2^{+3} O_4) structure. Similarly, apatite is known to contain significant amounts of Zr^{+4} (Taylor, 1965), thus the slight Zr enrichment may partially reflect the observed presence of apatite in the coarse plagiophyric and magnetite-rich flows. The enrichment of Ni and Cr in these flows also appears related to the magnetite content of these rocks.

Na_2O and K_2O concentrations show a high degree of scattering in the basalts of the Calmer Formation. This scattering is not as evident in the trace elements which show chemical affinities to the alkalies (e.g. Rb, Ba). The plagiophyric flows are typically enriched in these elements, but it is difficult to establish whether or not this enrichment is related solely to metasomatic effects. If the variation in concentration of Sr is dependent on the metamorphic domain as suggested by Smith and Smith (1976), then the epidote metadomains in the plagiophyric basalts (Section 5.3.2) would explain the Sr enrichment in these rocks.

The fine-grained amygdaloidal flows are characterized by high H_2O and CO_2 (Loss on Ignition) and by a high scatter of CaO relative to the rest of the Calmer Formation. The mobility of CaO during metamorphism is reflected in the albitization of calcic plagioclase but more so in the widespread occurrence of calcite and epidote in amygdules, veins and the groundmass of the basalts.

Major element and trace element discrimination diagrams

The basaltic rocks of the Calmer Formation are transitional between the alkaline and subalkaline fields of MacDonald (1978) and Irvine and Baragar (1971) in Figure 7:6. The wide scatter in alkalies in these rocks is evident in this diagram, and causes the analyses to plot in the calc-alkaline and alkaline fields of Kuno (1966). The Calmer Formation basalts lie within the field of typical alkalic suites on the AFM diagram in Figure 7:7. Ninety per cent of the analysis of the Calmer Formation fall within the field of continental basalts on the TiO_2-K_2O-P_2O_5 diagram in Figure 7:8 with only 10 per cent of the analysis showing "oceanic" affinities (cf. Pearce et al., 1975). The basalts are transitional with respect to the alkalic and tholeiitic fields on the TiO_2 vs. Zr/P_2O_5 and P_2O_5-Zr diagram (Figure 7:9) of Winchester and Floyd (1976). The more pronounced alkalic affinities of the amygdaloidal olivine basalts relative to the rest of the Calmer Formation are also evident from Figure 7:10. The SiO_2-Zr/TiO_2 diagram of Winchester and Floyd (1976) shows that the basalts of the Calmer Formation plot in the fields of alkaline and subalkaline basalt.

7.4.4 Late felsic volcanic rocks

The late felsic volcanic rocks of the Marystown Group can be chemically classified as rhyolites (sensu lato) and are generally characterized by high total alkalies, variabel K_2O/Na_2O, low CaO, MgO, total FeO, MnO, P_2O_5 and TiO_2 and molecular ratios of $K_2O + Na_2O/Al_2O_3 < 1$.

The albitic compositions of originally more calcic plagioclase and presence of significant proportions of devitrified glass would make any strictly modal classification of the felsic volcanic rocks limited in value. The classification of these rocks is more appropriately based on normative compositions, such as the classification scheme proposed by Baragar (1967) which has been reporduced in Figure 7:12. Inspection of the normative An-Or-Ab ternary plot shows that the felsic volcanic rocks of the Barasway Complex and the Hare Hills and Mount Saint Anne Formations vary in composition from rhyolite-trachyte to sodic rhyolite, although the volcanic rocks are more siliceous than typical trachytes (cf. Irvine and Baragar, 1971). The volcanic rocks of the Grand Beach Complex all fall within the field of rhyolite/trachyte, whereas a significant proportion of the felsic volcanic rocks of the Taylor's Bay Formation can be classified as rhyodacite or trachyandesite. A similar distribution is obtained when the anlayses are plotted on the normative classification diagram of Streckeison, 1976.

The felsic volcanic rocks are distinctly peraluminous, with normative corundum and total alkali contents ranging from 8% to 11%. On the K_2O-Na_2O plot in Figure 7:13 the analyses of the felsic volcanic rock define a negative slope which may be interpreted as a function of both the original K_2O/Na_2O ratios in the silicate melt and the local leaching or preferential addition of sodium and potassium during alkali-

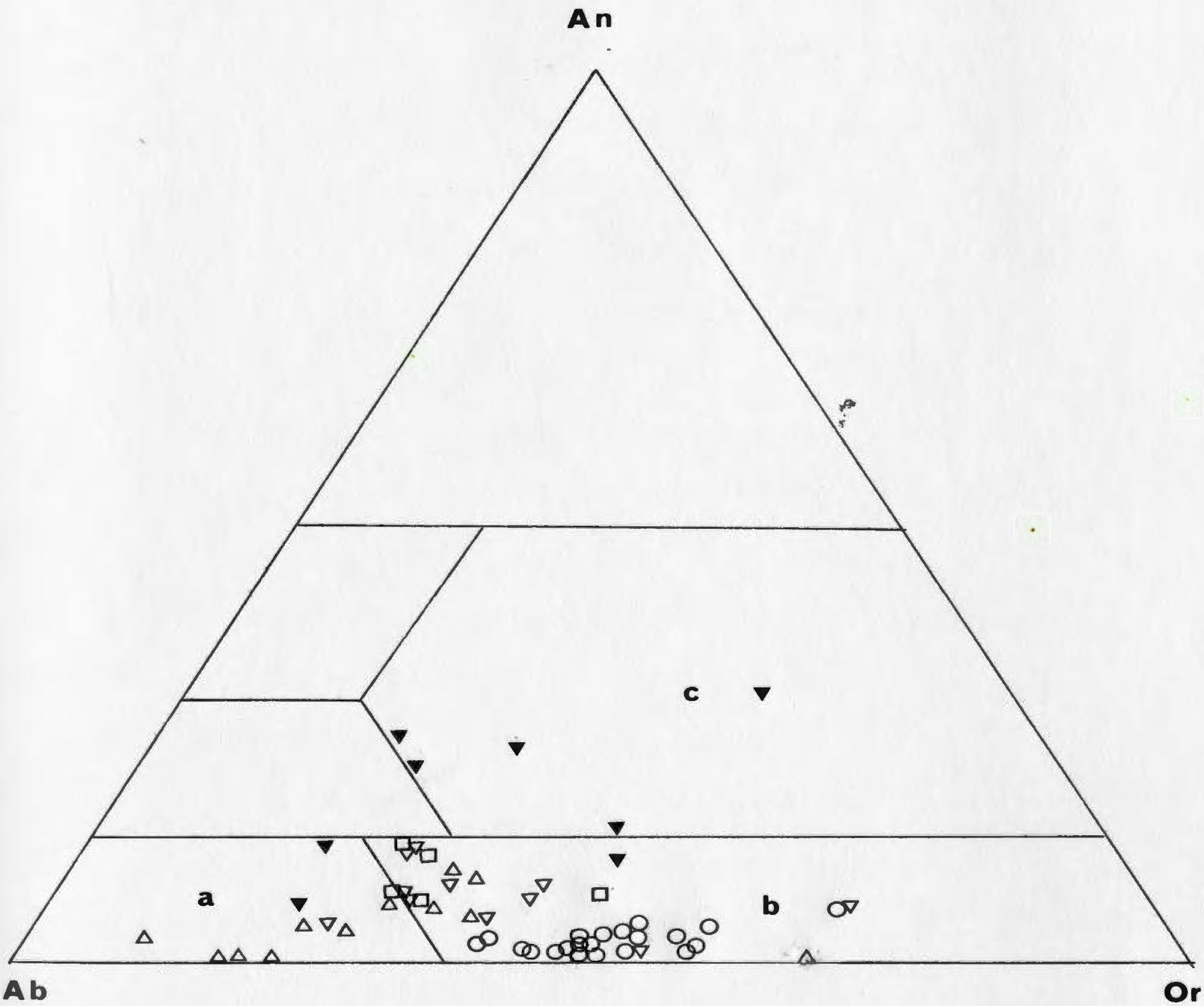


Figure 7:12: Normative albite-orthoclase-anorthite classification of felsic volcanic rocks of the Marystown Group after Baragar (1967). A = soda rhyolites and soda trachytes, B = rhyolites and trachytes, C = dacite.

exchange associated with subsequent alteration processes.

If the alkali exchange was completely isochemical, the whole rock compositions may tend to be concentrated towards the extremities of negative 1 slope defining the magmatic suite. However, if isochemical exchange did not occur the compositions would move towards the origin along a positive slope defined by the proportional loss of Na_2O to K_2O. The scatter in compositions (in Figure 7:13) of all units, with the exception of the Grand Beach Complex, reflects the superposition of such positive and negative slopes.

Inspection of the Harker variation diagrams (Figures 7:3 and 7:4) shows that linear to curved trends are relatively well defined for CaO, total FeO, TiO_2, MgO, Al_2O_3, P_2O_5 and MnO, all of which show negative correlations with SiO_2. A high degree of scattering is observed in the trends of Na_2O and K_2O and also in the trends of Rb, Ba and Sr in volcanic rocks of less than 75% SiO_2. Concentrations of the base metals (Pb, Cu and Zn) show no apparent systematic variation. Rb, Ba, Sr and Zr display a pronounced scattering but are clearly depleted in the most silicic compositions (e.g. > 75% SiO_2). Nb shows little variation, whereas concentrations of Y vary from 25 to 50 ppm in rocks of similar SiO_2 composition. Cr and Ni concentrations are typically depleted in all the felsic volcanic rocks.

The data also suggest certain variations corresponding to differences in stratigraphic position and petrologic characteristics. Three chemical groupings can be established; namely: (1) Taylor's Bay Formation, (2) Barasway Complex and the Hare Hills and Mount Saint Anne Formations, and (3) Grand Beach Complex.

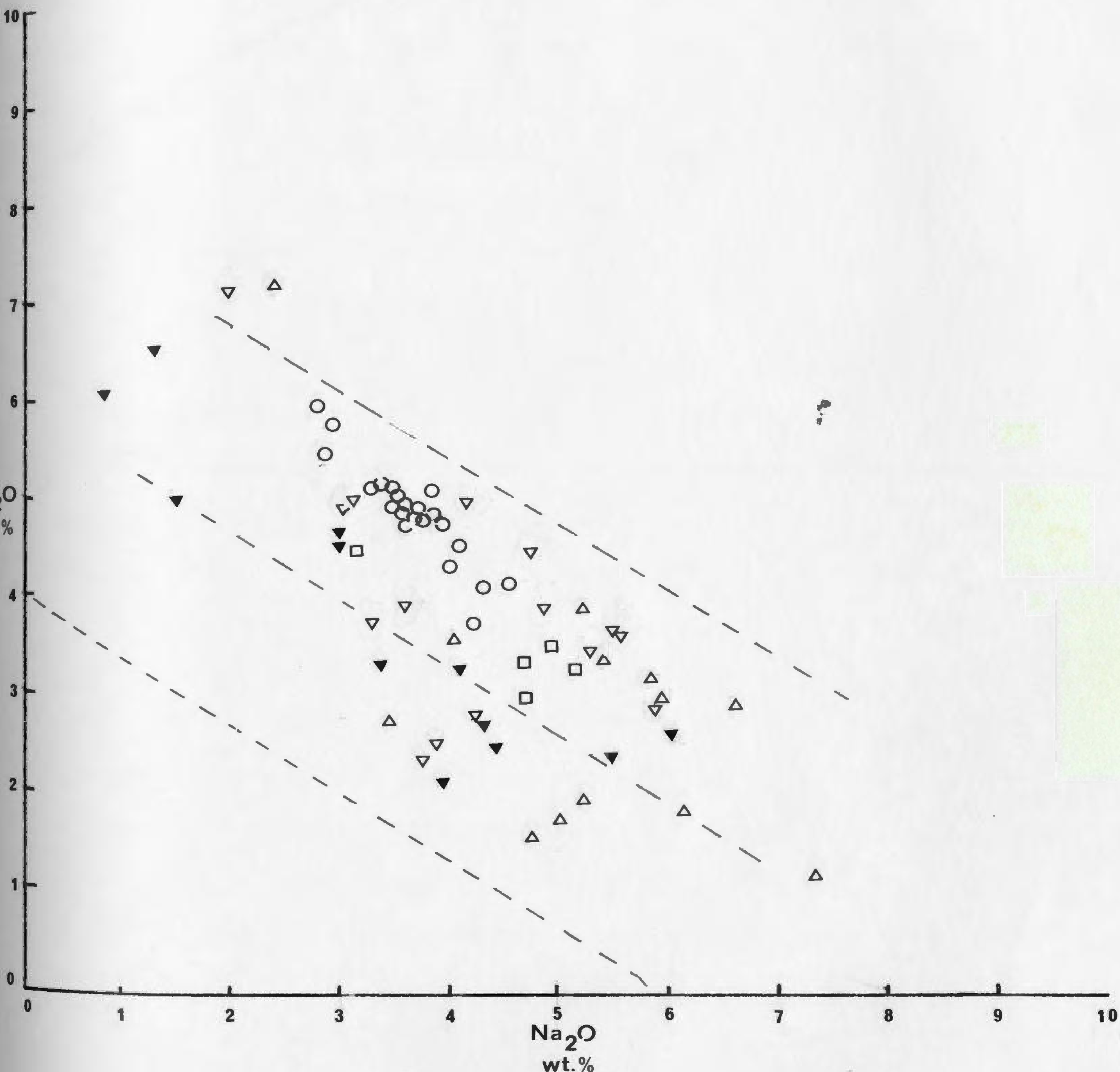


Figure 7:13: K_2O vs Na_2O for felsic volcanic rocks of the Marystown Group. Dashed lines are molecular per cent equivalent lines.

The Barasway Complex and the Hare Hills and Mount Saint Anne Formations show a scatter from 1% to 7% K_2O and 2 to 8% Na_2O, but appear enriched in average K_2O and Na_2O content relative to the underlying Taylor's Bay Formation. CaO concentrations are not as widely scattered, with the Taylor's Bay Formation enriched in calcium relative to the other units. The Grand Beach Complex shows no substantial scatter in either the alkalies or CaO and is enriched in K_2O and depleted in Na_2O and CaO relative to the other felsic volcanic rocks of the Marystown Group. TiO_2, MgO, MnO, P_2O_5, total FeO and Al_2O_3 show little scatter and the negative correlation with SiO_2 approximating a typical fractionation trend with the lowest concentrations present in the Grand Beach Complex. A slight increase in FeO_T in the Grand Beach Complex reflects the hematitization of the feldspars typical of this unit (see Section 5.3.4).

Sr and Ba concentrations show a high degree of scatter in all units, with the exception of the Grand Beach Complex. A comparison of average Sr concentrations indicates that the Taylor's Bay Formation is depleted in Sr and Ba relative to the Barasway Complex and the Hare Hills and Mount Saint Anne Formations while all units are enriched in Sr and Ba relative to the Grand Beach Complex. The variations in Rb reflect those of K_2O, and like K_2O, Rb is relatively enriched in the Grand Beach Complex.

Cu and Pb show no systematic trend and show a wide variation in all units. Zn shows a similar variation but is relatively depleted in the Grand Beach Complex. Zn shows a wide scatter in all units, with the exception of the Grand Beach Complex. Zr is enriched in the Barasway

Complex and the Hare Hills and Mount Saint Anne Formations relative to rhyolites of the Taylor's Bay Formation. The Grand Beach Complex is characterized by a depletion in Sr and enrichment in Nb and Y relative to the former three units.

Obviously, the variations in the chemistry of silicic volcanic rocks are related to a combination of a number of factors: crystal settling, assimilation, progressive partial melting, liquid immiscibility and thermogravitational diffusion (cf. Hildreth, 1979). Identification of individual processes cannot be carried out with the data available, therefore, the mechanisms delineated above cannot be considered the sole causes for the observed variations.

The origin of the chemical differences between the Grand Beach Complex and the other felsic volcanic rocks of the Marystown Group could be in part due to several other causes. Given that some degree of fractional crystallization did occur in the rhyolitic magmas which gave rise to the silicic volcanism, it is possible to explain several features by crystal fractionation. Crystallization of alkali feldspar and plagioclase could cause the enrichment of Rb in the Grand Beach Complex. The low Ba concentrations of the Grand Beach Complex are consistent with a model of late stage fractionation of phases such as biotite, given Nockolds and Allen's (1950) observation that Ba is not depleted in the magma until a relatively late stage of differentiation. The depletion of Sr could be related to either depletion and removal of Ca during isochemical alteration of calcic plagioclase or the appearance of alkali feldspar on the liquidus of the original melts. Depletion of Na_2O is closely related to addition of K_2O during isochemical alteration of alkalic silicic lavas (e.g. Noble, 1965 a,b). The presence of chequered albite in the Grand Beach Complex suggests some degree of albitization, possibly related to the localized release of Na from the hydrated, devitrified groundmass. The enrichment of Nb and Y in the Grand Beach Complex is typical of latest stages of fractionation of silicic melts (Noble, 1965 a,b; 1967; 1970a).

Also, the available data cannot disprove the possibility that the volcanism of the Grand Beach Complex is related to a period of magmatism which was significantly separated in time from that of the main period of Marystown Group volcanism (see Chapter 4), possibly related to plutonism associated with the intrusion of the St. Lawrence Granite during the Carboniferous.

7.5 Summary

All analysed samples show some degree of element mobility, presumably related to metamorphic effects. These must be considered when interpreting the data in terms of magmatic affinities and petrogenetic models. Despite these constraints, some generalized statements may be made in view of summarizing the geochemical features of the Marystown Group.

The Taylor's Bay Formation is a polymodal sequence of volcanic rocks which range in chemical and petrological composition from basalt to andesite and quartz andesite through dacite to rhyolite. In terms of the parameters P_2O_5, Zr and TiO_2, the mafic rocks of the Taylor's Bay Formation show moderate tholeiitic affinities, in contrast with the alkaline affinities of the overlying basaltic rocks. The occurrence of andesite, quartz andesite and dacite flows in the Taylor's Bay Formation is unique to that formation. Such intermediate rock types, common in compressional orogenic terrains, are of limited extent in the Newfoundland Avalon Zone and have been described only by Hussey (1979) and Hughes (pers. comm., 1978).

The Calmer Formation and the overlying felsic volcanic rocks of the Marystown Group form a bimodal sequence characterized by a lack of intermediate compositions. In general the Calmer Formation is characterized by continental basalts with alkaline affinities. These rocks are transitional between alkaline and subalkaline basalts in terms of major elements. The distribution of incompatible trace elements confirms the alkaline nature of the basalts. Chemical differences are present within the Calmer Formation and they can be related to petrographically unique rock types. Typical olivine basalts of the Calmer Formation show little geochemical variation. The geochemical variations in the magnetite-rich, aphyric flows and coarse grained plagiophyric basalts of the Calmer Formation are not necessarily indicative of fundamental chemical differences but more so reflect variations in metamorphism, minor petrologic variations and possibly variations in the stage of evolution of the basic magma. Nevertheless, the geochemistry of the latter two rock types supports the field observation that these lithologies are not characteristic of the Calmer Formation. In several respects, these rocks are similar to the mafic rocks of the Taylor's Bay Formation. The uncertainty of the stratigraphic position of these rocks has been discussed in Chapter 4.

The overlying felsic volcanics of the Barasway Complex and the Hare Hills and Mount Saint Anne Formation show little significant systematic chemical variation. This supports the stratigraphic correlation of these units documented in Chapter 4. The felsic volcanic rocks are rhyolites, soda rhyolites and keratophyres and are characterized by high total alkalies, variable K_2O/Na_2O, low CaO, MgO, total FeO, MnO, P_2O_5 and TiO_2 and molecular ratios of $K_2O + Na_2O$ less than 1. The possible causes for the unique chemistry of the Grand Beach Complex have been briefly discussed above.

Any interpretation of the petrogenetic significance of the geochemical data is limited by a variety of factors. Alteration and metasomatism has affected the concentrations of K_2O, Na_2O, CaO, Rb, Sr and Ba and has made interpretation of parameters K/Rb, Ba/Sr and Rb/Sr ratios limited in value. Nevertheless, some possibilities regarding the petrogenesis of these rocks can be entertained.

There is no strong geochemical evidence to suggest that the Marystown Group represents a complete mafic to felsic differentiation sequence. It may be thus suggested that the felsic volcanic rocks are not necessarily the result of fractional crystallization of a parental mafic magma. The presence of intermediate compositions in the Taylor's Bay Formation, however, could be interpreted as the result of fractionation but the chemical data are not sufficient to establish the origin of the andesitic and dacitic rocks in the Taylor's Bay Formation.

When silicic magmas evolve from mafic magmas, it is reasonable to expect that some volcanic products will show gradations in composition, the possibility that these compositions are the result of hybridization (cf. Eichelberger, 1975) cannot be ruled out. Such a hypothesis suggests that primary basalt and rhyolite magmas become contaminated or mix directly with one another to form intermediate compositions. This would suggest that rhyolitic and basaltic compositions are the result of partial melting and that subsequent fractional crystallization does not result in the andesitic compositions.

Similarly, the geochemical data are not sufficient to establish with certainty the relation between the basalts of the Calmer Formation and the overlying felsic volcanic rocks. The available chemical and petrological data suggest that the basaltic rocks of the Calmer Formation are the result of fractional crystallization of upper mantle material. Lack of isotopic data for these rocks makes it difficult to establish the effects of crustal contamination on the magmas. The available data are not consistent with a model whereby the rhyolitic volcanic rocks are derived by continued fractionation of a basaltic magma. A more applicable model involves melting at lower levels of the continental crust, possibly by mafic magmas related to the Calmer Formation volcanism. The partial melting at the base of the continental crust would result in the production of episodic felsic subaerial volcanism.

The variation in element distribution in the felsic volcanics may have some petrogenetic significance, but the lack of detailed stratigraphic control (e.g. at the level of individual ash flow units) hampers any meaningful discussion of this variation. The complexity of chemical variation within individual ash flow sheets has been demonstrated by a number of authors (e.g. Smith and Bailey, 1966; Hildreth, 1979). Discussion of the effects and causes of these variations is not possible with the available data and is beyond the scope of this thesis.

8. SUMMARY AND GENERAL CONCLUSIONS

8.1 Summary of the evolution of the Marystown Group

The Marystown Group consists of a late Precambrian sequence of dominantly subaerial volcanic and associated sedimentary rocks which is in fault contact with the older oceanic volcanic rocks of the Burin Group and which is disconformably overlain by terrestrial to shallow water marine sedimentary rocks of Eocambrian to Cambrian age.

The Marystown Group can be divided into five formations and two complexes. The Taylor's Bay Formation is a sequence of rhyolitic and dacitic to basaltic volcanic rocks which forms the lowermost stratigraphic subdivision of the Marystown Group. These rocks are overlain with apparent structural conformity by a sequence of terrestrial, fluviatile sedimentary rocks named the Garnish Formation. The sedimentary rocks are conformably and gradationally overlain by extensive flood basalts of the Calmer Formation. Basaltic volcanism gave way to renewed silicic volcanism represented by the various stratigraphic units which overlie the Calmer Formation, namely the Hare Hills and Mount Saint Anne Formations and the Barasway and Grand Beach Complexes. Neither a structural nor a depositional break is evident between the Calmer Formation and the overlying felsic volcanic units.

The Precambrian subaerial volcanic rocks on the Burin Peninsula can be divided into three lithologically, stratigraphically and geochemically distinct sequences. The Taylor's Bay Formation represents the earliest recorded volcanic episode. Volcanism at this time resulted in the deposition of a series of rhyolitic to basaltic flows and pyroclastic rocks. Many of the internal features of this Formation suggest that deposition occurred in both subaerial and submarine conditions. The nature of the deposits indicate that they represent distal facies of a larger volcanic field.

The upper contacts of the Taylor's Bay Formation are poorly exposed on the southern Burin Peninsula, but they are locally marked by a period of fluviatile sedimentation, indicating a cessation of volcanism and erosion of the volcanic paleotopography.

In the central and northern Burin Peninsula a series of shallow-water marine conglomerates and finer grained clastic rocks conformably and gradationally underlie the Garnish Formation. In the same localities, these rocks gradationally overlie equivalents of the Taylor's Bay Formation. The absence of these intervening sediments in the present area of discussion indicates that the basal contact of the Garnish Formation is locally disconformable.

Coarse grained sedimentary rocks in the lower parts of the Garnish Formation may be in part the result of erosion of fault scarps and steep sloped volcanic highlands. Continued erosion resulted in the retreat of the source area, producing a lowering of the gradients and a general decrease in energy of the fluviatile system . Such processes would result in the formation of the finer-grained, thinly bedded deposits in the upper parts of the Garnish Formation. These rocks were deposited in environments akin to present day braided or meandering stream systems.

The latest stages of sedimentation of the Garnish Formation were contemporaneous with the initiation of basaltic volcanism, represented by the Calmer Formation. The internal features of the flows of this Formation are indicative of deposition in a dominantly subaerial environment. The duration of this period of mafic volcanism is unknown, but the limited thickness of the Calmer Formation may indicate that it represents only a small part (in time) of the tectonic evolution of the area.

The upper contacts of the Calmer Formation indicate that no extensive period of erosion preceded the renewal of felsic volcanism throughout the area. This volcanism resulted in the deposition of a maximum of 300 metres of silicic, massive and pyroclastic volcanic rocks. Characteristic lithotypes of the late volcanic sequences are ash-flow and ash-fall tuffs, agglomerates, volcanic and epiclastic breccias, rhyolite flows and fine grained epiclastic rocks. The proportion of these rock types varies amongst the different units. The distribution of the various facies is consistent with a model in which one of the major volcanic centres for this period of volcanism is located within or to the northwest of the present exposure of the Barasway Complex.

The existence of three lithologically and stratigraphically unique volcanis suites within the sequence represented by the Marystown Group is evidenced in the petrological, and to a lesser extent, the chemical data available. The Taylor's Bay Formation consists of basaltic rocks of mild tholeiitic affinities. These rocks locally contain pigeonitic pyroxene phases and characteristically contain little olivine. The rhyolitic rocks show some systematic differences relative to the younger felsic volcanic sequences, but any clear petrogenetic differences are masked by alteration effects related to syn- and post-volcanic element mobility. The basaltic and rhyolitic rocks are spatially and temporally associated with rocks of intermediate composition which have been petrologically and geochemically classified as dacite, quartz andesite and andesite. The presence of such compositions could be interpreted as indicating extensive fractional crystallization of a parental basaltic magma resulting in the continuum of compositions observed in the Taylor's Bay Formation. Such a chemical suite is indicative of compressional orogenic environments. An alternative hypothesis would involve primarily a hybridization of initial magmas of mafic and felsic composition with limited crystal fractionation.

The majority of the basaltic rocks of the overlying Calmer Formation display alkaline affinities and characteristically contain abundant clinopyroxene, olivine and plagioclase. Ca-poor pyroxenes are not present, and no textural relationships between the olivines and augitic pyroxenes are evident. The Calmer Formation together with the overlying felsic volcanic rocks, the Hare Hills and Mount Saint Anne Formations and the Barasway Complex form a distinctly bimodal volcanic suite, suggestive of extensional tectonic environment. The relation of the basaltic and rhyolitic rocks cannot be definitely ascertained on the basis of the available data. Nevertheless, the data are not consistent with a model whereby the rhyolitic volcanic rocks are derived by fractionation of basaltic magma. A more applicable model involves a model of melting at lower levels of the continental crust, possibly by mafic magmas related to the Calmer Formation volcanism. The effects of contamination due to such basaltic underplating cannot be ascertained with the available data.

The relation of the chemically unique Grand Beach Complex to the rest of the late felsic volcanic sequences of the Marystown Group cannot be definitely ascertained. The available chemical data can be interpreted by means of a fractionation model. However, the limitations of such a model, given the data base available, are clear. An alternative hypothesis suggests the Grand Beach Complex is not related chemically to the remainder of the Marystown Group and may be related to later magmatic-tectonic events during the Carboniferous. The tectonic significance of the chemical and petrologic variations within the Marystown Group are unclear, although similar variations have been documented in Cenozoic volcanism in the Basin and Range Province. Possible analogies between both terrains are hazarded below (see Section 8.3).

8.2 Structural history

The main structural features of the southern Burin Peninsula are interpreted to be the result of an orogenic event which post-dates the deposition of Cambrian rocks and pre-dates the intrusion of the lower Carboniferous St. Lawrence Granite. Very recent results from an age dating program on the Burin Peninsula have bracketed the formation of the sericite schists of the Taylor's Bay Formation and its equivalents between 382 ± 5 and 391 ± 10 Ma. (D. Dallmeyer, pers. comm., 1979). The consistency of the results obtained from 6 samples collected over a distance of 190 km along strike strongly suggest that the main deformation is the result of the Acadian Orogeny.

The main period of deformation resulted in a regional northwest-southeast shortening, accompanied by the formation of upright to overturned folds with associated vertical to steeply west-dipping axial planar foliation. Continued compression resulted in the development of high angle reverse and thrust faults. These structural features are common to both Precambrian and Cambrian rocks within the map area.

Locally developed late structural features post-date structures formed during the main period of deformation. The most prominent of these structures are north-south and northwest-southeast trending shear zones and faults and the regional flexuring of earlier structures and stratigraphic units of the Precambrian and Cambrian sequences. This regional flexuring and related faulting may represent the latest effects of the Acadian Orogeny or possibly the onset of the Variscan (Hercynian) orogenic episode.

The main deformational events are interpreted to post-date the volcanism of the Marystown Group by a significant period of time; ca. 150 Ma. No direct evidence of an orogenic event relating to this Precambrian magmatism is preserved in the area.

8.3 Regional correlations

The internal stratigraphy of the Marystown Group compares with the late Precambrian volcanic sequences elsewhere in the western Avalon Zone in Newfoundland. The stratigraphic sequence of the Marystown Group shows marked similarities to the Precambrian Long Harbour and Connaigre Bay Groups of western Fortune Bay (see Chapter 4). Recent work in the Clode Sound area (Hussey, 1979) has resulted in the establishment of an internal stratigraphy of the Love Cove Group, which corresponds closely to that of the Marystown Group. Hussey (1979) describes a lower unit of basalts, andesites and rhyolites (White Point Formation) which is conformably overlain by shallow water to alluvial sedimentary rocks and extensive basaltic flows (Thorburn Lake Formation). The latter lithotypes are conformably overlain by a late felsic volcanic unit. The Marystown and Love Cove Groups also display similar geochemical variations in that the White Point Formation is a polymodal sequence with tholeiitic affinities whereas the overlying units constitute a bi-modal, alkaline assemblage.

Correlations with the Precambrian sequences in the eastern Avalon Zone are not as clear. The extensive flyschoid and "post-orogenic" molasse deposits which are characteristic of Avalon Peninsula geology are not well developed in the west. Similarly the deformation style, characteristic of the lower parts of the Marystown and Love Cove Groups is not readily identifiable in rocks of the eastern Avalon Zone.

A north-to northeast-trending series of vertical and reverse faults (Lewins Cove - Paradise Sound - Charlottetown - Cottles Island Fault System) marks the eastern extent of rocks which display an internal stratigraphy and deformation styles similar to the Marystown Group. This fault system also marks the western extension of extensive molasse and flyschoid deposits in the Avalon Zone.

The relationship between the Marystown Group and the Harbour Main Group are unclear. Strong et al., (1978 b) suggested the Rock Harbour Group of the Burin Peninsula and the Conception Group of the Avalon Peninsula were possible correlatives. Given that the Marystown Group overlies the Rock Harbour Group (Taylor, 1977; Strong et al., 1978 a,b), then the Harbour Main Group, which conformably underlies the Conception Group, would be significantly older.

A sound understanding of the relationship between the eastern and western belts of the Avalon Zone awaits detailed stratigraphic, geochemical and geochronological studies throughout the region, particularly in the Trinity Bay and Bonavista Bay regions. Until such data are available, correlation across the Avalon Zone will be based largely on speculation.

8.4 Possible analogies with the Basin and Range Area

The analogy of the silicic volcanism of the Avalon Zone to the Basin and Range Province was initially proposed by Papezik (1969, 1970, 1972). Similar comparisons were made by Nixon (1974); Strong et al., (1974); Strong and Minatides (1975); and Nixon and Papezik (1979). The following ideas are not intended to cover the entire tectonic history of the Avalon Zone, but solely the period represented by the Marystown Group.

As documented above, the geological history of the Marystown Group can be subdivided into various evolutionary periods which are represented by unique stratigraphic positions, depositional environments, and petrological and geochemical features. The differences between the two major divisions (e.g. (1) Taylor's Bay Formation and (2) Calmer Formation and overlying felsic volcanic rocks) are similar to variations seen within the Cenozoic volcanic rocks of the Southwestern United States (Lipman et al., 1972; Christiansen and Lipman, 1972).

Lower to middle Cenozoic lavas of the Southwestern U.S.A. erupted onto continental crust are predominantly andesite, quartz andesite, dacite and rhyodacite associated with more silicic ash flow sheets. The tectonomagmatic setting of this volcanism is typical of circum-

Pacific continental margins and ensimatic and ensialic island arcs. Lipman et al. suggest that these volcanic rocks are the result of subduction at a compressional plate margin. A major change in volcanic associations and tectonic settings occurred at the onset of late Cenozoic times. Late Cenozoic volcanic rocks include alkalic basalt fields and bimodal mafic and silicic volcanic sequences erupted in extensional environments. The inception of the late Cenozoic extensional environments is interpreted by Christiansen and Lipman (1972) to be the result of the collision of the East Pacific Rise with a mid-Tertiary continental margin trench. This resulted in the movement of the American and west Pacific plates along active transform faults.

The author does not imply that identical processes were active during the Precambrian evolution of the Avalon Zone. Nevertheless, the role of subduction in the Precambrian development of the Avalon Zone should not be overlooked. Evolutionary variations, similar to those within the Marystown Group, have been described in the Northwestern Avalon Zone of Newfoundland and in volcanic rocks of the Carolina Slate Belt in North Carolinas (Glover and Sinha, 1973; Seiders and Wright, 1977). Future tectonic models for the Precambrian evolution of the Avalon Zone should take into consideration the variations which occur in the Precambrian subaerial volcanic suites characteristic of this Zone.

REFERENCES

Abbey, S.
1968: Analysis of rocks and minerals by atomic absorption spectrophotometry; Pt. 2: Determinations of total iron, magnesium, calcium, sodium and potassium. Geol. Surv. Can., Pap. 68-20, 21 p.

Allen, J.R.L.
1970: Studies in fluviatile sedimentation: a comparison of fining-upward cyclothems, with special reference to coarse-member composition and interpretation. J. Sed. Petrol., V. 40, pp. 298-323.

Anderson, F.D.
1965: Belleoram, Newfoundland. Geological Survey of Canada, Map 8-1965.

Battey, M.H.
1955: Alkali metasomatism and the petrology of some keratophyres. Geol. Mag., V. 92, No. 2, pp. 104-126.

Baragar, W.R.A.
1967: Unpublished report to the Volcanology Sub-Committee, Assoc. Committee of Geodosy and Geophysics, National Research Council of Canada. (Incorporated in Irvine and Baragar, 1971).

Bartlett, G.H.
1967: Silica assessment, Fortune area; unpublished report, Newfoundland Department of Mines, Agriculture and Resources, unpublished report.

Bell, K. and Blenkinsop, J
1975: Geochronology of eastern Newfoundland. Nature, Vol. 254, April 3, 1975, pp. 410-411.

Bradley, D.A.
1962: Gisborne Lake and Terrenceville Map-Areas, Newfoundland (1 M/15 and 10). Geological Survey of Canada, Memoir 321, 56 p.

Brown, P.G. and Colman-Sadd, S.P.
1976: Hermitage Flexure: Figment or fact? Geology, Vol. 4, pp. 561-564.

Buddington, A.F.
1919: Precambrian rocks of southeast Newfoundland. J. Geol., Vol. 27, pp. 449-479.

REFERENCES (continued)

Cann, J.R.
1969: Spilites from the Carlsberg Ridge, Indian Ocean. J. Petrology, V. 10, pp. 1-19.

Cann, J.R.
1970: Rb, Sr, Y, Zr, and Nb in some ocean-floor basaltic rocks. Earth Planet. Sci. Letters, V. 10, pp. 7-11.

Carmichael, D.M.
1969: On the mechanism of prograde metamorphic reactions in quartz-bearing pelitic rocks. Contrib. Mineral. and Petrol. V. 20, pp. 244-267.

Carmichael, I.S.E., Truner, F.J. and Verhoogen, J.
1974: Igneous Petrology. McGraw-Hill, New York, 739 p.

Christie, A.M.
1950: Geology of Bonavista Map-Area, Newfoundland. Geological Survey of Canada, Paper 50-7.

Cox, K.G., Johnson, R.L., Monkman, L.J., Stillman,C.J., Vail,J.R. and Wood,D.N.
1965: The geology of the Nuanetsi Igneous Province. Phil. Trans. R. Soc., Ser. A, 257, pp. 71-218.

Cox, K.G., MacDonale, R. and Hornung, G.
1967: Geochemical and petrographic provinces in the Karoo basalts of Southern Africa. Am. Mineral., V. 52, pp. 1451-1474.

Coward, M.P.
1976: Large scale Paleozoic shear zone in Australia and present extension to the Antarctic Ridge. Nature, V. 259, pp. 648-649.

Crandell, D.R. and Waldron, H.H.
1956: A recent volcanic mudflow of exceptional dimensions from Mount Rainier, Washington. Amer. J. Sci., V. 254, pp. 349-362.

Dale, N.C.
1927: Precambrian and Paleozoic geology of Fortune Bay, Newfoundland. G.S.A. Bulletin, V. 38, pp. 411-430.

Davenport, P.H. and Butler, A.J.
1978: Distribution of U, Cu, Pb, Zn, Co, Ni, Ag, Mo, F, Mn & Fe in lake sediments, Burin Peninsula, Newfoundland. Nfld. Dept. of Mines & Energy, Mineral Dev. Div. Open File 1 M/166.

Eichelberger, J.C.
1975: Origin of andesite and dacite: evidence of mixing at Glass Mountain in California and at other circum-Pacific volcanoes. Bull. Geol. Soc. Amer., V. 86, pp. 1381-1391.

REFERENCES (continued)

Elston, W.E., and Smith, E.I.
1970: Determination of flow direction of rhyolitic ash-flow tuffs from fluidal textures. Geol. Soc. Amer. Bull., V. 81, pp. 3393-3406.

Evans, J.L.
1978: Contact metamorphism around the St. Lawrence Granite, Burin Peninsula, Newfoundland. Unpubl. B.Sc. (Hons.) thesis, M.U.N., St. John's, Newfoundland, 119 p.

Ewart, A., Taylor, S.R., and Capp, A.C.
1968b: Geochemistry of the pantellerites of Mayor Island, New Zealand. Contrib. Mineral. and Petrol., V. 17, pp. 116-140.

Fenner, C.N.
1948: Incandescent tuff flows in southern Peru. Geol. Soc. Amer. Bull., V. 59, pp. 879-893.

Fisher, R.V.
1960: Classification of volcanic breccias. Geol. Soc. Am. Bull., V. 71, pp. 973-982.

Fisher, R.V.
1961: Proposed classification of volcaniclastic sediments and rocks. Geol. Soc. Amer. Bull., V. 72, pp. 1409-1414.

Fisher, R.V.
1966: Rocks composed of volcanic fragments and their classification. Earth Sci. Rev., V. 1, pp. 287-298.

Fletcher, T.P.
1972: Geology and Lower to Middle Cambrian Trilobite Faunas of the southwest Avalon, Newfoundland. Unpubl. Ph.D. thesis, Christ's College, Cambridge.

Floyd, P.A., and Winchester, J.A.
1975: Magma type and tectonic setting discrimination using immobile elements. Earth Plan. Sci. Letters, V. 27, pp. 211-218.

Gibson, I.L.
1970: A pante-leritic welded ash-flow tuff from the Ethiopian rift valley. Contrib. Mineral. and Petrol., V. 28, pp. 89-111.

Glover, L., III, and Sinha, A.K.
1973: The Virgilian deformation, a late Precambrian to early Cambrian (?) orogenic event in the central Piedmont of Virginia and North Carolina. Amer. J. Sci., V. 273-A, pp. 234-251.

Greene, B.A. and O'Driscoll, C.F.
1976: Geology, Gaultois map area (1 M/12), Newfoundland. Newfoundland Dept. of Mines & Energy, Mineral Dev. Div., Map 767.

REFERENCES (continued)

Gunn, B.M.
1966: Modal and element variation in Antarctic tholeiites, Geochem. Cosmochem. Acta, V. 30, pp. 881-920.

Hart, S.R., Erlank, A.J., and Kable, E.J.D.
1974: Sea-floor basalt alteration: some chemical and Sr isotope effects. Contrib. Mineral. and Petrol., V. 44, pp. 219-230.

Hayes, A.O.
1948: Geology of the Area between Bonavista and Trinity Bays, Eastern Newfoundland. Geol. Surv. Nfld. Bull. 32, pt. 1.

Hildreth, W.
1979: The Bishop Tuff: Evidence for origin of compositional zoning in silicic magma chambers. G.S.A. Symposium volume on ash flow tuffs (in press).

Hjelmquist, S.
1955: On the occurrence of ignimbrite in the Precambrian. Sveriges Geol. Undersökning, Arsbok 49, Ser. C, pp. 1-12.

Howell, B.F.
1925: The Faunas of the Cambrian Paradoxides Beds at Manuels, Newfoundland. Bulletin American Paleontology, V. 11, No. 43, 1925, Pr. U. Contr. Geol. Nfld. No. 7.

Howley, J.P., and Murray, A.
1918: Reports of Progress, 1881-1909. Geol. Surv. Newfoundland.

Hughes, C.J.
1972: Geology of the Avalon Peninsula, Newfoundland and its possible correspondence with Morocco. Notes et Mem. Serv. Geol. Maroc, Number 236, pp. 265-275.

Hughes, C.J. and Brueckner, W.D.
1971: Late Precambrian rocks of Eastern Avalon Peninsula, Newfoundland - a volcanic island complex, Canadian Journal of Earth Science, V. 8, pp. 899-915.

Hughes, C.J., and Malpas, J.G.
1971: Metasomatism in the late Precambrian Bull Arm Formation in southeastern Newfoundland: recognition and implications. Geol. Assoc., Can., Proc., V. 24, pp. 85-93.

Hughes, C.J.
1973: Spilites, keratophyres, and the igneous spectrum. Geol. Mag., V. 109, pp. 513-527.

REFERENCES (continued)

Hussey, E.M.
1979: Geology of Clode Sound area; M.Sc. thesis, Memorial University of Newfoundland, St. John's, Newfoundland.

Hutchinson, R.D.
1953: Geology of Harbour Grace Map-area, Newfoundland. Geological Survey of Canada, Memoir 275.

Hutchinson, R.D.
1962: Cambrian Stratigraphy and Trilobite Faunas of Southeastern Newfoundland. Geological Survey of Canada, Bulletin 88, 156 p.

Irvine, T.N., and Baragar, W.R.A.
1971: A guide to the chemical classification of the common volcanic rocks. Can. J. Earth Sci., V. 8, pp. 523-548.

Jenness, S.E.
1957: Gander Lake (East Half), Newfoundland. Geol. Surv. of Canada, Map 3-1957.

Jenness, S.E.
1963: Terra Nova and Bonavista map areas, Newfoundland. Geol. Surv. of Canada, Memoir 327, 184 p.

Jolly, W.T. and Smith R.E.
1972: Degradation and metamorphic differentiation of the Keweenawan tholeiitic lavas of Northern Michigan. J. Petrology, V. 13, pp. 273-309.

Jooste, R.F.
1954: Report on "exploration" of exclusive permission granted Newfoundland Fluorspar Limited on the Burin Peninsula. Newfoundland Fluorspar Limited, unpublished report.

Jukes, J.B.
1843: General Report of the Geological Survey of Newfoundland during the years 1839-1840. Vol. I and II, John Murray, England, 180 p.

Kauffman, R.
1936: Reconnaissance of the regional and economic geology of the St. Lawrence area, Newfoundland, with notes on fluorite. B.A. thesis, Princeton University, New Jersey.

Keppie, J.D.
1977: Browns Mountain Group, Antigonish Highlands, Nova Scotia - Preliminary reassessment. Nova Scotia Department of Mines, Mineral Resources Division, Report of Activities.

REFERENCES (continued)

Kerrich, R., Fyfe, W.S., Gorman, B.E., and Allison, I.
1977: Local modification of rock chemistry by deformation. Contrib. Mineral. and Petrol., V. 65, pp. 183-190.

King, A.F., Breuckner, W.D., Anderson, M.M. and Fletcher, T.P.
1974: Late Precambrian and Cambrian Sedimentary Sequences of Eastern Newfoundland. Field Trip Manual, B6, G.A.C./M.A.C., 1974.

Kuno, H.
1966: Lateral variation of basalt magma across continental margins and island arcs. Bull. Volcanol., V. 29, pp. 195-222.

LeBlanc, M.
1976: Proterozoic Oceanic Crust at Bou Azzer. Nature, V. 261, May 6, 1976, pp. 34-35.

Levi, B.
1969: Burial metamorphism of a Cretaceous volcanic sequence west from Santiago, Chile. Contrib. Mineral. and Petrol., V. 24, pp. 30-49.

Lipman, P.W.
1967: Mineral and chemical variations within an ash-flow sheet from Aso Caldera, southwestern Japan. Contrib. Mineral. and Petrol., V. 16, pp. 300-327.

Lipman, P.W. and Mehnert, H.H.
1975: Late Cenozoic basaltic volcanism and development of the Rio Grande Depression in the Southern Rocky Mountains. Geol. Soc. Amer. Memoir 144, pp. 119-154.

Lipman, P.W., Prostka, H.J., and Christiansen, R.L.
1972: Cenozoic volcanism and plate-tectonic evolution of the western United States. Phil. Trans. Royal Soc. London, series A, V. 271, pp. 217-284.

Lofgren, G.
1970: Experimental devitrification rate of rhyolitic glass. Geol. Soc. Amer. Bull., V. 81, pp. 553-560.

MacDonald, G.A.
1968: Composition and origin of Hawaiian lavas. Geol. Soc. Amer. Memoir 116, pp. 477-522.

MacDonald, G.A.
1972: "Volcanoes", Prentice-Hull, Inc., Englewood Cliffs, New Jersey, 510 p.

REFERENCES (continued)

MacDonald, G.A., and Katsura, T.
1964: Chemical composition of Hawaiian lavas. J. Petrol. V. 5, pp. 82-133.

Malpas, J.
1971: The Petrochemistry of the Bull Arm Formation near Rantem Station, southeast Newfoundland. Unpubl. M.Sc. thesis, Memorial University, St. John's, Newfoundland, 95 p.

Manson, V.
1967: Geochemistry of basaltic rocks: major elements in Basalts: The Poldervaart Treatise on Rocks of Basaltic Composition. Editors, Hess, H., and Poldervaart, A., Interscience Publishers, New York, N.Y., 495 p.

Marshall, P.
1935: Acid rocks of the Taupo-Roturua volcanic district. Royal Soc. New Zealand, Trans., V. 64, pp. 328-366.

Martin, R.F. and Piwinski, A.J.
1972: Magmatism and tectonic setting. J. Geophys. Res., V. 77, pp. 4966-4975.

Maxwell, J.A.
1968: Rock and Mineral Analyses. Interscience Publishers, New York, 584 p.

McCartney, W.D.
1967: Whitbourne map-area, Newfoundland. Geol. Surv. of Canada Memoir 341.

Murray, A., and Howley, J.P.
1881: Geol. Surv., Newfoundland, 1864-1880, Edward Stanford, London.

Murray, D.P., and Skehan, S.J., J.W.
1978: Tectonostratigraphic frameword for Southeastern New England; A review. Northeastern G.S.A. 13th annual meeting, Abstracts with Programs, p. 77.

Mullineaux, D.R., and Crandell, D.R.
1962: Recent lahars from Mount St. Helens, Washington. Geol. Soc. Amer. Bull., V. 73, pp. 855-869.

Nixon, G.T.
1974: Late Precambrian (Hadrynian) ahs-flow tuffs and associated rocks of the Harbour Main Group near Colliers, Avalon Peninsula, southeast Newfoundland. Unpubl. M.Sc. thesis, Memorial University, St. John's, Newfoundland.

Nixon, G.T., and Papezik, V.S.
1979: Late Precambrian ash flow tuffs and associated rocks of the Harbour Main Group near Colliers, eastern Newfoundland; chemistry and magmatic affinities. Can. J. Earth Sci., V. 16, pp. 167-181.

REFERENCES (continued)

Noble, D.C.
1965a: Gold Flat member of the Thirsty Canyon Tuff - a pantellerite ash flow sheet in southern Nevada. U.S. Geol. Surv. Prof. Paper, 525B, pp. B85-B90.

Noble, D.C.
1965b: Ground-water leaching of sodium from quickly cooled volcanic rocks. (Abstr.). Am. Mineral., V. 50, p. 289.

Noble, D.C.
1967: Sodium, potassium, and ferrous iron contents of some secondarily hydrated natural silicic glasses. Am. Mineral., V. 52, pp. 280-286.

Noble, D.C.
1970a: Loss of sodium from crystallized comendite welded tuff of the Miocene Grouse Canyon member of the Belted Range Tuff, Nevada. Geol. Soc. Am. Bull., V. 81, pp. 2677-2688.

Nockolds, S.R., and Allen, R.
1953: The geochemistry of some igneous rock series. Geochem. Cosmochem. Acta, V. 4, pp. 105-142.

O'Brien, S.J.
1978: Geology of the Baine Harbour Map Area, West Half (1 M/7); in Report of Activities for 1977, Newfoundland Department of Mines and Energy, Mineral Development Division, St. John's, Newfoundland, pp. 156-161.

O'Brien, S.J., Strong, P.G. and Evans, J.L.
1977: Geology of the Grand Bank and Lamaline map areas; in Report of Activities for 1976, R.V. Gibbons (editor); Newfoundland Department of Mines and Energy, Mineral Development Division, Report 77-1, pp. 35-42.

O'Brien, S.J. and Taylor, S.W.
1979: Geology of the Baine Harbour and Point Enragée map areas, Newfoundland; in Report of Activities for 1978, Mineral Development Division, Nfld. Department of Mines and Energy, Report 79-1.

O'Driscoll, C.F.
1977 : Geology, Petrology and Geochemistry of the Hermitage Peninsula, Southern Newfoundland. Unpublished M.Sc. thesis, Memorial University of Newfoundland, 144 p.

REFERENCES (continued)

O'Driscoll, C.F. and Hussey, E.M.
1977: The Avalonian orogeny of the western Avalon Zone, Newfoundland. Geological Society of America, Abstracts with Programs, Northeastern Meeting, p. 306.

O'Driscoll, C.F. and Muggridge, W.W.
1978: Merasheen Project, in Preliminary Project Reports for 1978. Nfld. Dept. of Mines and Energy, Min. Development Division, Report 78-10, pp. 61-63.

Papezik, V.S.
1969: Late Precambrian ignimbrites of the Avalon Peninsula, Newfoundland. Can. J. Earth Sci., V. 6, pp. 1405-1414.

Papezik, V.S.
1970: Petrochemistry of volcanic rocks of the Harbour Main Group, Avalon Peninsula, Newfoundland. Can. J. Earth Sci., V. 7, pp. 1485-1498.

Papezik, V.S.
1972: Late Precambrian ignimbrites in eastern Newfoundland and their tectonic significance; Proceeding of the 24th Internation Geological Congress, Section 1, pp. 147-152.

Pearce, J.A., and Cann, J.R.
1971: Ophiolite origin investigated by discriminant analysis using Ti, Zr, and Y. Earth and Planet. Sci. Letters, V. 12, pp. 339-349.

Pearce, J.A., and Cann, J.R.
1973: Tectonic setting of basic volcanic rocks determined using trace element analyses. Earth and Planet. Sci. Letters, V. 19, pp. 290-300.

Pearce, T.H., Gorman, B.E., and Birkett, T.C.
1975: The TiO_2-K_2O-P_2O_5 diagram: a method of discriminating between oceanic and non-oceanic baslats. Earth and Planet. Sci. Letters, V. 24, pp. 419-426.

Pearce, J.A., and Gale, N.H.
1978: Identification of ore-deposition environments from trace-element geochemistry. In Volcanic Processes in ore genesis, Spec. Publ. 7, Geol. Soc. London, pp. 14-24.

REFERENCES (continued)

Parsons, W.H.
1969: Criteria for the recognition of volcanic breccias: a review. Geol. Soc. Am. Mem. 115, pp. 263-304.

Pettijohn, F.J.
1975: Sedimentary Rocks (3rd edition), Harper and Row, publ., 628 p.

Poole, W.H.
1976: Plate tectonic evolution of the Canadian Appalachian Region. Geol. Surv. of Canada, Paper 76-1B, pp. 113-126.

Potter, D.B.
1951: Geology of the Fortune - Grand Bank area, Burin Peninsula, Newfoundland, Canada. M.Sc. thesis, Brown University (unpublished).

Ramsay, J.G. and Graham, C.
1970: Strain variation in shear belts. Canadian J. of Earth Sci., V. 7, pp. 786-813.

Rast, N., O'Brien, B. and Wardle, R.J.
1976: Relationships between Precambrian and Lower Palaeozoic Rocks of the "Avalon Platform" in New Brunswick, the Northeast Appalachians and the British Isles. Tectonophysics, 30 (1976), pp. 315-338.

Rittman, A.
1962: Volcanoes and their activity. Interscience Publ., John Wiley and Sons, New York, 305 p.

Rodgers, J.
1970: "The tectonics of the Appalachians". Wiley-Intersciences, 271 p.

Rodgers, J.
1972: Late Precambrian (post-Grenville) rocks of the Appalachian region. American Journal of Science, V. 272, pp. 507-520.

Rose, E.R.
1952: Torbay Map-Area, Newfoundland. Geol. Surv. of Canada, Memoir 265, 64 p.

Schenk, P.E.
1971: Southeastern Atlantic Canada, northeastern Africa, and continental drift. Can. J. Earth Sci., V. 8, pp. 1218-1251.

Scott, R.B.
1971: Alkali exchange during devitrification and hydration of glasses in ignimbrite cooling sheets. J. Geol. V. 79, pp. 100-110.

REFERENCES (continued)

Seiders, U.M. and Wright, J.E.
1977: Geology of the Carolina Volcanic Slate Belt in the Asheboro, North Carolina area. In Field Guides for G.S.A. Southeastern Meeting, Winston - Salem, North Carolina, edited by E.R. Burt.

Scott, R.B.
1966: Origin of chemical variations within ignimbrite cooling units. Amer. J. Sci., V. 264, pp. 273-288.

Singer, A., and Navrot, J.
1970: Diffusion rings in altered basalt. Chem. Geol., V. 6, pp. 31-41.

Smith, M.M.
1975: Geology of an area around Mose Ambrose - English Harbour West, southern Newfoundland. B.Sc. thesis, Memorial University of Newfoundland, St. John's.

Smith, R.E.
1968: Redistribution of major elements in the alteration of some basic lavas during burial metamorphism. J. Petrology, V. 9, pp. 191-219.

Smith, R.L.
1960: Zones and zonal variations in welded ash flows. U.S. Geol. Surv. Prof. Paper 354-F, pp. 149-159.

Smith, R.L., and Bailey, R.A.
1966: The Bandelier tuff: a study of ash flow eruption cycles from zoned magma chambers, Bull. Volcanol., Ser. 2, V. 29, pp. 83-104.

Smith, R.L. and Bailey, R.A.
1968: Resurgent Caldrons. G.S.A. Memoir 116, pp. 613-662.

Sparks, R.S.J., Self, S., and Walker, G.P.L.
1976: Products of ignimbrite eruptions. Geology, B. 1, pp. 115-118.

Spooner, E.T.C. and Fyfe, W.S.
1973: Subsea-floor meatmrophism, heat and mass transfer. Contrib. to Min. and Pet., V. 42, pp. 287-304.

Strong, D.F., Dickson, W.L., O'Driscoll, C.F. and Kean, B.F.
1974a: Geochemistry of Eastern Newfoundland Granitoid Rocks. Report 74-3, Newfoundland Dept. of Mines & Energy, 1974, 140 p.

REFERENCES (continued)

Strong, D.F. and Minatides, D.G.
1975: Geochemistry of the late Precambrian Holyrood Plutonic Series of eastern Newfoundland. Lithos, 8, pp. 283-295.

Strong, D.F., O'Brien, S.J., Taylor, S.W., Wilton, D.H. and Strong, P.G.
1975: Geology of the St. Lawrence and Marystown map sheets, Newfoundland. Mineral Development Division, Newfoundland Department of Mines and Energy, Open File Newfoundland 895, 38 p.

Strong, D.F., O'Brien, S.J., Taylor, S.W., Strong, P.G. and Wilton, D.H.
1978a: Aborted Proterozoic rifting in eastern Newfoundland. Can. Jour. of Earth Sci., 15, pp. 117-131.

Strong, D.F., O'Brien, S.J., Taylor, S.W., Strong, D.G. and Wilton, D.H.
1978b: Geology of the Marystown (1 M/3) and St. Lawrence (1 L/14) Map Sheets, Newfoundland. Newfoundland Department of Mines and Energy, Report 77-8, 81 p.

Strong, D.F., O'Brien, S.J., Strong, P.G., Evans, J.L. and Swinden, H.S.
1979: Geology of the Grand Bank (1 M/4) and Lamaline (1 L/13) map areas, Newfoundland. Nfld. Dept. of Mines and Energy (in press).

Strong, P.G.
1967: Geology of the Lawn area, Burin Peninsula, Newfoundland. B.Sc. thesis, Memorial University of Newfoundland, St. John's.

Stukas, V.
1978: Plagioclase release patterns: a high resolution ^{40}Ar - ^{39}Ar study. Doctoral thesis, Dalhousie University, Halifax, Nova Scotia, 141 p.

Teng, H.C.
1974: A lithogeochemical study of the St. Lawrence Granite, Newfoundland. Unpubl. M.Sc. thesis, Memorial University, St. John's, Newfoundland, 194 p.

Taylor, S.R.
1965: The application of trace element data to problems in petrology. In Physics and Chemistry of the Earth, Editors Ahrens, L.H., Press, F., Runcorn, S.K., and Urey, H.C., V. 6, pp. 133-213.

Taylor, S.W.
1976: Geology of Marystown Map Sheet (E/2), Burin Peninsula, Southeastern Newfoundland. Unpubl. M.Sc. thesis, Memorial University, St. John's, Newfoundland, 165 p.

REFERENCES (continued)

Thieme, J.G.
1970: The Geology of the Mansa Area: explanation of Degree Sheet 1128, parts of N.W. Quarter and N.E. Quarter. Rep. Geol. Surv. Zambia.

Thompson, R.N., Esson, J. and Dunham, A.C.
1972: Major element chemical variation in Eocene lavas of the Isle of Skye, Scotland. J. Petrol., V. 13, pp. 219-253.

Twenhofel, W.H. and MacClintock, P.
1940: The surface of Newfoundland. G.S.A. Bulletin, V. 51, pp. 1755-1929.

Vallance, T.G.
1969: Spilites again: some consequences of the dehydration of basalts. Linn. Soc. N.S.W., Proc., V. 94, pp. 8-51.

Vallance, T.G.
1974: Spilitic degradation of a tholeiitic basalt. J. Petrology, V. 15, p. 79.

Vanderveer, D.G.
1976: Surficial and glacial geology, gravel resources inventory, Burin Peninsula, Newfoundland. Mineral Development Division, Nfld. Dept. of Mines and Energy, Open File Report, 12 p.

Van Alstine, R.
1948: Geology and Mineral Deposits of the St. Lawrence Area, Burin Peninsula, Newfoundland. Geological Survey of Newfoundland, Bulletin 23, 64 p.

Van Bemmelen, R.W.
1949: The geology of Indonesia, V. 1A, General Geology of Indonesia and adjacent archipelagos. Govt. Printing Office, The Hague, 732 p.

Van Ingen, G.
1914: Table of Geological Formations of the Cambrian and Ordovician Systems about Conception and Trinity Bays, Newfoundland. Princeton University Contributions to Geology of Newfoundland, No. 4.

Wager, L.R., and Deer, W.A.
1939: The petrology of the Skaergaard intrusion, Kangerd Liugssuag, East Greenland. Meddl. om Gronland, V. 105, No. 4, pp. 1-352.

REFERENCES (continued)

Walcott, C.D.
1900: Precambrian Upper Algonkian Terrane. Geological Society of America Bulletin, V. 11, 1900.

Walker, G.P.L.
1972: Crystal concentration in ignimbrites. Contrib. Mineral. and Petrol., V. 36, pp. 135-146.

Walker, R.G.
1976: Facies Models: 1, General Introduction. Geoscience Canada, V. 3, pp. 21-24.

Walthier, T.N.
1948: Geology of the Grand Bank quadrangle, Burin Peninsula, Newfoundland. Unpublished field report, File 1 L/14(11), 24 p.

Waters, A.C.
1961: Stratigraphic and lithologic variations in the Columbia River Basalt. Am. J. Sci., V. 259, pp. 583-611.

Waters, A.C.
1962: Basalt magma types and their tectonic associations: Pacific Northwest of the United States. In The Crust of the Pacific Basin, Editors, MacDonald, G.A., and Kuno, H., Amer. Geophys. Union Monograph 6, pp. 158-170.

Wentworth, C.K., and Williams, Howel
1932: The classification and terminology of the pyroclastic rocks. Nat. Research Council, Rept. Comm. Sedimentation, Bull., V. 89, pp. 19-53.

West, W.D.
1958: The petrography and petrogenesis of forty-eight flows of the Deccan Trap. Nat. Inst. Sci. Indian Trans., V. 4, pp. 1-56.

White, D.E.
1939: Geology and Molybdenite Deposits of the Rencontre East Area, Fortune Bay, Newfoundland. Princeton University, doctoral dissertation.

Whitney, J.A., Paris, T.A., Carpenter, R.H. and Hartley, M.E.
1978: Volcanic evolution of the southern Slate Belt of Georgia and South Carolian: a primitive oceanic island arc. J. Geol., V. 86, pp. 173-192.

REFERENCES (continued)

Widmer, K.
1950: The Geology of the Hermitage Bay Area, Newfoundland. Princeton University, doctoral dissertation.

Willars, J.
1953: Field report of geological exploration, Burin Peninsula, Newfoundland. Newfoundland and Labrador Corporation (NALCO), unpublished.

Wilson, A.D.
1955: A new method for the determination of ferrous iron in rocks and minerals. Bull. Geol. Surv. of Gt. Britain, V. 9, pp. 56-58.

Wilton, D.H.
1977: Petrological studies of the southeastern part of the Burin Group, Burin Peninsula, Newfoundland. B.Sc. thesis, Memorial University of Newfoundland, St. John's, 115 p.

Williams, H.
1971: Geology of Belleoram map-area. Geol. Surv. of Canada, Paper 70-65, 39 p.

Williams, H.
1979a: Tectonic Lithofacies Map of the Appalachian Orogen. Map No. 1, Memorial University of Nfld., International Geological Correlation Project No. 27.

Williams, H., Kennedy, M.J. and Neale, E.R.W.
1970: The Hermitage Flexure, the Cabot Fault and the disappearance of the Newfoundland Central Mobile Belt. Bull. Geol. Soc. Amer., V. 81, pp. 1563-1568.

Williams, H., Kennedy, M.J. and Neale, E.R.W.
1974: The northeastward termination of the Appalachian orogen. In The Ocean Basins and Margins (A.E.M. Nairn and F.G. Stehli, Eds.), New York Plenum Publishing Corporation, V. 2, pp. 70-123.

Williams, H. and King, A.F.
1976: Southern Avalon Peninsula, Newfoundland, Trepassey map-area. Geological Survey of Canada Paper 76-1A, pp. 179-182.

Williamson, D.H.
1956: Geology of Oderin and adjacent islands, Placentia Bay. Geol. Surv. of Newfoundland, Report No. 9, 34 p.

REFERENCES (continued)

Winchester, J.A., and Floyd, P.A.
1976: Geochemical magma type discrimination: application to altered and metamorphosed basic igneous rocks. Earth and Planet. Sci. Letters, V. 28, pp. 459-469.

Winchester, J.A., and Floyd, P.A.
1977: Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chem. Geology, V. 20, pp. 325-343.

Wood, D.A., Gibson, I.L., and Thompson, R.N.
1976: Elemental mobility during zeolite facies metamorphism of the Tertiary basalts of eastern Iceland. Contrib. Mineral. and Petrol., V. 55, pp. 241-254.

Wright, A.E., and Bowes, D.R.
1963: Formation of explosion breccias. Bull. Volcanol., V. 32, pp. 15-32.

Wright, J.V., and Walker, G.P.L.
1977: The ignimbrite source problem: significance of a co-ignimbrite lag-fall deposit. Geology, V. 5, pp. 729-732.

Younce, G.B.
1970: Structural geology and stratigraphy of the Bonavista Bay region, Newfoundland. Unpubl. Ph.D. dissertation, Cornell University, Ithaca, New York, 188 p.

APPENDIX 1: MAJOR AND TRACE ELEMENT ANALYSES

	GB0850	GB0870	GN0871	GB0852	GB0853	GB0855	GB0856	GB0857	GB0858
SiO_2	76.90	76.80	75.10	77.30	77.50	76.20	76.20	74.6	75.6
TiO_2	0.0	0.08	0.12	0.00	0.10	0.00	0.10	0.00	0.14
Al_2O_3	12.1	12.6	11.9	12.40	12.10	11.80	12.00	12.60	11.90
Fe_2O_3	0.14	1.12	1.42	0.24	0.38	0.37	0.37	0.00	0.97
FeO	0.82	0.19	0.35	0.85	0.71	0.73	0.51	1.13	0.68
MnO	0.02	0.02	0.03	0.01	0.01	0.02	0.02	0.04	0.02
MgO	0.22	0.20	0.48	0.18	0.18	0.38	0.16	0.24	0.60
CaO	0.14	0.10	0.62	0.34	0.24	0.24	0.20	0.28	0.20
Na_2O	3.47	3.73	2.78	3.65	3.69	3.47	3.79	4.38	2.89
K_2O	4.88	4.96	5.90	4.82	4.88	4.82	4.78	4.08	5.73
P_2O_5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
L.O.I.	0.85	1.09	1.02	0.69	0.74	0.68	0.80	1.14	1.23
Total	99.54	100.89	99.72	100.48	100.53	98.71	98.93	98.49	99.96
Zr	188	144	185	180	202	178	189	201	188
Sr	35	33	75	26	43	38	28	20	57
Rb	193	278	372	217	210	262	208	282	321
Zn	49	62	59	58	55	63	52	78	69
Cu	0	0	0	0	0	0	0	0	0
Ba	85	95	131	74	0	66	61	63	96
Nb	32	25	63	35	0	35	34	106	51
Pb	13	20	14	13	11	13	12	59	12
Ni	0	0	11	2	2	3	0	0	0
Cr	0	0	0	0	0	0	0	0	0
Y	35	51	57	43	41	43	39	61	46
	*(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

GRAND BEACH COMPLEX

GB0850-GB0869 - Porphyritic rhyolite tuffs, Grand Beach Complex, GB0852-GB0857 are air fall tuffs, remainder are ash flow deposits

* Sample location reference number

	GB0859	GB0861	GB0862	GB0863	GB0865	GB0866	GB0867	GB0868	GB0869
SiO_2	75.00	76.90	76.90	75.70	75.60	76.80	76.40	77.60	75.10
TiO_2	0.08	0.06	0.10	n.d.	0.14	0.0	0.02	0.02	n.d.
Al_2O_3	11.90	12.10	12.10	12.40	12.30	12.20	12.30	12.40	12.30
Fe_2O_3	0.95	0.69	0.51	0.26	0.17	0.85	n.d.	n.d.	0.27
FeO	0.92	0.39	0.80	0.77	0.73	0.43	0.60	0.59	0.45
MnO	0.03	0.02	0.03	0.02	0.03	0.04	0.03	0.03	0.03
MgO	0.51	0.17	0.65	0.18	0.15	0.23	0.26	0.15	0.35
CaO	0.28	0.14	0.14	0.16	0.12	0.12	0.12	0.15	0.18
Na_2O	3.48	3.87	3.57	4.02	4.00	3.10	2.79	3.95	3.70
K_2O	4.80	4.76	4.93	4.48	4.48	4.88	5.38	4.34	4.74
P_2O_5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
L.O.I.	0.73	0.74	1.36	0.63	0.63	0.87	1.11	0.91	0.68
Total	98.68	99.79	100.69	98.62	98.35	99.52	98.00	100.15	97.80
Zr	91	196	194	*	184	142	147	156	185
Sr	34	19	31	15	13	30	27	28	27
Rb	266	309	263	306	302	272	312	230	221
Zn	69	45	78	49	44	56	58	53	59
Cu	34	*	*	*	*	*	*	*	*
Ba	83	65	81	57	57	147	156	79	82
Nb	44	92	96	78	86	20	22	22	42
Pb	13	17	20	16	15	19	20	19	13
Ni	7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cr	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Y	51	54	59	56	57	38	46	33	43
	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)

GRAND BEACH COMPLEX (cont'd.)

	*	*	*	*	*	*	*	*	*	*	*	*
	S1045	S1046	JS-9	JS-5A	JS-35A	JS-31B	JS-31A	JS-10	1056	1050	1049	1048
SiO_2	75.90	74.80	77.60	76.90	71.10	76.60	76.90	77.50	74.50	75.00	76.50	76.20
TiO_2	0.10	0.12	0.02	0.09	0.58	0.01	n.d.	0.09	0.05	0.10	0.05	0.10
Al_2O_3	11.80	12.80	12.40	11.90	13.10	12.10	11.80	12.40	12.30	12.00	12.00	12.00
Fe_2O_3	0.63	0.60	0.19	0.39	1.19	0.52	0.22	0.12	1.37	0.55	0.57	1.38
FeO	0.32	0.73	0.78	0.58	2.06	0.64	0.53	0.42	0.35	0.68	0.55	0.27
MnO	0.02	0.03	0.01	0.01	0.05	0.02	0.01	n.d.	0.01	0.02	0.02	0.01
MgO	0.20	0.18	0.19	0.16	0.88	0.22	0.19	0.17	0.21	0.15	0.20	0.12
CaO	0.24	0.33	0.29	0.21	0.34	0.28	0.40	0.21	0.35	0.33	0.44	0.40
Na_2O	3.48	3.77	3.00	3.71	3.88	3.43	3.30	3.56	3.21	4.20	3.48	3.43
K_2O	4.87	5.04	4.92	4.80	4.26	5.08	5.12	4.73	5.04	4.04	5.02	4.92
P_2O_5	0.15	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
L.O.I.	0.60	0.90	0.87	0.64	1.63	0.87	1.00	0.95	0.78	0.50	0.09	0.55
Total	98.31	99.30	100.27	99.39	99.07	99.77	99.47	100.15	98.17	97.57	98.97	99.50
Zr	126	114	141	140	242	*	143	146	129	115	121	118
Sr	56	80	31	30	138	*	53	56	38	45	88	39
Rb	225	180	204	194	127	*	212	201	182	159	234	245
Zn	41	66	46	41	66	*	32	27	55	49	57	51
Cu	3	11	3	9	9	*	6	4	7	7	7	5
Ba	85	168	61	83	278	*	68	61	159	106	95	98
Nb	57	47	35	36	31	*	35	37	51	47	56	56
Pb	*	*	10	4	4	*	6	2	n.d.	n.d.	n.d.	n.d.
Ni	19	19	7	9	4	*	8	6	19	19	20	20
Cr	8	7	5	2	11	*	1	1	8	9	6	11
Y	*	*	*	*	*	*	*	*	*	*	*	*
	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)

* Analysis of Grand Beach Complex from Strong et al., 1979.

	BO155A	BO85A	BD1025	BO71B	BARA 1	BARA 2	BO10A	BO12C	BO72	BO388	BO356
SiO_2	73.40	77.90	70.50	68.00	73.50	71.00	70.20	76.20	70.30	76.30	74.30
TiO_2	0.30	0.06	0.53	0.52	0.20	0.40	0.40	0.0	0.04	0.0	0.16
Al_2O_3	13.70	13.10	15.50	14.90	14.80	15.00	15.30	13.00	14.70	13.30	13.30
Fe_2O_3	1.20	0.90	1.33	3.10	1.88	2.21	1.36	0.74	2.78	0.66	1.68
FeO	0.82	n.d.	1.29	0.07	n.d.	n.d.	0.91	0.17	0.27	0.24	0.20
MnO	0.04	0.07	0.10	0.10	0.10	0.11	0.09	0.02	0.13	0.03	0.13
MgO	0.62	0.21	0.67	0.77	0.55	0.67	0.73	0.27	1.10	0.15	0.10
CaO	0.80	0.82	0.71	1.13	1.76	0.72	1.10	0.90	1.30	0.12	2.48
Na_2O	1.95	3.60	5.84	5.11	4.20	4.70	5.42	3.22	4.80	3.04	3.84
K_2O	7.16	4.00	2.94	3.42	2.84	4.48	3.68	3.74	3.92	4.92	2.52
P_2O_5	0.04	n.d.	0.15	0.08	0.14	0.04	0.08	n.d.	0.10	n.d.	0.02
L.O.I.	0.93	0.58	0.89	0.81	0.93	0.76	0.72	1.55	0.92	0.74	0.7
Total	100.96	101.24	100.45	98.01	100.90	100.09	99.99	99.81	100.36	99.50	99.45
	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)	(39)	(40)	(41)
Zr	320	203	343	320	245	350	371	150	308	174	322
Sr	120	88	343	*	188	144	340	40	267	*	294
Rb	253	97	67	*	71	132	86	114	128	*	62
Zn	64	61	104	*	74	96	69	48	85	*	58
Cu	n.d.	n.d.	9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ba	*	*	880	*	*	*	*	953	952	932	681
Nb	*	*	14	*	*	*	*	7	8	7	5
Pb	25	18	n.d.	*	15	16	12	13	13	n.d.	18
Ni	14	n.d.	18	13	2	4	41	n.d.	9	1	4
Cr	n.d.	n.d.	10	n.d.	n.d.	n.d.	n.d.	n.d.	8	n.d.	n.d.
Y	42	18	*	*	17	31	27	20	26	n.d.	25

BARASWAY COMPLEX

BO155A: albite porphyritic vitric tuff; BO85A, 71B, 72 fine grained welded rhyolite tuffs;

BD1025: rhyolite flow; BARA 1, BARA 2: albite porphyritic rhyolite; BO12C, 10A: rhyolite porphyry;

Bo388: aphyric rhyolite; BO356: rhyolitic rheoignimbrite

	OS232	OS731	T265A	T375B	T266A	T088	T159A	T160A	OS22A	OS681	OS682	OS776A
SiO_2	79.50	80.06	68.00	69.10	71.10	72.00	71.40	78.60	69.40	72.01	72.38	72.25
TiO_2	0.22	0.16	0.58	0.43	0.54	0.33	0.65	0.65	0.28	0.50	0.59	0.42
Al_2O_3	12.04	10.56	15.50	14.80	14.50	14.50	10.10	16.50	13.76	13.76	13.98	13.78
Fe_2O_3	1.35	0.97	2.29	1.88	2.19	0.87	1.98	1.87	1.58	2.68	3.07	2.22
FeO	n.d.	n.d.	0.91	0.40	0.52	0.96	0.64	0.50	0.36	n.d.	n.d.	n.d.
MnO	0.04	0.04	0.13	0.06	0.13	0.07	0.06	0.06	0.04	0.07	0.08	0.07
MgO	0.11	0.69	0.86	0.43	0.51	0.39	0.45	0.35	0.64	0.43	0.32	0.33
CaO	0.10	1.41	0.75	0.94	0.27	1.01	0.86	0.40	0.50	0.72	0.45	1.25
Na_2O	4.71	3.44	5.70	6.41	5.97	5.31	5.17	5.18	5.78	4.54	7.26	3.93
K_2O	1.61	2.79	3.14	2.86	1.83	3.37	3.92	1.99	2.95	4.06	1.21	3.52
P_2O_5	0.05	0.04	0.18	n.d.	0.18	0.08	n.d.	0.11	n.d.	0.06	0.09	0.11
L.O.I.	1.28	0.62	1.12	0.72	0.90	0.68	0.82	0.56	1.78	1.06	0.00	2.16
Total	101.01	100.78	99.16	98.03	98.64	99.57	100.45	100.37	99.81	99.89	100.42	100.04
	(42)	(43)	(44)	(45)	(46)	(47)	(48)	(49)	(50)	(51)	(52)	(53)
Zr	127	102	416	404	411	368	448	267	127	305	357	224
Sr	162	161	81	82	66	138	198	55	266	108	244	135
Rb	87	50	65	46	40	79	78	8	50	101	32	84
Zn	52	19	114	68	109	41	104	99	112	72	58	61
Cu	6	4	8	7	11	5	5	3	41	6	7	8
Ba	699	764	893	639	533	952	1083	115	1052	905	505	904
Nb	9	10	13	7	14	11	12	8	8	13	14	11
Pb	2	12	13	12	11	13	13	17	7	8	8	9
Ni	*	*	8	4	4	6	12	*	6	3	2	*
Cr	8	4	n.d	n.d	n.d	n.d	n.d	n.d.	n.d.	6	12	7
Y	*	*	29	19	25	26	32	25	*	*	*	*

MOUNT SAINT ANNE FORMATION

T265A, T375B, T266A, T088, T159A, T160A - porphyritic rhyolites (from Taylor, 1976).

OS776A: red, vitric tuff; OS681, OS682, red vitrophyric containing red lithic fragments of similar composition, OS22A, grey rhyolite flow, spherulitic: OS732, OS731: massive rhyolite flows.

	CO537	CO4	CO722	CO724	CO721	CO726	CO798	COP632	COP625	CO17	CO13	CO14	JS-177
SiO_2	51.71	45.70	47.69	52.34	49.02	48.25	52.36	46.40	46.46	43.50	46.60	45.10	43.92
TiO_2	1.61	0.98	1.25	1.01	1.29	1.13	1.39	1.06	1.11	1.20	1.45	1.60	1.59
Al_2O_3	14.81	15.70	16.17	17.57	17.53	17.68	15.34	14.75	17.16	18.70	16.40	15.90	16.31
Fe_2O_3	11.30	3.95	11.22	10.23	11.56	7.97	8.12	6.54	8.20	8.77	6.97	6.94	11.26
FeO		6.34				2.20	4.03	4.47	2.08	3.76	4.36	4.32	
MnO	0.16	0.22	0.27	0.18	0.21	0.18	0.28	0.17	0.20	0.17	0.23	0.21	0.19
MgO	3.39	8.74	7.47	4.18	5.71	5.89	4.05	9.39	6.70	5.71	7.43	6.91	6.40
CaO	8.26	7.97	5.82	8.29	3.80	8.29	3.80	6.91	9.89	8.79	5.37	7.52	8.20
Na_2O	3.87	3.32	3.50	2.91	4.14	3.57	2.63	2.55	2.83	0.66	4.76	2.83	3.82
K_2O	0.11	0.70	0.95	0.52	1.33	0.03	0.07	2.11	1.22	3.06	0.12	1.05	0.78
P_2O_5	0.59	0.36	0.23	0.18	0.22	0.31	0.27	0.19	0.22	0.12	0.49	0.53	0.41
L.O.I.	4.04	4.78	4.68	2.50	4.07	4.42	4.07	3.81	2.38	4.96	6.29	5.78	6.20
Total	99.85	98.76	99.25	99.91	98.88	99.27	100.10	98.41	98.45	99.40	100.47	98.69	99.08
	(54)	(55)	(56)	(57)	(58)	(59)	(60)	(61)	(62)	(63)	(64)	(65)	(66)
Zr	229	131	101	105	103	117	99	77	95	137	140	176	157
Sr	373	421	563	349	211	349	605	362	539	924	477	512	181
Rb	1	13	22	12	23	2	4	66	35	72	3	27	12
Zn	103	85	90	86	187	95	109	87	80	74	93	92	92
Cu	94	110	99	45	172	106	125	90	58	23	55	57	42
Ba	106	303	785	170	734	27	49	911	442	1087	131	784	329
Nb	11	6	8	7	9	8	5	6	5	5	8	9	11
Pb	17	n.d.	1	77	26	7	12	8	1	9	6	6	1
Ni	14	98	48	11	10	54	22	114	49	79	100	98	82
Cr	4	209	92	12	15	75	58	265	69	146	179	184	151
Y	*	*	*	*	*	*	*	*	*	*	*	*	*

CALMER FORMATION

CO722: aphanitic mafic flow; O724 mafic flow with chlorite vesicles; O721 aphanitic basalt; O726, O798: oxidized basalt; P632A: green amygdaloidal basalt flow; P625A grey aphanitic basalt; Co17, banded basalt; Co13 slightly vesicular plagiophyric flow; CO14, CO4: aphanitic basalt; JS-177 fine grained grey basalt.

	JS 189	JS 199	CO1	CO2
SiO_2	48.31	54.68	48.40	46.10
TiO_2	1.27	1.27	1.00	1.20
Al_2O_3	16.97	15.58	20.10	19.60
Fe_2O_3	16.38	10.62	4.38	3.96
FeO	4.00		3.97	6.57
MnO	0.17	0.22	0.15	0.19
MgO	6.29	3.13	2.75	4.37
CaO	8.08	5.71	8.48	7.65
Na_2O	3.36	3.75	2.93	2.86
K_2O	1.51	1.70	0.93	0.64
P_2O_5	0.38	0.29	0.19	0.30
L.O.I.	3.28	2.87	5.07	6.35
Total	100.00	99.82[illegible]	98.35	99.79
	(67)	(68)	(69)	(70)
Zr	138	113	118	126
Sr	364	521	649	522
Rb	47	35	27	19
Zn	86	117	78	93
Cu	75	20	44	50
Ba	474	747	260	265
Nb	9	5	5	8
Pb	3	1	2	5
Ni	72	n.d.	8	17
Cr	116	12	10	24
Y	*	*	*	*

CALMER FORMATION

CO1, CO2 massive, aphanitic mafic flows; JS 189, JS 199 green massive fine grained plagiophyric basalt.

	TL04	TL05	TL03	TL09	TL02	TL56	TL41	TL039	TL037	TL055
SiO_2	47.50	48.40	48.80	48.80	51.50	45.60	45.60	46.2	55.2	55.0
TiO_2	1.24	1.46	1.32	1.24	1.24	1.28	1.20	0.92	1.44	1.31
Al_2O_3	16.90	17.20	16.80	15.60	16.90	22.00	17.70	18.70	15.60	17.80
Fe_2O_3	5.25	6.08	5.44	4.64	4.87	7.17	7.49	4.78	6.47	4.18
FeO	5.11	4.67	5.21	5.19	4.65	6.15	5.21	5.36	4.21	2.89
MnO	0.36	0.17	0.17	0.19	0.39	0.28	0.54	0.30	0.13	0.13
MgO	7.92	8.00	7.86	7.41	8.00	3.80	6.46	8.64	3.90	2.24
CaO	8.88	8.40	8.72	10.04	8.86	5.70	8.08	7.36	7.16	5.15
Na_2O	3.34	3.96	3.61	2.58	1.41	3.70	2.39	2.07	3.92	4.13
K_2O	1.17	0.71	0.85	0.50	1.00	1.94	2.23	1.90	1.11	4.98
P_2O_5	0.32	0.30	0.32	0.21	0.38	0.32	0.19	0.10	0.60	0.61
L.O.I.	1.67	1.63	1.84	1.80	1.56	3.43	3.38	3.97	1.74	1.49
Total	99.56	100.98	100.94	98.2	100.76	101.37	101.47	100.30	101.50	100.41
	(71)	(72)	(73)	(74)	(75)	(76)	(77)	(78)	(79)	(80)
Zr	179	180	189	168	209	190	136 —	124	181	239
Sr	609	719	613	465	309	483	388	270	449	558
Rb	22	17	18	15	30	135	110	104	43	116
Zn	104	111	122	87	106	126	187	133	56	67
Cu	22	n.d.	n.d.	15	11	4	76	n.d.	n.d.	7
Ba	392	192	348	234	319	395	361	226	223	1358
Nb	4	5	6	1	6	6	3	3	3	7
Pb	9	8	9	9	7	9	9	7	7	8
Ni	85	73	77	102	87	96	31	79	4	23
Cr	162	158	148	12	124	48	26	121	*	*
Y	20	18	19	17	23	30	26	23	24	35

PLAGIOPHYRIC BASALT (FROM TILT HILLS)

TL04, TL05, TL03, TL09, TL56, TL41, TL039: plagioclase porphyritic basalt. TL02, TL037, TL055, TL042, TL057: very coarse grained plagiophyric basalt, glomeroporphyritic. TO267A, TO38: fine grained plagiophyric basaltic sill.

	TL038	TL042	TL057	T0267A	HH155B	HH157B	HH578	HH153	P604A
SiO_2	47.90	50.00	51.00	46.10	73.60	71.60	68.07	70.40	69.82
TiO_2	2.27	1.28	1.39	1.31	0.82	0.12	0.58	0.45	0.47
Al_2O_3	14.60	18.40	18.40	17.30	12.80	13.60	14.62	13.90	14.39
Fe_2O_3	4.28	4.54	5.77	3.85	1.36	1.15	3.34	1.15	2.50
FeO	8.13	6.02	3.94	7.85	0.58	0.95	n.d.	1.11	n.d.
MnO	0.35	0.43	0.18	0.27	0.02	0.13	0.13	0.10	0.08
MgO	3.26	3.62	2.97	5.79	0.40	0.53	0.97	0.52	0.63
CaO	6.00	9.24	8.18	8.14	0.83	1.34	2.54	1.73	1.07
Na_2O	2.61	2.84	3.03	2.48	3.08	5.02	4.57	4.54	4.77
K_2O	0.20	1.54	1.78	2.50	4.43	3.24	2.97	3.30	3.46
P_2O_5	1.48	0.52	0.50	0.15	n.d.	0.06	0.17	0.04	0.11
L.O.I.	4.86	2.32	2.20	4.99	1.39	1.24	1.28	2.26	1.30
Total	101.94	99.75	99.34	100.72	99.31	99.18	99.18	99.50	98.55
	(81)	(82)	(83)	(84)	(85)	(86)	(87)	(88)	(89)
[illegible]r	158	183	215	160	159	314	234	235	*
[illegible]r	311	706	609	647	123	171	289	192	*
Rb	6	55	75	69	124	74	86	94	*
Zn	194	181	83	101	37	26	70	69	*
[illegible]	44	19	15	46	8	6	10	8	*
Ba	63	406	332	243	1134	8	699	806	*
[illegible]b	6	5	5	1	11	14	12	12	*
[illegible]b	[illegible]	7	7	[illegible]	[illegible]	13	11	9	*
[illegible]	[illegible]	21	25	35	2	1	4	1	*
[illegible]	[illegible]	12	11	32	6	12	16	5	*
[illegible]	[illegible]	26	29	22	*	*	*	*	*

[illegible]RE HILLS FORMATION

[illegible]155B: grey, partially devitrified rhyolite flow; HH157B: red, glassy devitrified rhyolite flow.

[illegible]578: fine grained grey plagioclase vitrophyre; HH153: grey vitric tuff.

[illegible]604A: red crystal tuff, plagiophyric (from Strong et al., 1979).

	MO240	MO236	MO49	MO235	MO101A	MO237A	MO102	MO530	MO206	MO531	MO205	MO66C
SiO_2	43.10	47.20	46.80	46.30	45.20	48.00	48.00	49.00	50.50	52.20	52.70	47.90
TiO_2	2.05	0.76	0.85	1.14	1.57	1.10	1.48	1.00	1.78	1.12	1.73	1.07
Al_2O_3	16.40	17.00	18.60	16.90	14.50	17.90	18.10	17.10	16.90	16.50	15.60	16.61
Fe_2O_3	11.09	4.36	5.78	4.19	7.45	4.51	4.47	5.61	8.79	4.85	7.59	5.24
FeO	6.47	5.46	5.14	6.17	9.97	5.45	5.81	4.89	5.05	4.63	5.35	5.23
MnO	0.28	0.16	0.26	0.37	0.64	0.14	0.26	0.43	0.69	0.22	0.35	0.20
MgO	6.57	7.58	5.88	8.68	6.07	7.18	8.12	7.72	5.16	7.08	4.37	9.04
CaO	4.66	8.27	10.63	8.92	9.05	9.74	6.67	7.70	5.68	6.02	6.91	8.40
Na_2O	4.91	3.04	1.94	2.71	1.57	3.36	3.75	3.74	3.56	4.30	3.23	2.86
K_2O	0.05	1.19	0.80	0.69	0.49	0.45	1.87	0.81	0.12	1.34	0.05	1.55
P_2O_5	0.40	0.27	n.d.	0.28	0.14	0.21	0.42	0.32	0.42	0.19	0.54	0.18
L.O.I.	3.00	2.81	1.36	3.09	1.88	2.84	2.09	1.83	2.80	2.10	1.39	1.85
Total	98.98	98.10	98.04	99.46	98.53	100.88	101.04	100.15	100.45	100.55	99.81	100.13
	(90)	(91)	(92)	(93)	(94)	(95)	(96)	(97)	(98)	(99)	(100)	(101)
Zr	94	174	141	171	131	166	196	180	151	199	124	165
Sr	191	578	491	591	457	684	708	700	811	627	308	536
Rb	3	36	56	15	15	15	56	46	5	34	4	76
Zn	210	48	113	96	2370	52	190	133	150	108	117	59
Cu	n.d.	24	90	88	40	689	12	85	11	43	7	26
Ba	63	287	130	299	135	174	*	139	123	425	72	269
Nb	2	4	84	3	2	1	*	7	4	8	2	2
Pb	7	7	9	6	14	7	11	11	8	9	8	6
Ni	2	112	48	114	n.d.	60	141	129	1	94	6	210
Cr	6	201	99	182	5	69	*	242	2	277	*	508
Y	20	19	20	19	20	16	25	21	20	20	20	23

MAGNETITE RICH BASALT FLOWS (CALMER EQUIVALENTS)

MO240, MO236, MO235, MO237A: aphanitic magnetite rich basalt flows; MO49, MO101A, MO102, MO531, MO66C, fine grained plagiophyric, slightly vesicular flows.

MO206, MO205: basalt flows, magnetite porphyroblasts.

	TPO614A	TOJ108	TOJ93	TPO608A	TOP607C	TOP589B	TPO592B	TOS40	TPO654B
SiO_2	47.44	47.00	60.00	58.89	55.46	41.64	62.75	60.00	66.45
TiO_2	1.19	1.20	1.02	1.36	1.71	1.21	0.88	1.04	0.92
Al_2O_3	16.07	15.70	17.10	14.34	14.57	15.15	15.31	15.70	14.49
Fe_2O_3	10.52	4.44	2.79	8.35	10.29	10.42	6.41	1.91	4.70
FeO	n.d.	5.79	2.34	n.d.	n.d.	n.d.	n.d.	3.82	n.d.
MnO	0.18	0.19	0.22	0.10	0.13	0.26	0.13	0.19	0.18
MgO	7.52	6.58	3.06	2.88	2.42	6.24	2.10	2.08	1.21
CaO	9.12	7.57	4.49	2.08	3.53	9.55	2.86	4.10	2.24
Na_2O	2.20	3.00	5.59	1.22	0.79	2.93	3.79	4.24	5.37
K_2O	1.28	2.11	0.39	6.31	5.85	1.87	2.07	2.39	2.39
P_2O_5	0.25	0.42	0.18	0.17	0.25	0.41	0.21	0.45	0.27
L.O.I.	2.98	4.21	2.22	3.72	4.65	10.24	4.18	2.18	1.75
Total	98.75	98.21	99.40	99.42	99.65	99.92	100.69	98.10	99.97
	(102)	(103)	(104)	(105)	(106)	(107)	(108)	(109)	(110)
Zr	106	134	140	207	265	122	157	241	189
Sr	383	406	316	119	86	425	535	500	473
Rb	36	57	12	207	199	52	20	61	53
Zn	78	86	108	87	100	89	93	113	103
Cu	87	27	8	21	14	68	69	14	6
Ba	560	892	72	924	1322	1801	436	550	802
Nb	7	8	7	13	18	6	7	6	10
Pb	5	5	5	17	4	4	3	11	8
Ni	133	66	3	6	9	80	113	15	1
Cr	302	181	*	*	*	152	154	2	4
Y	*	*	*	*	*	*	*	27	*

TAYLOR'S BAY FORMATION

TOP614A fine grained chloritized basalt; TOJ108: aphanitic basalt flow; TOH93: grey mafic flow; TPO608A, 607C: mafic tuffs; TPO589B: basalt; TPO592B aphanitic mafic flow, TOS40: aphanitic flow; TPO654B; aphanitic dacite flow.

	TOJ86	TL104	TL015	TO81A	TPO500C	TOO572C	TP621A	TOJ176A
SiO_2	69.80	65.60	62.50	60.50	69.37	73.99	71.45	73.46
TiO_2	0.40	0.93	1.09	0.72	0.49	0.19	0.32	0.35
Al_2O_3	15.10	15.50	15.90	14.30	14.05	11.84	13.32	14.23
Fe_2O_3	1.79	1.40	2.94	2.74	2.77	1.54	1.88	1.75
FeO	0.21	2.85	1.65	3.53	n.d.	n.d.	n.d.	n.d.
MnO	0.04	0.12	0.13	0.14	0.08	0.56	0.06	0.05
MgO	0.49	1.87	1.42	3.04	0.82	0.19	0.53	0.52
CaO	0.67	3.56	7.64	5.76	1.73	1.56	1.91	1.34
Na_2O	3.61	1.48	1.88	3.26	5.91	3.96	2.88	2.97
K_2O	6.09	4.95	2.33	3.28	2.61	3.25	4.56	4.63
P_2O_5	0.10	0.02	0.17	0.22	0.12	0.08	0.09	0.06
L.O.I.	1.74	1.17	1.13	2.05	1.42	0.84	1.38	1.45
Total	100.04	99.45	98.78	99.54	99.37	98.00	98.38	100.81
	(111)	(112)	(113)	(114)	(115)	(116)	(117)	(118)
Zr	245	204	*	248	223	118	190	194
Sr	229	649	1626	499	204	117	292	168
Rb	194	184	70	95	41	78	110	137
Zn	45	98	98	92	50	36	38	39
Cu	8	13	15	*	6	9	20	15
Ba	1253	1067	502	*	745	577	810	1053
Nb	18	3	3	*	12	8	12	12
Pb	20	13	12	10	7	11	22	24
Ni	6	16	5	14	*	1	*	3

TAYLOR'S BAY FORMATION

TOJ86: red aphanitic vitrophyre; TL104: dacite flow; TL015 massive mafic flow; TO081 massive glassy flow; TPO500C: grey crystalline porphyritic rhyolite; TPO572C; rhyolitic crystal-lithic tuff; TP621A rhyolitic vitric tuff; TOJ176A: massive rhyolite.

APPENDIX 2 : C.I.P.W. NORMS (Weight % normative minerals)

Normative Minerals - Wt. %

	GBO850	GBO870	GBO871	GBO852	GBO853	GBO855	GBO856	GBO857	GBO858	GBO859	BGO861	GBO862	GBO863	GBO865	GBO866	GBO867	GBO868	GBO869
Q	37.26	35.67	34.86	36.08	36.26	36.73	35.64	32.44	35.87	35.38	35.97	35.41	34.70	35.05	39.94	39.24	37.22	35.25
Or	29.22	29.37	35.32	28.54	28.90	29.05	28.78	24.77	34.30	28.96	28.40	29.33	27.02	27.09	29.23	32.48	25.84	28.84
Ab	29.75	31.62	23.83	30.95	31.29	29.95	32.68	38.07	24.77	30.06	33.06	30.41	34.71	34.63	26.59	24.12	33.68	32.23
An	.67	.51	2.60	1.66	1.21	1.19	0.99	1.41	1.01	1.40	0.68	0.68	0.78	0.58	0.62	0.59	0.81	0.79
Ne																		
Le																		
Lc																		
Cor	0.88	0.91		0.57	0.31	0.46	0.24	0.49	0.58	0.49	0.34	0.65	0.67	0.68	1.62	1.71	0.92	0.79
Di			0.42															
Hy	2.00	0.50	1.02	1.83	1.29	2.06	0.92	2.82	1.77	2.14	0.43	2.57	1.72	1.43	0.74	1.84	1.49	1.58
Wol																		
Ol																		
Mt	0.21	0.45	0.89	0.35	0.55	0.55	0.55		1.42	1.41	1.00	0.74	0.38	0.25	1.25			0.40
Il		0.15	0.23		0.19		0.19		0.27	0.16	0.12	0.19		0.27			0.04	
Hm		0.81	0.82															
Ap																		
Fl	0.02	0.01	0.01	0.01		0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02

	1045	1046	JS-9	JS-5A	JS-31B	JS-31A	JS-10	1056	1050	1049	1048	JS-35A	BO155A	BO85A	BD1025	BO71B	BARA 1
Q	37.46	32.78	40.07	36.42	36.33	37.15	38.04	36.40	34.88	36.10	37.09	30.02	32.05	39.31	22.87	22.47	33.98
Or	29.45	30.27	29.25	28.72	30.36	30.73	28.18	30.58	24.59	30.00	29.38	25.83	42.30	23.48	17.44	20.79	16.79
Ab	30.13	32.42	25.54	31.79	29.35	28.36	30.37	27.89	36.61	29.78	29.33	33.69	16.49	30.26	49.60	44.48	35.54
An	0.26	1.72	1.47	1.08	1.40	2.05	1.08	1.83	1.72	1.93	1.25	1.83	3.75	4.07	2.85	5.28	7.89
Ne	-																
Le	-																
Lc	-																
Cor	0.73	0.53	1.61	0.21	0.46	0.09	1.04	0.94	0.11	0.14	0.58	1.49	1.37	1.34	1.68	0.95	1.93
Di	-																
Hy	0.51	1.17	1.74	1.02	1.33	1.38	0.95	0.54	1.07	1.00	0.3	4.23	1.64	0.52	2.26	1.97	1.37
Wol	-																
Ol	-																
Mt	0.82	0.88	0.28	.57	0.76	0.32	0.18	1.04	0.82	.84	0.62	1.77	1.74	0.05	1.94		
Il	0.19	0.23	0.04	.17	0.02		0.17	.10	0.20	.10	0.19	1.13	.59	0.11	1.01	0.37	0.21
Hm	0.08							.69			0.97			0.86		3.19	1.88
Chr	-																
Ap	0.36									0.12	0.28		0.09		0.35		0.33
Fl	-																

	BARA 2	BO10A	BO12C	BO72	BO388	BO356	OS232B	OS731	OS105	T265A	T375B	T266A	T088	T159A	T160A	OS-22A	OS682	OS776
Q	24.22	21.45	41.46	23.23	39.72	37.45	45.72	45.64	34.78	20.75	19.02	29.13	25.58	23.79	40.80	22.77	24.38	33.65
Or	26.65	21.90	22.48	33.28	29.43	15.08	9.54	16.45	42.58	18.92	17.36	11.06	20.13	23.24	11.78	17.77	7.19	21.24
Ab	40.03	46.19	27.72	40.82	26.04	32.89	39.95	29.05	20.24	49.17	55.72	51.67	45.41	43.88	40.95	49.86	61.76	33.96
An	3.38	5.09	4.71	6.11	0.74	11.76	0.37	5.12	0.20	2.82	3.25	0.31	4.77	4.50		2.83	1.84	5.84
Ne																		
Le																		
Lc																		
Cor	1.20	0.55	1.99	0.33	2.74		2.42		0.81	1.75		2.65	0.39	0.11		2.83	.06	1.44
Di						0.54		1.09			1.29				0.95			
Hy	1.68	1.88	0.68	2.75	0.38		0.27	1.21	0.23	2.18	0.50	1.30	1.62	1.12	0.43	1.62	0.80	0.84
Wol						0.03												
Ol																		
Mt		1.99	0.62	1.18	0.88	0.61			0.78	1.71	0.25	0.55	1.27	0.38		0.49		
Il	0.24	0.77		0.08		0.31	0.08	0.08		1.12	0.84	1.05		1.24	1.19	0.56	0.17	0.15
Hm	2.22		0.32	1.98	0.06	1.28	1.35	0.97	0.38	1.16	1.76	1.86		1.74	0.97	1.27	3.09	2.27
Chr		.01																
Ap	0.09	.19		0.23		0.05	0.12	0.09		0.43		0.43	0.19		0.26		0.21	0.26
Fl			0.01		0.02	0.01					0.01			0.02				

	C0537	C077-4	C0722	C0724	C0721	C0726	C0798	COP632A	COP625	CO-17	CO-13	CO-14	CO-15	JS177	JS189	JS199	CO-1	CO-2
Q	11.23		1.10	11.63	3.92	3.86	16.91			1.74		1.05	1.77			11.80	5.75	1.70
Or	0.68	4.40	5.93	3.15	8.29	0.19	0.43	13.17	7.50	19.12	0.75	6.67	21.43	4.96	9.22	10.35	5.89	4.05
Ab	34.16	29.87	31.29	25.27	36.93	31.83	23.09	22.78	24.91	5.91	42.73	25.75	20.83	34.78	29.37	32.71	26.56	25.88
An	23.70	27.50	27.05	34.22	18.60	33.86	30.96	23.83	31.74	41.27	24.43	29.65	9.15	26.96	27.65	21.29	41.73	38.76
Ne																		
Le																		
Lc																		
Cor					2.97								7.92					0.99
Di	7.80	9.83		3.15		1.33	2.83	6.32	11.57	3.56	0.51	5.54		6.92	5.86	2.04	1.85	
Hy	5.19	2.48	19.65	9.22	14.99	14.84	9.15	12.65	6.45	13.39	9.63	15.93	22.60		12.29	7.09	8.91	19.30
Wol																		
Ol	-	16.92						6.38	3.88		7.04			9.77	0.83			
Mt	0.36	6.09								9.69	10.72	10.68	8.41				6.80	6.14
Il	11.79	1.98	11.85	0.39	0.47	0.39	0.61	0.34	0.43	2.41	2.92	3.27	4.36	0.41	0.36	0.48	2.06	2.44
Hm		0.05	0.02	10.50	12.19	10.51	12.61	11.69	10.69	2.54		0.10	1.69	12.12	10.72	10.95		
Chr						0.02				0.03	0.04	0.04	0.06	0.03	0.03			0.01
Ap	1.43	0.89	0.56		0.54	0.76	0.65	0.47	0.53	0.29	1.21	1.32	1.79		0.91	0.69	0.47	0.75
Fl																		
Rut			0.36	0.43	0.11									1.03				
Sph	3.66		1.58	2.04		2.41	2.75	2.30	2.27					1.56	2.76	2.59		

	TLO4	TLO5	TLO3	TLO9	TLO2	TL56	TL41	TLO39	TLO37	TLO55	TLO38
Q				2.21	9.22				10.59	1.01	5.77
Or	7.06	4.22	5.06	3.06	5.95	11.70	13.57	11.65	6.57	29.72	1.22
Ab	28.85	33.70	30.80	22.64	12.02	31.95	20.82	18.17	33.40	35.29	22.74
An	28.24	27.22	27.35	30.60	37.11	26.98	31.89	37.35	21.64	15.48	20.90
Ne											
Lo											
Lc											
Cor						4.21		0.05			2.73
Di	11.8	10.21	11.43	15.76	3.85		6.56		8.00	5.29	
Hy	0.3	1.63	5.59	15.80	21.46	5.64	6.41	13.71	6.26	3.18	32.28
Wol											
Ol	12.8	10.64	8.50	6.98		5.67	6.77	9.79			
Mt	7.70	8.87	7.95	2.44	7.11	10.61	11.18	7.19	9.40	6.00	6.39
Il	2.40	2.79	2.53		2.37	2.48	2.35	1.81	2.74	2.51	4.44
Hem										0.08	
Chr	0.04	0.03			0.03	0.01	0.01	0.03			
Ap	0.76	0.70	0.75	0.51	0.89	0.76	0.45	0.24	1.40	1.43	3.54

	TL042	TL057	HH155B	HH157B	HH578	HH153	HH604A
Q	4.29	7.21	36.99	27.09	24.35	27.56	26.75
Or	9.33	10.82	26.72	19.55	17.92	20.05	21.03
Ab	24.65	26.38	26.60	43.36	39.48	39.49	41.50
An	33.75	32.25	4.48	5.11	10.83	8.02	4.47
Ne							
Le							
Lc							
Cor			1.36				1.24
Di	4.11	5.05		1.07		.62	
Hy	13.38	5.77	1.02	1.35	2.47	1.58	1.61
Wol							
Ol							
Mt	6.75	8.61		1.79		1.71	
Il	2.49	2.72	1.29	0.62	0.28	0.88	0.18
Hem			1.39		3.41		2.57
Chr							
Ap	1.24	1.20		0.14	0.40	0.10	0.26
Fl							
Ru			0.16				0.39
Sphene							
Acmite							

	MO240	MO236	MO49	MO235	MO101A	MO237A	MO102	MO530	MO206	MOS31	MO205	MO66C
Q			2.06		4.14				10.49		14.11	
Or	0.31	7.37	4.89	4.23	2.99	2.71	11.16	4.86	0.72	8.04	0.30	9.31
Ab	43.28	26.97	16.97	23.77	13.74	28.98	29.86	32.16	30.15	36.92	27.76	24.59
An	21.46	30.64	41.02	33.09	32.13	33.06	27.31	27.92	26.08	22.08	28.36	28.36
Ne							1.19					
Le												
Lc												
Cor	0.75								1.50			
Di		8.62	10.89	9.02	11.08	12.02	2.87	7.16		5.75	2.39	10.31
Hy	1.92	7.83	13.81	9.56	21.32	5.41		10.04	13.38	15.37	11.30	5.33
Wol	10.6	9.72		11.08		8.51	17.25	6.85		2.04		11.77
Ol	16.48	6.63	8.66	6.30	11.17	6.67	6.55	8.26	12.91	7.14	11.18	7.72
Mt	4.06	1.51	1.67	2.24	3.08	2.13	2.84	1.93	3.42	2.16	3.34	2.07
Il												
Hm		0.05	0.02			0.02		0.05		0.06		0.11
Chr	0.97	0.66		0.67	0.34	0.50	0.99	0.76	0.99	0.45	1.27	0.43

	TO614A	TOJ108	TOJ93	TPO608A	TPO697C	TPO589B	TPO592B	TO540	TPO654B	TOJ86	TL104	TL015	TL081A	TPO500C	TOP572C	TP621A	TOJ176A
Q	2.65		12.46	20.3	18.80	-	24.85	14.37	20.72	23.85	26.69	26.99	14.23	21.59.	36.59	33.49	35.07
Or	7.89	13.25	2.37	38.95	36.37	12.30	12.67	14.71	14.37	36.59	29.74	14.08	19.88	15.74	19.76	17.77	27.52
Ab	19.42	26.98	48.66	10.78	7.03	19.68	33.20	37.38	46.23	31.05	12.73	16.27	28.28	51.03	34.47	25.11	25.28
An	31.50	24.59	21.00	9.86	17.03	25.24	13.55	17.45	8.52	3.05	18.24	28.70	15.07	4.19	5.08	9.43	6.59
Ne						4.29											
Lé																	
Lc																	
Cor				2.13	1.06		2.11			1.49	1.15					0.30	1.95
Di	8.24	10.22	0.65			16.75		0.81				7.45	10.43	2.01	1.05		
Hyp	15.71	5.57	8.27	7.49	6.34		5.41	9.24	3.07	1.24	7.54	0.16	6.10	1.15	-	1.36	1.30
Wol															0.49		
Ol		9.06				6.68											
Mt		6.84	4.16					2.89			2.06	2.64	4.07		1.31		
Il	0.36	2.42	1.99	0.22	0.29	0.59	0.26	2.06	0.39	0.54	1.80	2.12	1.40	0.17	0.37	0.13	0.11
Hem	10.97			8.72	10.82	11.60	6.64		4.78	1.82		1.18		2.83	0.68	1.94	1.76
Chr	0.07	0.04				0.04	0.03										
Ap	0.61	1.04	0.43	0.41	0.61	1.06	0.51	1.09	0.64	0.2	0.05	0.40	0.52	0.28	0.19	0.22	0.14
Fl																	
Rutile				1.30	1.65		0.77		0.35	0.12						0.26	0.30
Sphene	2.59								0.93					1.0			
Acmite																	

APPENDIX 3: ANALYTICAL METHODS

Samples were prepared by crushing to -2 cm chips with a steel jaw crusher and pulverizing to -100 mesh in a tungsten carbide Siebtechnik "Tema" swing mill. Major elements were determined by atomic absorption spectrometry using a Perkin Elmer 403 digitized spectrometer, after dissolution of samples in a solution of 5 ml HF, 50 ml saturated H_3BO_3 amd 145 ml H_2O on a steam bath overnight. Ferrous iron was determined by titration (Wilson, 1955), P_2O_5 by colorimetry (Maxwell, 1968) and "Loss on Ignition" after heating in porcelain crucibles at 1050°C for 2 hours in a muffle furnace. Trace elements were determined with a Phillips 1450 computerized X-ray fluorescence spectrometer calibrated against international standards.

Samples were run as pellets prepared by subjecting a mixture of 10 g of rock powder with 1.25 g of phenol formaldehyde to a 50 MPa pressure in a 40 mm diameter die for 1 minute. The resulting pellets were heated in a muffle furnace for 10 minutes at 200°C.

APPENDIX 4: PRECISION AND ACCURACY DATA

A. MAJOR ELEMENT DATA

Major element oxide determinations by atomic absorption spectrophotometry for U.S.G.S. standards GSP-1 and AGV-1.

P = published values; Abbey, 1968; M = mean value;

S = standard deviation; N = number of determinations.

GSP-1 (granodiorite)

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO
P	67.27	0.65	15.18	4.26	2.06	0.98	2.77	5.50	0.04
M	68.65	0.60	14.77	4.22	1.94	0.96	2.74	5.44	0.04
N	7	7	7	8	8	8	8	6	8
S	0.60	0.08	0.08	0.07	0.07	0.07	0.06	0.12	0.01

AGV-1 (andesite)

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO
P	58.97	1.06	17.01	6.73	4.94	1.53	4.26	2.86	0.10
M	59.63	1.08	17.13	6.70	4.78	1.47	4.06	2.88	0.10
N	3	3	4	4	4	4	4	3	4
S	0.90	0.11	0.23	0.33	0.16	0.07	0.07	0.10	0.00

Major element oxides : Analyses by G. Andrews

Trace element analyses by D. Press and the author.

B. TRACE ELEMENT DATA

Trace element determinations by XRF for U.S.G. and University of Toronto standard rocks, Memorial University.

Note: all determinations in ppm

S = standard deviation
N = number of determinations
P = published values

	V	Cr	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Ba	Pb
W-1	240	92	70	117	85	20	22	189	24	98	8	171	7
S	5	6	3	4	2	2	2	6	2	2	1	12	3
N	13	13	13	13	13	13	13	13	11	13	13	13	13
P	240	120	78	110	86	16	21	190	25	105	95	160	8
G-2	43	13	2	17	85	24	166	474	11	292	10	1865	27
S	3	3	2	1	2	1	2	7	2	3	1	30	2
N	10	10	10	10	10	10	10	10	11	10	10	10	10
P	34	9	6	11	85	23	170	480	12	300	14	1850	29
GSP-1	60	13	8	38	102	24	252	237	25	471	21	1285	56
S	5	5	2	4	2	2	3	5	2	2	2	13	4
N	6	6	6	6	6	6	6	6	11	6	6	6	6
P	44	13	9	35	98	21	250	230	32	500	29	1300	53
BCR-1	402	25	11	28	121	22	49	338	36	188	12	740	18
S	4	6	3	1	2	1	2	8	1	1	3	10	4
N	6	6	6	6	6	6	6	6	11	6	6	6	6
P	410	16	13	19	120	23	47	330	37	185	14	680	15
AGV-1	129	12	13	64	87	23	70	687	22	233	12	1218	37
S	5	3	3	2	2	2	3	11	1	3	1	27	5
N	10	10	10	10	10	10	10	10	11	10	10	10	10
P	125	12	17	63	84	20	67	660	26	220	15	1200	36
UTA-1	102	22	10	29	57	22	47	507	19	165	9	446	6
S	4	3	1	1	3	2	3	9	1	2	1	17	3
N	5	5	5	5	5	5	5	5	10	5	5	5	5
UTB-1	433	32	22	44	136	23	32	316	43	194	15	599	5
S	7	4	1	4	2	2	2	5	1	2	2	27	4
N	5	5	5	5	5	5	5	5	10	5	5	5	4
UTB-2	353	12	4	26	111	23	55	312	36	190	13	755	14
S	6	2	5	2	2	2	4	6	1	3	1	22	5
N	5	5	5	5	5	5	5	5	10	5	5	5	4

SYMBOLS

Geological boundary (defined, approximate, assumed)..

Bedding, tops known (horizontal, inclined, overturned)..

Bedding, tops unknown (inclined, vertical)..

Primary layering, volcanic rocks (horizontal, inclined, vertical)..

Slaty cleavage (inclined, vertical)..

Schistosity, foliation (inclined, vertical)..

Anticline (arrow indicates direction of plunge)..

Syncline (arrow indicates direction of plunge)..

Overturned syncline, anticline..

Fault (defined, approximate, assumed)..

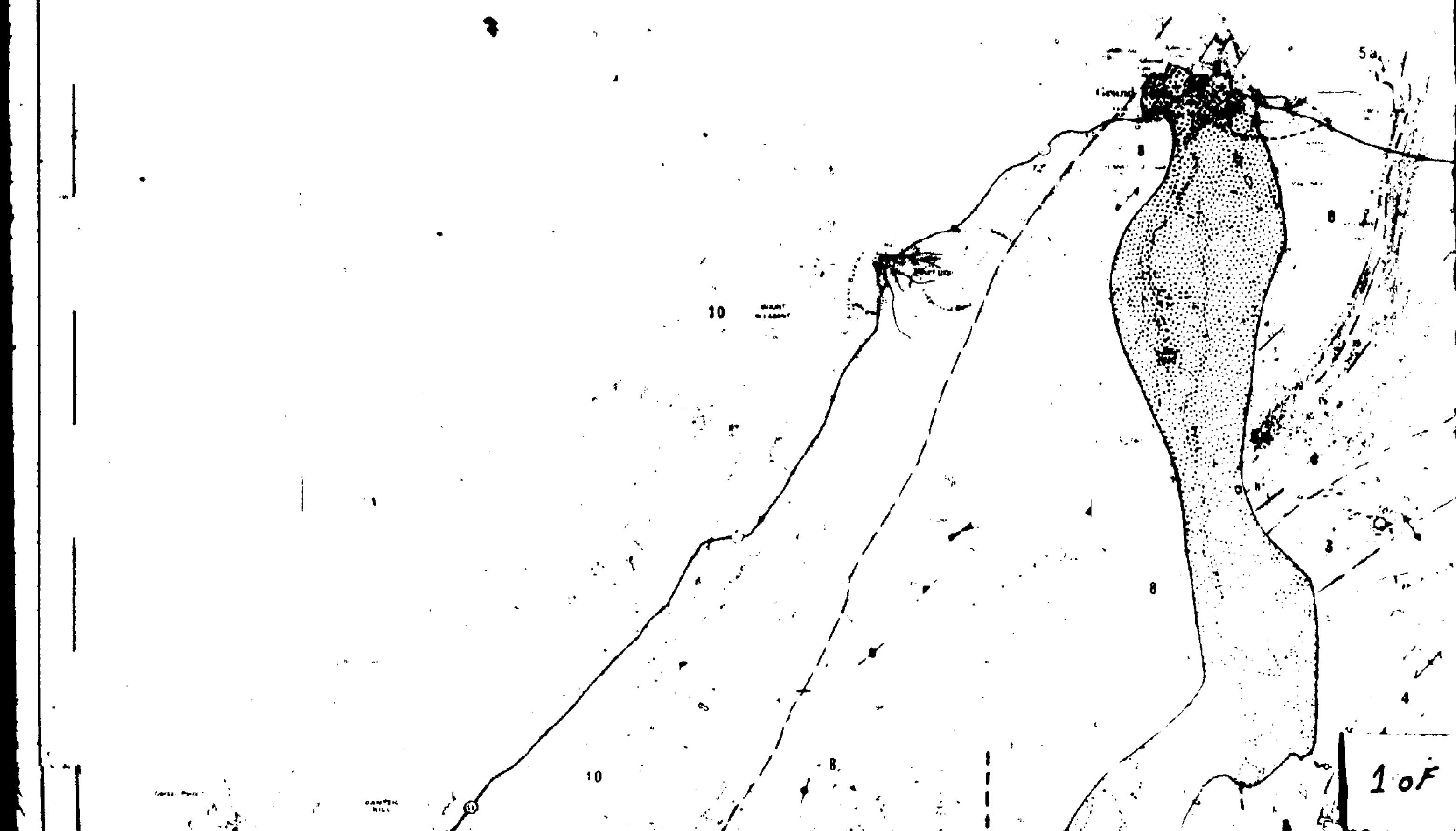
Thrust Fault (teeth in direction of dip) (defined, approximate, assumed..

Drift covered area..

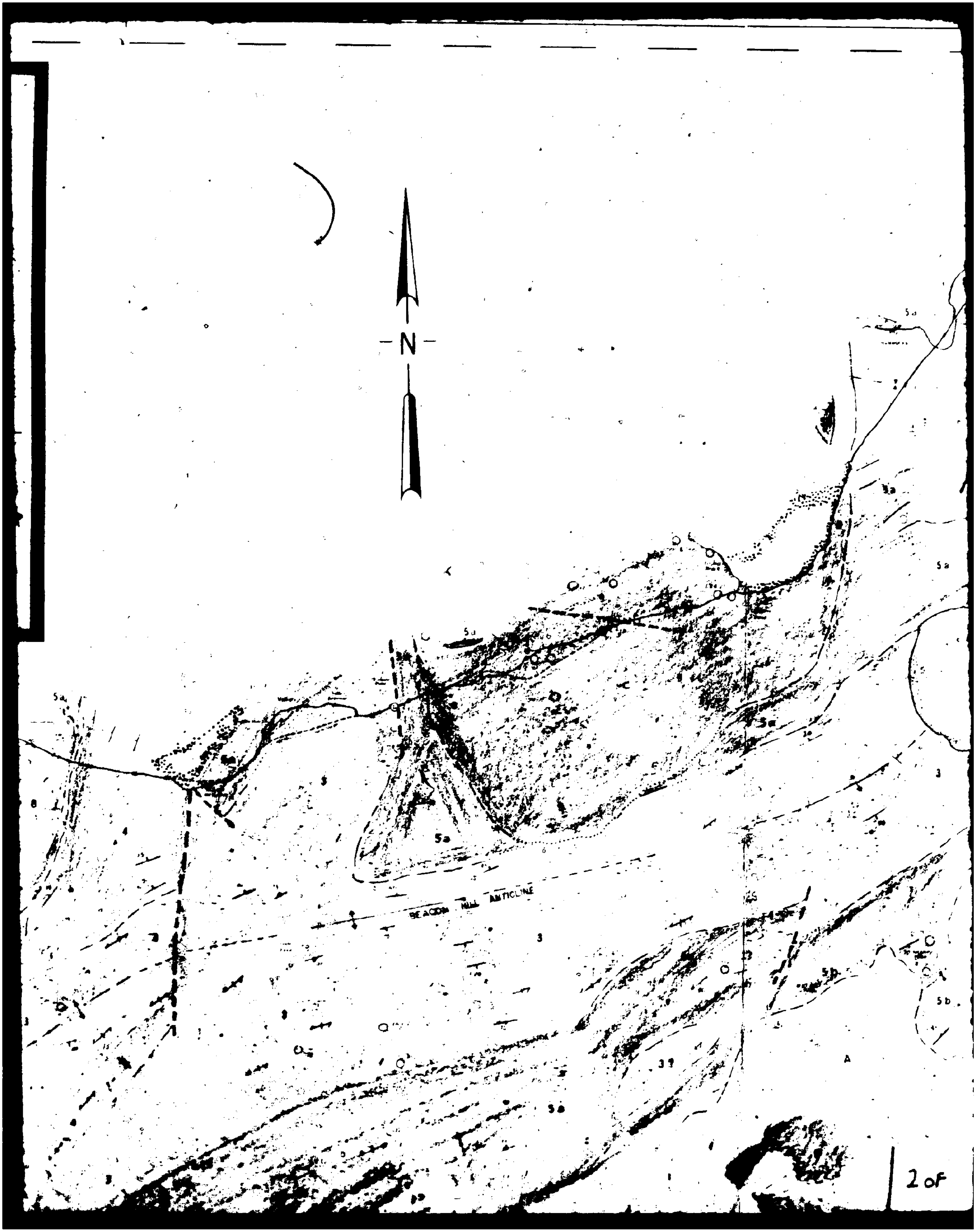
Eastern limit of geological mapping in Marystown Group..

Geochemical sample location..

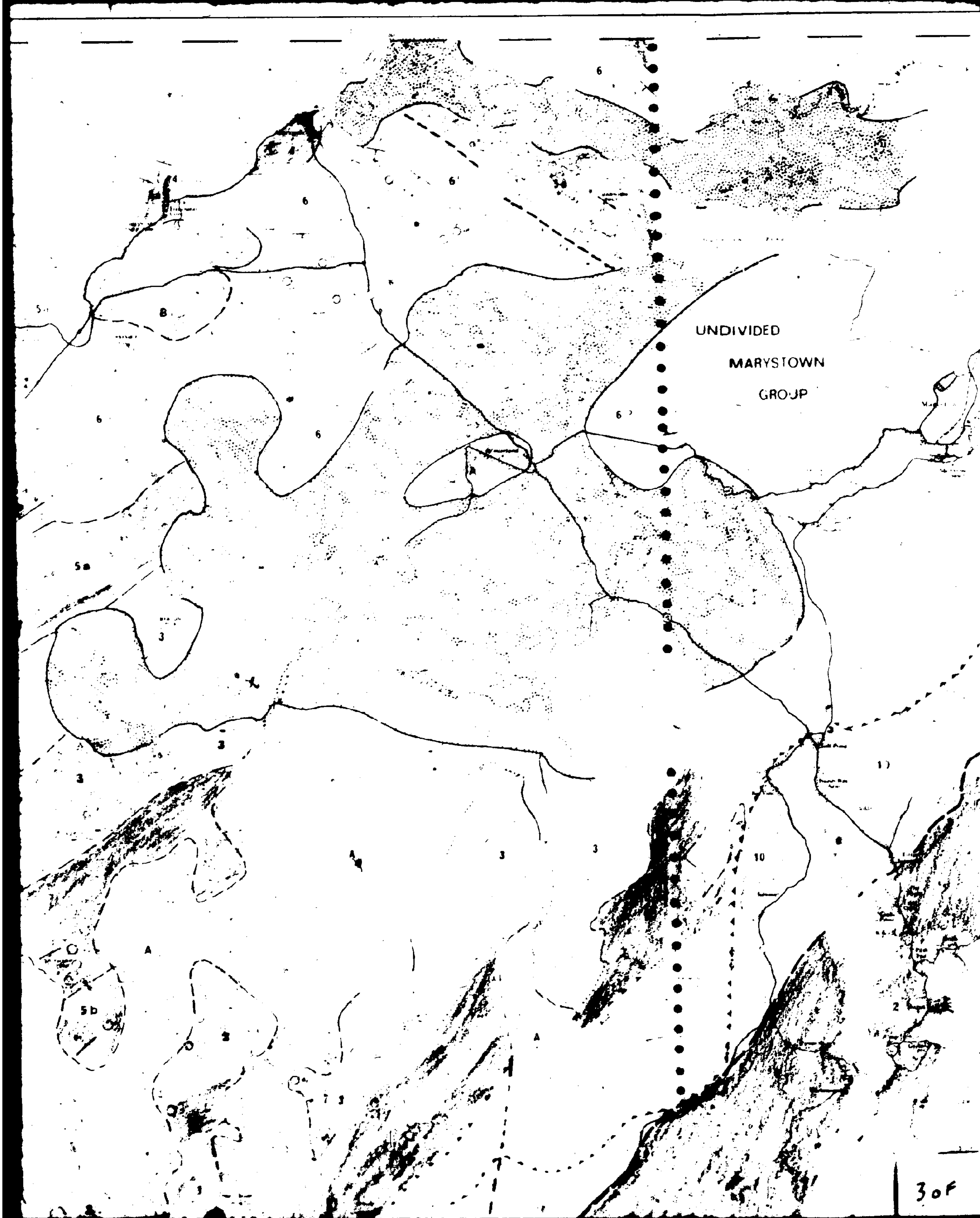
Shearing and dip..

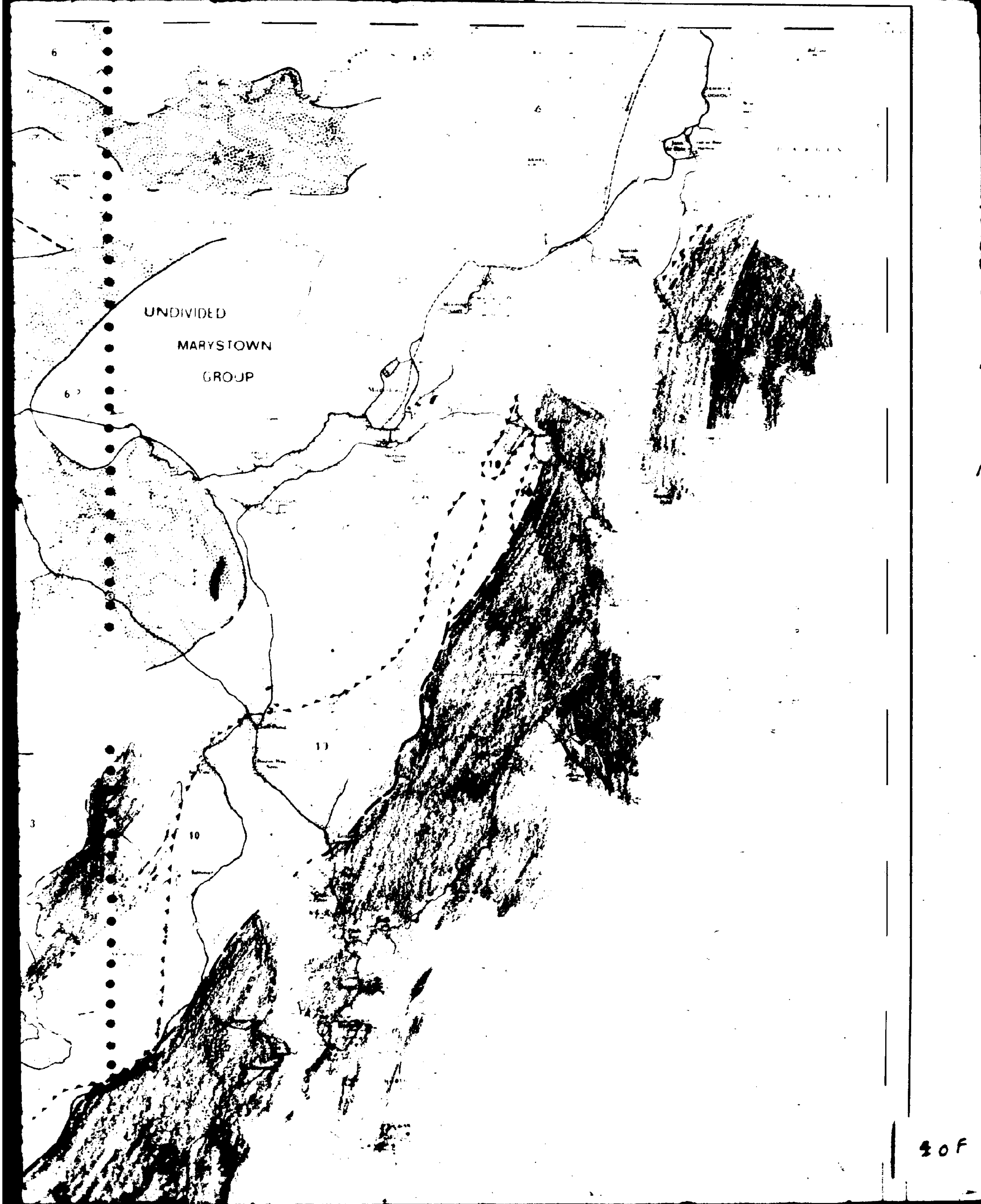


1 oF

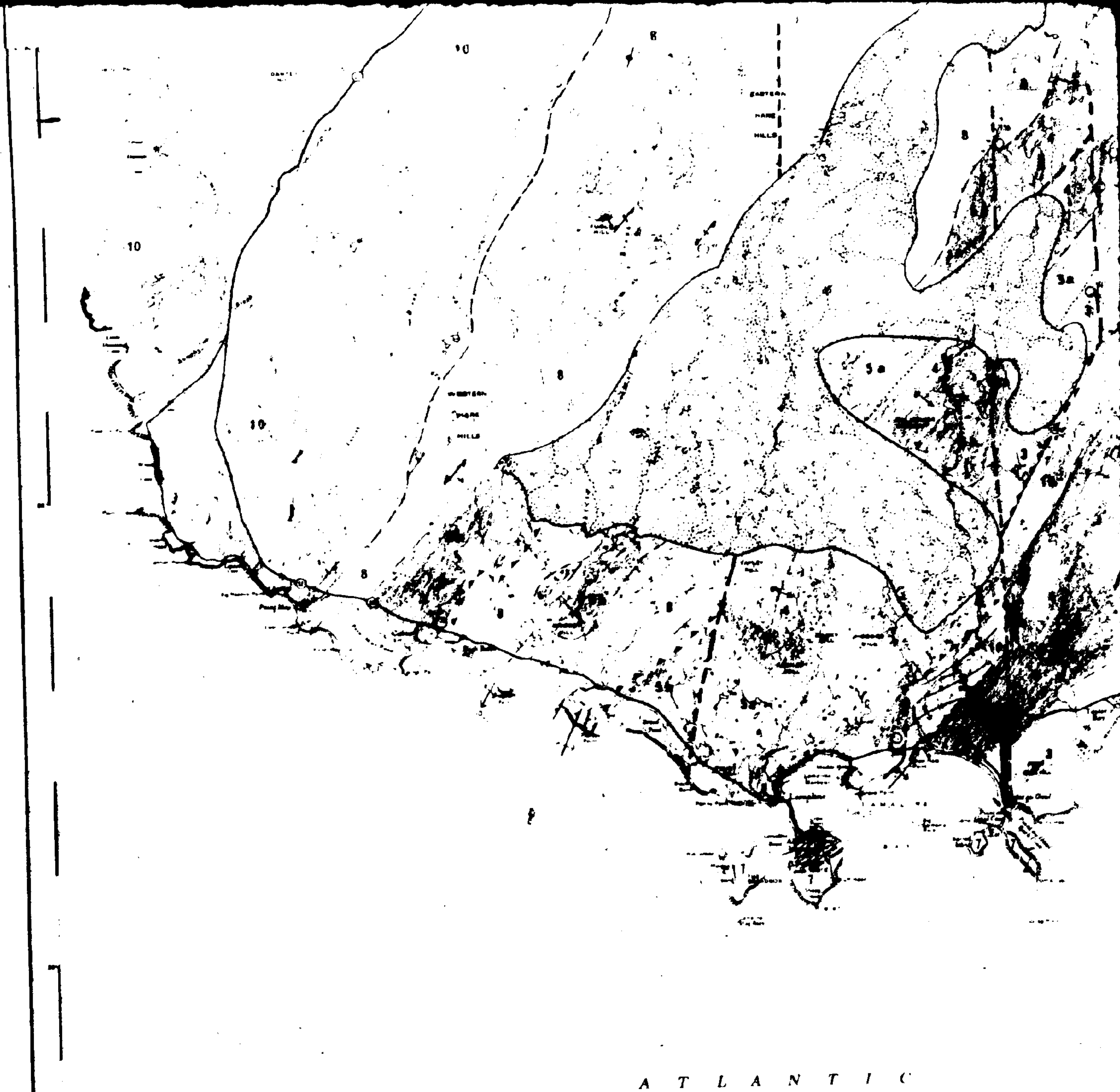


2 of


UNDIVIDED
MARYSTOWN
GROUP
6
6
6
6
8
5a
3
3
3
3
3
A
A
A
10
2
5b
3oF



40F



GEOLOGICAL MAP OF THE MARYSTOWN GROUP
AND ADJACENT ROCKS

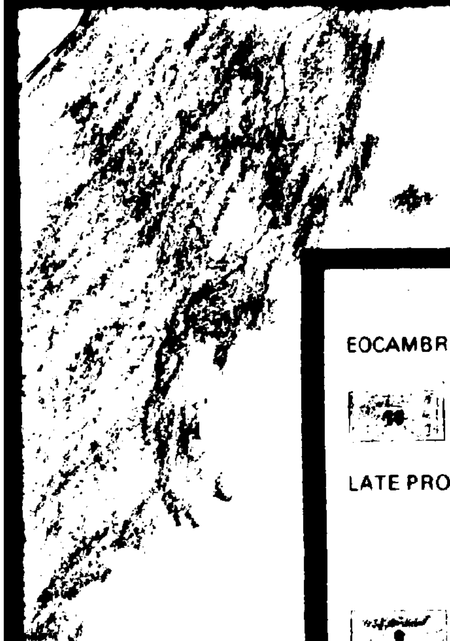
BURIN PENINSULA, NEWFOUNDLAND

5oF


O C E A N
60F


10
FORTUNE HEAD
St. Lawrence
A
EOCAMBRIAN CAM
LATE PROTEROZO
PROTEROZOIC
CARBONIFEROUS
Undivide
and sha
Marystov
Grand
lomerate
Hare
rhyolite
Mount
schists
Baraswa
litholog
Calmer
sediment
associate
felsic tu
Garnish
shales
Taylors
Unwelde
flows
sill
limesto
St. La
include
Seal Co

70F



VOLCANIC AND SEDIMENTARY ROCKS

EOCAMBRIAN CAMBRIAN

Undivided Eocambrian to Cambrian sedimentary rocks: Red and green siltstone, sandstone and shale; limestone, quartzite.

LATE PROTEROZOIC

Marystown Group: Units 2 to 9 (units 6, 7 and 8 are stratigraphically correlative and numbering does not infer relative ages)

Grand Beach Complex: Ash-flow and ash-fall tuffs, epiclastic and sedimentary breccias, agglomerates, minor rhyolite porphyries and divitrified rhyolites. ●

8 Hare Hills Formation: Ash-flow tuffs, waterlain epiclastic volcanic rocks, vitric tuffs, minor rhyolites and felsites.

7 Mount Saint Anne Formation: Flow-banded, autobrecciated and spherulitic rhyolites, sericite schists, ash flow tuffs, waterlain epiclastic volcanic rocks.

6 Barasway Complex: Ash-flow tuffs, massive, autobrecciated and flow-banded rhyolites, monolithologic and hiterolithologic epiclastic and pyroclastic breccias, minor sericite schists.

Calmer Formation: 5a, Subaerial mafic flows, locally highly amygdaloidal; mafic tuffaceous sediments, minor mafic breccias; 5b, medium to coarse grained plagiophyric flows and sills and associated mafic tuffaceous rocks; 5c, aphyric, locally magnetite rich flows, minor mafic and felsic tuffaceous sediments and chlorite schists.

Garnish Formation: Red cross-bedded conglomerates and red sandstones, red siltstones and shales. Minor mafic tuffaceous sediments.

3 Taylors Bay Formation: Rhyolitic, intermediate and mafic flows and tuffaceous volcanic rocks. Unwelded, fine grained felsic pyroclastic rocks, minor rhyodacite, dacite and quartz andesite flows, sericite and chlorite schists.

PROTEROZOIC

Undivided Burin Group: Pillow basalts, mafic aquagene tuffs, limestone, gabbro to quartz diorite sill.

Undivided Rock Harbour Group: Conglomerates, turbidites, olistostrome and fossiliferous limestone breccias.

INTRUSIVE ROCKS

CARBONIFEROUS

A St. Lawrence Granite: Undivided peralkaline and alkaline alaskite and associated granitic rocks; includes minor unseparated extrusive phases.

B Seal Cove Pluton: Gabbro, diorite and quartz diorite.

Anchor Droque Pluton: Hornblende-biotite granite, quartz monzonite and granodiorite.

Laughlins Hill Gabbro: Coarse grained hornblende gabbro

● possibly Carboniferous