STRATIGRAPHY, PETROLOGY AND GEOCHEMISTRY OF VOLCANIC ROCKS OF LONG ISLAND, NEWFOUNDLAND

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STRATIGRAPHY, PETROLOGY AND GEOCHEMISTRY OF VOLCANIC ROCKS OF LONG ISLAND, NEWFOUNDLAND

by

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Abstract

The map area lies at the north of Halls Bay, Notre Dame Bay in the Central Mobile Belt of Newfoundland, i.e., at the northeastern extremity of the Appalachian mountain system.

The map units consist of a south-dipping, south-facing pile of Ordovician pillow lavas, pyroclastics and volcaniclastic sediments approximately 17,000 feet in thickness. There is a lateral facies change from predominantly pyroclastics with minor lava tongues in the northwest to predominantly lava with intercalated discontinuous lenses of pyroclastics in the southeast.

The pyroclastics and volcaniclastic sediments are mainly intermediate-composition reworked tuffs with common agglomeratic horizons. There are minor lenses of acid pyroclastics and pseudo-iron formation.

The flows vary from massive, glassy pillow basalt, crystalline pillow basalt and associated pillow breccia with rare intercalated pyroclastics or sediments at the base to highly vesicular and porphyritic pillowed andesites with numerous and in places thick intercalated pyroclastic lenses. Chemically the flows form two distinct chemical groups corresponding to the stratigraphic level in the pile thus suggesting a general but consistent differentiation sequence from the lower basalts to the upper andesites. The chemistry and stratigraphy suggest that the succession is of island-arc affinity rather than oceanic affinity.

Each type or group has a mineral assemblage characteristic of the lower greenschist facies · epidotite, chlorite, actinolite, calcite, albite;

however, the originally igneous mineralogy can generally be recognized.

A shallowing environment is suggested by the presence of shallow water limestone and limestone breccias and current bedded greywackes near the top of the sequence. However, the recurrence of pillow-lavas and reworked tuffs above this unit suggest either not a completely emergence or a resubmergence.

The early gabbro, diabase and andesite type intrusions predate the regional, probably Acadian deformation and are probably genetically related to the volcanism. The Long Island pluton and quartz-feldspar porphyries are post-deformation.

One phase of regional deformation is represented by a locally or zonally developed steep, generally E-W penetrative cleavage. This cleavage is obscured and/or intensified by faulting in the southern area of Long Island. Small scale folds, angular relationships and cleavage-bedding relationships combined with stratigraphic tops suggest that the sequence occupies the south limb of a west plunging anticline. Kink bands fold the earlier fabric but are restricted to fault zones and may be related to faulting. Similarly minor local crenulations of the first cleavage seem to be related to intrusions.

1. GENERAL INTRODUCTION

1.1. Location and Accessibility

Long Island is located at the mouth of Halls Bay in the western part of Notre Dame Bay on the northeastern coast of Newfoundland (Fig. 1.1). It is triangle-shaped, with sides approximately 9 x 6 x 7 miles. The two villages on the island, Beaumont on the north coast and Lush's Bight on the west coast, are served by a biweekly CN passenger and freighting service. There is also a twice daily car ferry operating between Lush's Bight and the village of St. Patricks on the Springdale Peninsula. However, the most common means of transportation is by boat to Roberts Arm, which is connected to the Trans-Canada Highway (Route 1) by a gravel road.

1.2. Physiography

The northern end of Long Island and the islands lying off the north coast are characterized by a low-lying ($<$100 feet) gently-rolling topography which is barren or covered by dwarfed spruce, a reflection of the poor soil and their exposure to the prevailing N-NE winds.

The southern half of the island is covered with a dense black spruce growth which has been extensively logged in the past. The topography is characterized by EW-ENE trending ridges with steep escarpments. The highest elevation is approximately 750 feet.

The area was glaciated by ice moving in a general NE direction, leaving a thin cover of coarse till. Inland exposure is moderate to good in the northern sector but is rather poor in the south; coastal sections are excellent.

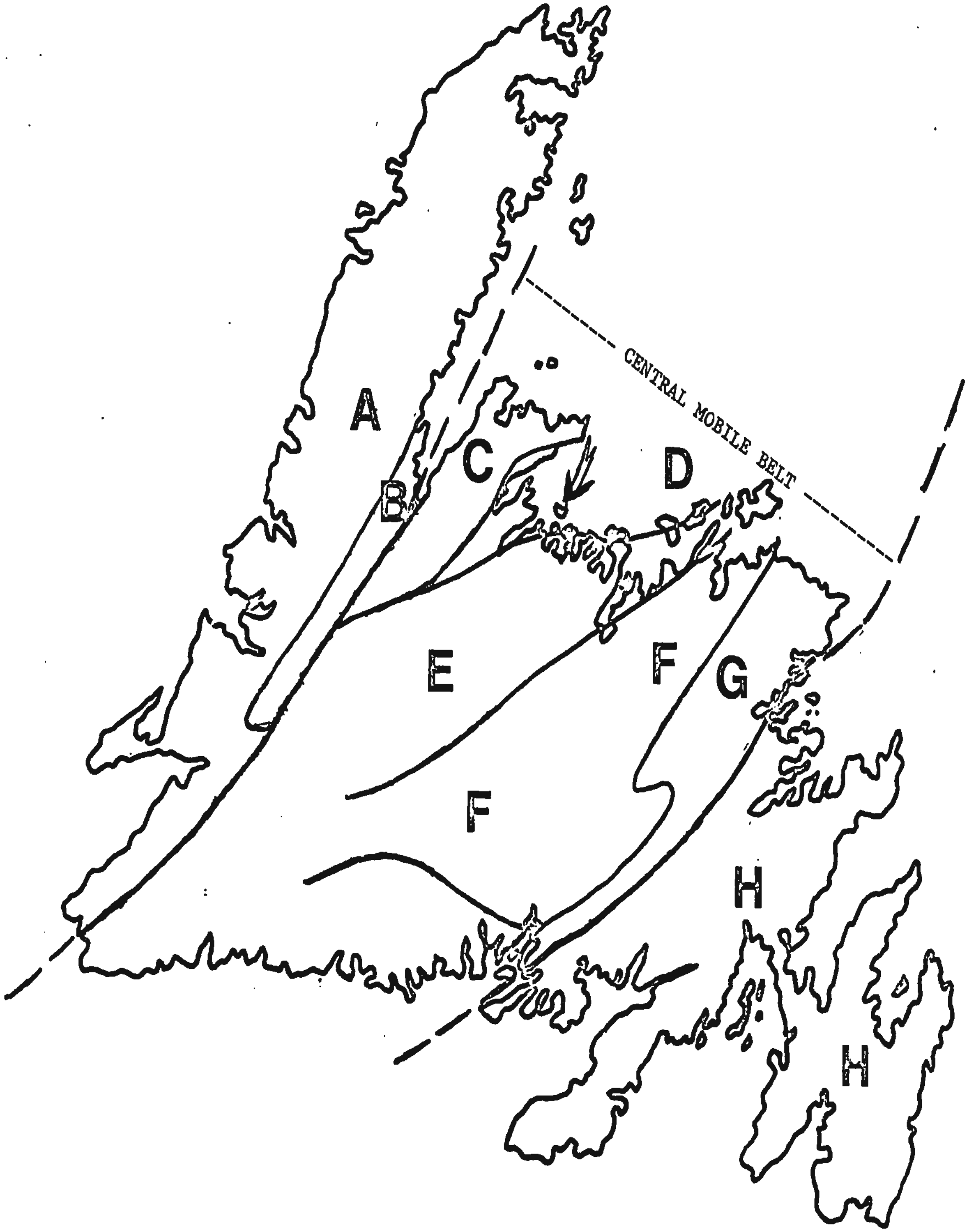

Figure 1.1. Map of Newfoundland showing the location of the map area, the Central Mobile Belt, and the tectonostratigraphic zones. (after Williams et al., 1972).

1.3. Previous Work

Geological investigation of the Notre Dame Bay area was first begun in 1864 by Alexander Murray, who assigned the volcanics to the middle division of the "Quebec Group" (1881, 1918). It was Murray who first recognized the spatial association of copper mineralization with such volcanic rocks, both in Newfoundland and throughout Canada, and considered this relationship to be a useful factor in mineral exploration (p. 32; cf. Williams, 1963). Murray was assisted and later succeeded by J.P. Howley and their geological reports were published in two volumes by the Newfoundland Geological Survey in 1881 and 1918.

In 1915, 1916 and 1919 the regional geology and some of the ore deposits of Notre Dame Bay were investigated by Princeton University Expeditions headed by E. Sampson, A.F. Buddington, and W.M. Agar. The general geology and mineral deposits of the Pilley's Island area were studied in detail by G.H. Espenshade during the 1934, 1935 and 1936 Princeton Expeditions. He called the whole volcanic sequence (volcanic flows and pyroclastics) north of the Lobster Cove fault, the "Pilley's Series" which he subdivided into a dominantly pyroclastic lower unit (Cutwell Group) and a conformably overlying chiefly pillow lava unit (Lush's Bight Group). MacLean (1947) divided the rocks approximately 10 miles west on the Springdale Peninsula into two sections - a lower section (Little Bay Head Section) consisting of approximately 15,000 feet of mainly pillowed basalts; an upper section (Western Arm Section) consisting of approximately 13,000 feet of pillow lava, tuff, more pillow lava and agglomerate in ascending order. He dated the Western Arm Section as lower

Ordovician, (?) Arenigian ("Canadian", 1947) by the presence of a brachiopod, Discotreta sp., at the base of the section, and correlated the two above described sections with the Lush's Bight Group.

Williams (1962) and Neale and Nash (1963) carried out regional studies in the area (1 inch = 4 miles) and generally agreed with MacLean, although they inferred that there had been more repetition of beds by tight folding than MacLean recognized. Williams (1962) reported fossils of probable Lower Middle Ordovician (? Llanvirnian) age in the Cutwell Group (Limestone Island) and inferred that the Cutwell Group must therefore be younger than the early Ordovidian Lush's Bight Group. However, Horne and Helwig (1969) questioned the reliability of such gross stratigraphic correlations across a structurally complex area and reverted back to the stratigraphy of Espenshade.

Marten (1971) suggested a correlation between the Lush's Bight Group of Espenshade's "Pilley's Series" and the "Little Bay Head" section of MacLean (Table 1.1). He then equated the Western Arm Section, which he called the Western Arm Group, to the Cutwell Group (Espenshade, 1937) and Snooks Arm Group and because he found the Western Arm Group to overlie the Little Bay Head section he suggested that the stratigraphy of Williams (1962) is valid.

See Table 1.1 for a summary of the historical development of ideas and interpretation of the stratigraphy in western Notre Dame Bay.

1.4. Regional Setting

The island of Newfoundland occupies the northeastern extremity of

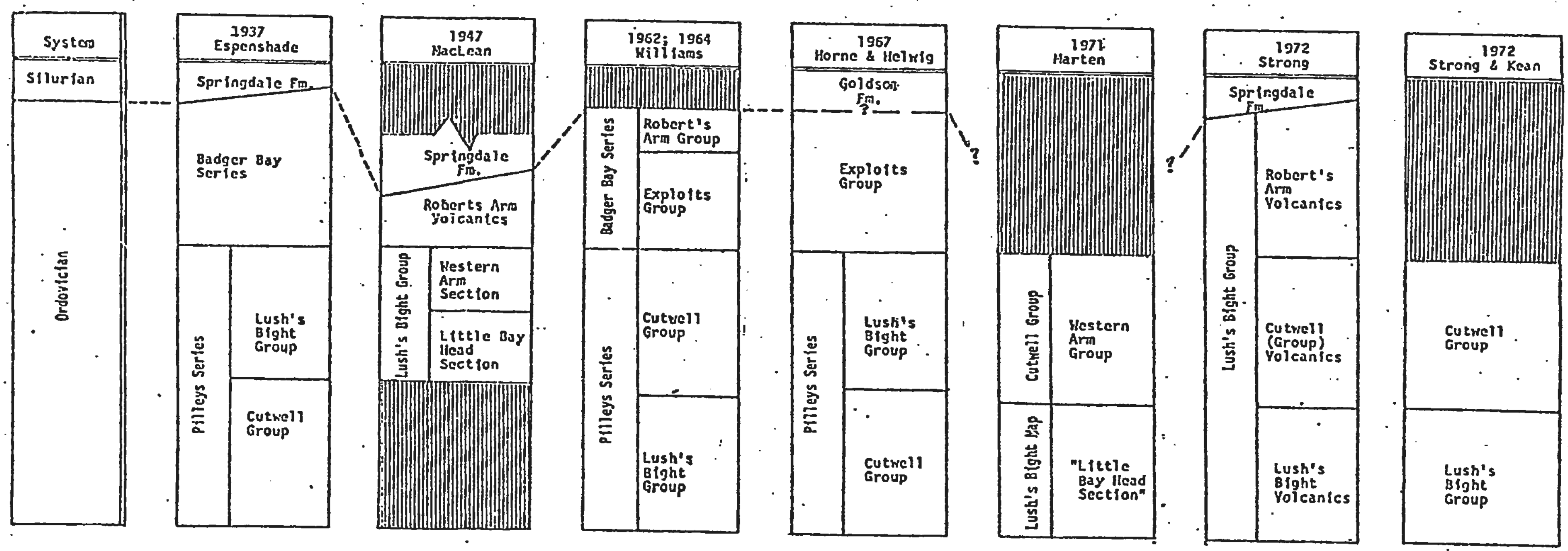

Table 1.1. Historical development of ideas and interpretations of the stratigraphy in Western Notre Dame Bay, Newfoundland. Dashed line represents Ordovician - Silurian boundary. Striped areas indicate stratigraphy unmapped by the respective workers.

the Appalachian mountain system. Here the Appalachians are broadly subdivided into three distinct geological provinces defined on the bases of distinct Precambrian and early Paleozoic geological histories (Williams, 1964). The map area lies in the central belt or province (Fig. 1.1 and Fig. 1.2) which is the lower Paleozoic central mobile belt. This is bordered by two northeasterly trending belts of late Precambrian to Cambrian age. This gives rise to the above two-sided symmetrical system of Williams (1964). Recently the island has been divided into seven tectonostratigraphic zones whose boundaries are defined by faults, melange zones, and structural discontinuities (Williams et al., 1972) (Fig. 1.1).

Espenshade (1937) was the first to recognize the importance of a major E-W structural discontinuity, the Lobster Cove fault, which bounds the Silurian Springdale formation on the north and separates it and the Badger Bay Series (Ordovician) from the Pilley's Series. The nature or amount of displacement could not be definitely determined; however, Espenshade proposed both an horizontal and vertical component. Horne and Helwig (1969) considered this fault to be a continuation of the Lukes Arm fault mapped in the Bay of Exploits area by Heyl (1936). It was Horne and Helwig (1969) who emphasized this fault, now called the "Lukes Arm Fault", and coined the term "Lush's Bight terrane" for the predominantly basaltic pillow lavas and pyroclastics north of the fault, in contrast to flows of both basaltic and rhyolitic composition and intercalated fossiliferous sediments south of the fault. This fault now marks the boundary between the two structurally distinct zones D and E of the tectonostratigraphic division of Newfoundland by Williams _et al._ (1972).

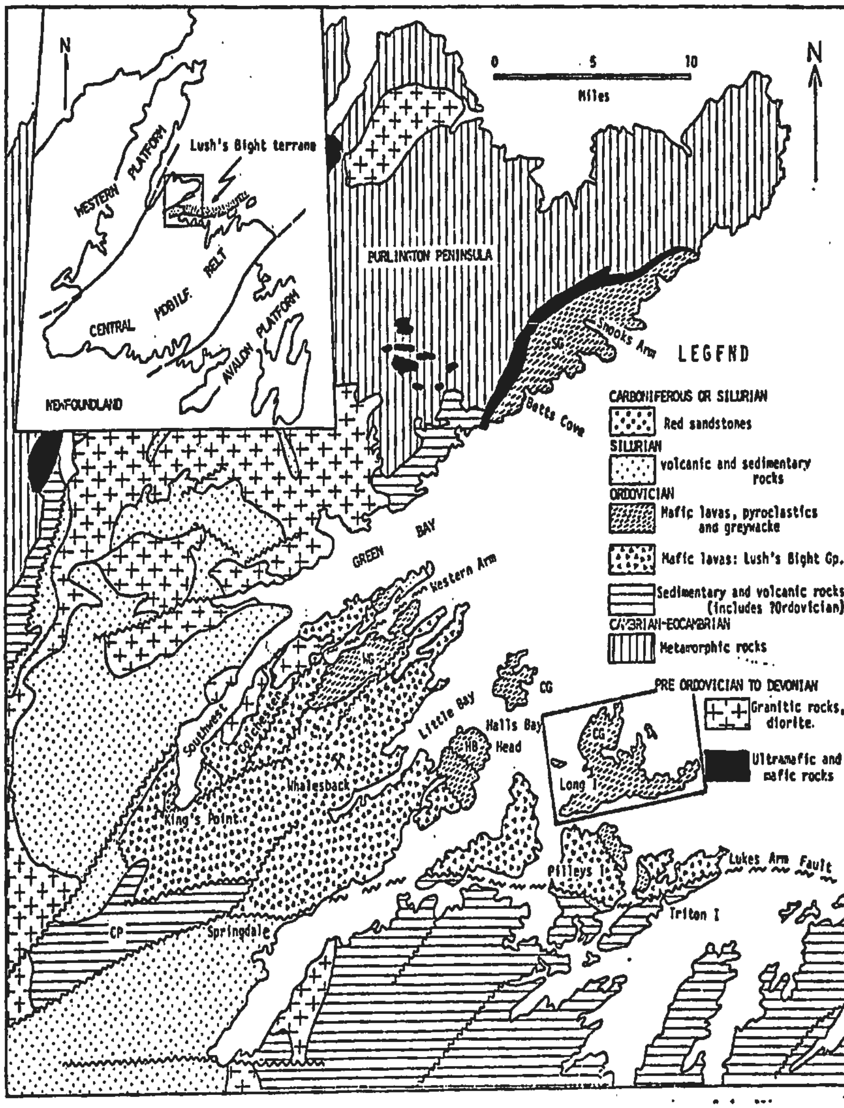

Figure 1.2. Geological sketch map of part of central Newfoundland showing location of the Long Island area (outlined). WG, Western Arm Group, SG, Snooks Arm Group; CP, Catchers Pond sequence; CG, Cutwell Group; HB, Halls Bay Head section. (After Marten, 1971.)

An important corollary of Wilson's (1966) hypothesis on the opening and closing of the Atlantic is that the rocks of the Lush's Bight terrane were deposited on a "proto-Atlantic" ocean-floor. This focused attention on central Newfoundland and it has since become a key area for the study and/or application of new global tectonics to an old mountain system. Bird and Dewey (1970) and Dewey and Bird (1971) in their later models interpret the Lush's Bight Group as oceanic crust (part of layer 2) of late Precambrian age formed by sea-floor spreading of a main proto-Atlantic ocean. The Snooks Arm Group with its basal ophiolite complex was suggested to have developed in Early Ordovician time by sea-floor and basin-infillings in a marginal basin separated by an island arc, which gave rise to the Western Arm and Cutwell Groups, from the main early Paleozoic Proto-Atlantic ocean (Upadhyay et al., 1971).

Church and Stevens (1971) differed from this view by suggesting that all of the ophiolites in west and central Newfoundland, including the Bay of Islands complex and the Baie Verte ophiolites, formed part of a single sheet of proto-Atlantic oceanic crust and mantle which was emplaced in middle Ordovician times.

The tectonic setting of the Lush's Bight terrane is a subject of much discussion and speculation with many opposing views. However, studies on the stratigraphy and chemistry of subaqueously erupted lavas and sheeted dyke complexes in western Notre Dame Bay have established they are of the low-K, oceanic variety (Strong, 1972; Smitheringale, 1972), whereas the stratigraphy (Section 1.5) and chemistry of the Cutwell Group suggest they are of island arc affinity. It is for this reason that a review of possibly similar present day environment will be made (Section 1.6).

1.5. Summary of Long Island Geology

The map area is underlain by an essentially south-dipping, south-facing pile of Ordovician pillow-lavas, pyroclastics and volcaniclastic sediments approximately 17,000 feet in thickness. The sequence has been subdivided into six formations (Table 1.2) and one "complex", and all are placed within the Cutwell Group as defined by Williams (1962).

The pyroclastics are mainly intermediate-composition reworked tuffs with common agglomeratic horizons and very minor acid pyroclastic zones. The volcaniclastic sediments occur as black shale horizons and very fine-grained grey-green laminated tuffs. The pyroclastics and volcaniclastic sediments are interbedded with and interfingered by the pillowed-flows.

The lavas are mainly of porphyritic andesite type and show a general but consistent differentiation from basalts to andesites.

A shallowing environment is suggested by the presence of shallow water limestone and limestone breccias and current bedded greywackes near the top of the sequence. However, the recurrence of pillow-lavas and reworked tuffs above this unit indicate only a partial emergence or a resubmergence.

The early gabbro, diabase and andesite type intrusions predate the regional, probably Acadian deformation, and are probably genetically related to the volcanism. The Long Island pluton and quartz-feldspar porphyries are post-deformation.

LITHOLOGY	LITHOSTRATIGRAPHIC CLASSIFICATION				AGE
Granodiorite, diorite, diabase, Lamprophyric;		Long Island Pluton; Quartz-Feldspar Porphyry, Porphyritic Diabase Dykes, Lamprophyre Dykes			Late Ordovician or Later
Dacite, Gabbro-diabase, Andesite		Dacitic Plugs, Dykes-Flows; Gabbro plugs, sills and dykes; Andesite dyke and sills.			
INTRUSIVE CONTACT					
Interbedded and interfingered lava, agglomerate, tuff, and limestone beds and lenses.	INTRUSIVE CONTACT	LONG TICKLE Formation (? 3,000 ft.)		CUTWELL GROUP	Early Ordovician (? Late Caradocian)
Dacitic intrusive (dykes, sills, plugs) and explosive (agglomerate, tuff) complex.		SEAL COVE COMPLEX			
Interbedded limestone breccia, feldspathic greywackes, pyroclastics and black shales.		PARSON'S POINT Formation (c. 200 ft.)			
Green, porphyritic pillowed andesites, isolated pillows, pillow breccias; minor massive flows. Intercalated reworked tuff.		PILLOW-ANDESITE Member	BURNT HEAD Formation (c. 5,500 ft.)		
Basic and intermediate reworked tuff; volcanogenic sediments (black shales); chert; agglomerate; pseudo iron formation; minor acid pyroclastics; slump breccias.		PYROCLASTIC Member			
Coarse agglomerate with minor tuff horizons.		QUINTON COVE Formation (c. 3,000 ft.)			
Black shales (volcanogenic); basic & intermediate pyroclastics; arkose; slump zones.		PIGEON HEAD Formation (c. 1,500 ft.)			
Black, massive pillowed-basalt.		UPPER BASALT Member	STAG ISLAND Formation (c. 4,000 ft.)		
Grey-green, glassy pillow-basalt; pillow-breccia.		LOWER BASALT Member			
Water-worked, explosive breccia of gabbro, diabase, lava, limestone, pyroclastics.		BRECCIA Member			
Diabase dykes & screens; basaltic pillows.		INTRUSIVE Member			

Table 1.2 - Table of Formations
(Thicknesses are given for the section D-D', E-E')

One phase of regional deformation is represented by a locally or zonally developed steep, generally E-W penetrative cleavage. This cleavage is obscured and/or intensified by faulting in the southern area of Long Island. Small scale folds, angular relationships and cleavage-bedding relationships combined with stratigraphic tops suggest that the sequence occupies the south limb of an east plunging anticline. Kink bands fold the earlier fabric but are restricted to fault zones and may be related to faulting. Similarly, minor local crenulations of the first cleavage seem to be related to intrusions.

These stratigraphic and structural features support Marten's (1971) suggestion that the Cutwell Group is correlative with the Western Arm Group.

1.6. Geology of the Similar Present-day Environments

1.6.1. Geology

Although the tectonic setting of the Lush's Bight terrane is still largely unresolved, it can be shown that the Cutwell Group on Long Island represents a volcanic pile of inland arc affinity (see Chapters 2 and 5). Before doing this it is necessary to outline the general features of present-day island arc environments.

Matsuda (1963) and Mitchell (1970) give detailed descriptions of modern island-arc successions in the Bonin and New Hebrides arcs, respectively. In both areas the succession is at least several thousand metres thick and accumulated during a period of not more than 10 m.y. Consequently, there is rarely any evidence of major unconformities within these successions, or island-arcs in general, although there are abundant local unconformities.

The successions consist largely of pyroclastic and epiclastic rocks forming tuffs, agglomerates and breccias. These deposits are often reworked and slumped down slope giving doubly reworked and laminated tuffs, immature volcanic sediments, turbidites, slump zones and lahars.

Massive lavas and pillow lavas form a minor to major proportion of the succession, depending on location within the succession and varying from volcano to volcano. In the shallower zones limestone and limestone breccia are often interbedded with these flows and the pyroclastics. The flows also interfinger and are interbedded with the pyroclastics. Numerous minor intrusions, similar in composition to the flows and volcaniclastics, cut the successions.

Emergent reef facies are characterized by the development of limestone, forereef talus, quiet lagoonal deposition and air-fall debris which is often contained in a carbonate matrix.

Many of the present-day island-arc successions have undergone metamorphism to the zeolite facies. According to Miyashiro (1972) the motion and descent of plates has probably become more rapid in younger geological time, in particular in the Pacific region, resulting in the abundant formation of Mesozoic and Cenozoic glaucophane shists in the high-pressure, low-temperature subduction zone metamorphic complex, paired with the high-temperature, low-pressure metamorphic complex developed in island arcs. In some cases the lavas are spilitized and K-enriched. Deformation is due mainly to block-faulting; low-amplitude folds may be present but tight folding is rare and there is little evidence of low-angle thrusting.

Plutons vary from small plugs to batholithic dimensions (Donnelly, 1964) and vary from gabbroic to granitic in composition. However, most plutons are dioritic or granodioritic. Pluton emplacement, as does faulting, often occurs during or immediately after the volcanic activity.

1.6.2. Chemistry

It has generally been considered that most of the island-arc volcanicity is of the calc-alkaline type, ranging from saturated basalt with a high alumina and silica content, to andesite, dacite and rhyolites. However, it has been shown that in many island arcs the calc-alkaline series is subordinate to volcanic rocks which have a lower silica mode, are less potassic and more iron-enriched - the "island arc tholeiitic series" (Jakeš and Gill, 1970).

Kuno (1959) was one of the earliest workers to recognize the presence of three rock series - tholeiitic, alkaline and calc-alkaline - in island arcs. Dickinson and Hatherton (1967) and Hatherton and Dickinson (1969) showed that there is an increase in K_2O content from the convex side to the concave of many arcs and correlated this with the depth of the Benioff zone. In general there is a change from less alkalic and more siliceous tholeiitic rocks on the convex side of the arc, through high-alumina basalt and calc-alkaline types, to either alkali-olivine basalt or shoshonite rocks on the concave side (Kuno, 1966; Jakeš and White, 1969). Furthermore this spatial (lateral) variation in composition toward the concave side of the arc may be matched by a temporal one, i.e., an increasing K_2O content in later rocks (Fig. 1.3) (Jakeš and White, 1969; Jakeš and White, 1972).

This lateral and temporal variation across island arcs from the convex

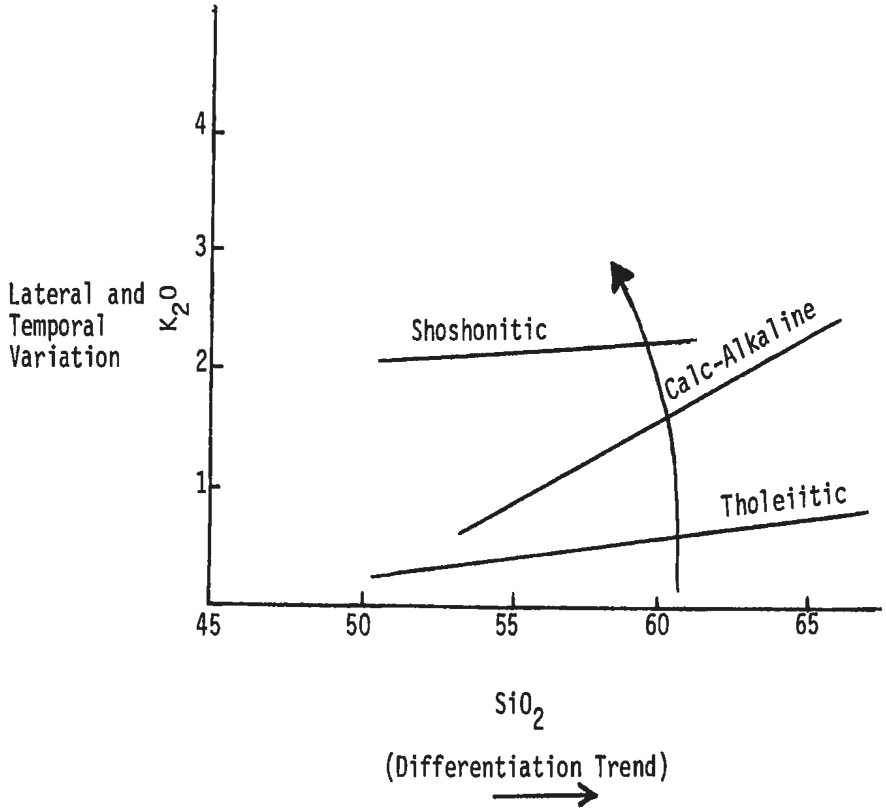

Figure 1.3. Lateral and Temporal Variation in the K_2O content of island arc andesitic rocks. (After Jakeš & White, 1972.)

to the concave side is also reflected by a decrease in iron enrichment, Na_2O/K_2O and K/Rb ratios, Ni, Cr and rare earth element content and an increase in Rb, Ba, Cs, Pb and Sr.

The lateral variation in lava composition across arcs is well developed in island arcs in an advanced stage of evolution. In younger arcs the lateral variation may not be fully developed but often displays a good stratigraphic compositional variation. In general, tholeiitic rocks are the earliest manifestation of island-arc evolution and are followed in time by calc-alkaline rocks and finally by shoshonites. However, it should be emphasized that lower-K volcanicity in any stage usually does not cease. The further stages of arc evolution are characterized by the presence of higher-K rocks with concurrent eruption of lower-K rocks on the oceanic side.

1.7. Present Study

Although the Pilley's Island - Long Island area of Notre Dame Bay offers a continuous cross-section through the "Lush's Bight terrane" of Horne and Helwig (1967) it is perhaps the least known part of this whole volcanic belt. It is thus an important locality to study the structural and stratigraphic relationship of these rocks, and critical to any attempts to establish their tectonic setting. The present study was undertaken to obtain detailed geological information, the lack of which has already led to contrasting interpretations of their origin (Strong, 1972), in the hope that such information would ultimately be useful in exploration of the numerous mineral deposits of the area.

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2. STRATIGRAPHY

2.1. Introduction

2.1.1. Field Methods

Long Island was mapped by the writer during the summer of 1971 (June - September) using 1/4 inch = 1 mile aerial photographs and a 1 inch = 1000 feet base map. Coastal mapping was emphasized partly because of poor and nondescript inland exposures and partly because of lack of time.

2.1.2. New Formational and Member Names Introduced in This Thesis*

The Cutwell Group as defined by Espenshade (1937) is now expanded to include that segment of the Lush's Bight Group (Espenshade, 1937) on the southwest corner of Long Island.

The redefined Cutwell Group has been subdivided into six formations and one complex as follows (in ascending order): -

The name STAG ISLAND Formation is proposed for the sequence of rocks developed on Stag Island and neighbouring islands north of Long Island. This formation is further subdivided into four members: Upper Basalt member

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*The status of the following formational names have been cleared by the Committee on stratigraphic nomenclature: - STAG ISLAND Formation
PIGEON HEAD Formation
SEAL COVE Complex
LONG TICKLE Formation

Of the remainder, the formation name BURNT HEAD has been previously used; whereas, the PARSON'S POINT Formation and the 'member names' have not been formally cleared as yet.

consisting of black basaltic pillow lavas found on Bread Box Island and area. Lower Basalt member consisting of grey-green, glassy, basaltic pillows and pillow breccias. Breccia member consisting of water-worked, explosive breccia (diatreme) deposit. Intrusive member consisting of diabase and gabbro dykes screens and plugs.

The name PIGEON HEAD Formation is proposed for the reworked pyroclastics (tuffs) and volcanogenic sediment (black shales, argillites, etc.) exposed on Pigeon Head and Seal Island.

The name QUINTON COVE Formation is proposed for the coarse intermediate and basic agglomerate and minor tuffs exposed in the Quinton Cove - Indian Head area, Long Island.

The name BURNT HEAD Formation is proposed for the sequence of rocks exposed in the Burnt Head area and the northwest shore of Long Island. This formation is subdivided into two members: Pyroclastic member consisting mainly of reworked tuffs and black shales (volcanogenic sediments) with minor chert, acid pyroclastics, agglomerate and iron formation. This member is excellently developed in the Burnt Head area but reaches its maximum thickness along the northwest shore of Long Island. Pillow-Andesite member consisting of green, porphyritic andesite pillow lava, isolated pillows, pillow breccias and intercalated pyroclastics, best exposed in the Burnt Head - Wild Bight area.

The name PARSON'S POINT Formation is proposed for the interbedded limestones, black shales, greywackes and pyroclastics in Lush's Bight Village.

The name SEAL COVE Complex is proposed for an intrusive - extrusive (in places flow-banded) complex found in the Seal Cove area on the west coast of Long Island. The complex is probably coeval with part of the BURNT HEAD Formation through to the LONG TICKLE Formation.

The name LONG TICKLE Formation is proposed for the sequence of interbedded and intertongued lava, agglomerate, tuffs and limestone exposed along the west half of the south shore of Long Island. Besides including the top of the Cutwell Group it includes the rocks Espenshade (1937) assigned to the Lush's Bight Group on Long Island.

2.2. Stratigraphy

2.2.1. Introduction

In this section a megascopic and microscopic physical description is given of all the rocks of pyroclastic nature. The flow rocks are also discussed on a megascopic scale, but their petrography will be discussed in Chapter 5. The thicknesses given at the beginning of each section are for the cross-section D-D', E-E'. (See map in pocket.)

An idealized schematic cross-section is included (Fig. 2.2) but structural cross-sections are described in Chapter 4.

2.2.2. STAG ISLAND Formation (c. 4,000 feet)

At least one or more of the members of this NW-SE trending, southwest dipping and facing formation can be found on Stag Island, Little Stag Island, Crab Island, Crow Island, Middle Island, Burnt Island, Gunning Islands, Duck Islands, Seal Island and Bread Box Island. It forms the base of the exposed sequence and is conformably overlain by the PIGEON HEAD Formation.

The base of this formation is represented by the INTRUSIVE member exposed on the north side of Little Stag Island and southeast Stag Island. The member consists of fine-grained, green, E-SE trending, subvertical - vertical, diabase dykes intruding fine to medium-grained gabbros. Both are texturally and mineralogically similar but the dykes are distinguishable by the presence of chilled contacts despite extensive faulting. The dykes range in width from less than half a foot to five feet and are spaced from a few inches to tens of feet.

Although faulting prevents these dykes from being traced into, they are directly overlain by fine-grained, green, diabasic-textured pillow basalts, sometimes with a sheared isolated-pillow, pillow-breccia horizon. A faulted and sheared ten-foot lens of silicified (cherty) and pyritized black shales occurs within the pillow unit on Stag Island. Very pale-green, microcrystalline, massive pillows form a thin unit ($\sim$10 feet) above the basaltic pillows, and may be equivalent to the Duck Island pillow lava.

The contact with the overlying BRECCIA member is generally faulted, but in some cases it is sharp and irregular. The breccia member is exposed on Stag Island, Little Stag, Middle Islands, Crab Island and Crow Island giving a linear outcrop pattern.

This member is a very poorly sorted, locally bedded, coarse pyroclastic unit of diatreme or explosive breccia affinity. Generally there is a completely unsorted jumble of fragments ranging in size from matrix to 3 feet. Coarse-grained, gabbro fragments predominate (up to 80%) and are often found in blocks 20 to 30 feet in dimensions with the greatest concentration ($\sim$80%) and largest sizes occurring on the NE side of the islands. There is then a general, but not distinct, decrease in the number and size of gabbro fragments to the west and correspondingly the amount of matrix increases at least in local zones.

The gabbro varies from medium grained to pegmatitic and is often sufficiently rich in plagioclase to be called anorthosite. Large gabbroic bodies (500 feet in dimensions) on Crab and Crow Islands, are of the BRECCIA member type and do not appear to be inclusions in the pyroclastic deposit, but instead may represent the original gabbro source. These bodies may then be part of the previously discussed INTRUSIVE member.

The gabbro fragments (blocks) often have a fluidized or gas breccia appearance with a white felsic veining. This feature is not extensively developed in the other fragments or the matrix.

The gabbro fragments and the large bodies on Crab and Crow Islands are microscopically similar. The coarse and pegmatitic phases are rich in moderate to extensively sericitized and saussuritized plagioclase ($\sim An_{35}$ - An_{45}). The uralitized and chloritized pyroxene (augite) has an intergranular, sometimes poikilitic relationship to the plagioclases. The finer grained phases have a diabasic texture. Minor alkali feldspar, opaques and rare epidote are also present. Secondary carbonate is common.

The next most common fragments are diabase, ranging from fine-grained grey to diabasic textured green and medium-grained gabbros. These fragments vary from matrix size to blocks 4 feet in dimensions (average $<$ 1/2 foot). Microscopically they consist of saussuritized plagioclase and chloritized and epidotized pyroxene with secondary amoeboid quartz and extensive carbonate.

Carbonate, chlorite and quartz also occur as vesicle fillings. Disseminated iron oxides are common.

Fragments of recrystallized limestone, black shale, glassy pillow rims and green lava are scattered throughout the deposit, but are much less common and smaller than any of the previously discussed fragments.

The green lava fragments have a similar texture and mineralogy to the underlying basaltic pillow unit. The texture is diabasic with a few phenocrysts and microphenocrysts of chloritized and faintly epidotized augite. The groundmass is also masked by chlorite making feldspar identification impossible. Secondary carbonate and quartz are common.

The glassy pillow rims consist of a light brown, devitrified glass with iron oxides disseminated throughout and concentrated along fractures. Chlorite and carbonate occur in vesicles and as fracture fillings.

Near the base of the sequence on Little Stag Island and Crow Island, subangular blocks of massive sulphide (pyrite, pyrrhotite and minor chalcopyrite) and minor magnetite ranging in size from $<1/2$ inch to 4 feet occur in a random and unsorted pattern, but with a suggestion of an overall linear distribution.

Within the deposit there are local bedded zones or lenses ($\sim$1 - 2 feet thick) giving tops to the west - southwest; however, one such zone near the northern end of Stag Island gives a questionable tops determination to the northeast suggesting an anticlinal structure. On the southwestern-most island of the Middle Islands a one hundred foot sequence of the deposit consists of alternating beds of poorly sorted, coarse ($\sim$20 feet thick) and medium to fine ($\sim$3 feet thick) fragments. This sequence gives a westerly facing direction and appears to overlie the very coarse, unbedded equivalents on the northern islands.

The top of the succession on Stag Island is marked by a rapid change in facies to a medium to fine-grained, bedded but poorly sorted, slump-folded, arkosic equivalent of the breccia deposit. This grades into thinly bedded, cherty, black shales. The arkose consists of mainly rock fragments of glassy basalt, quench-textured feldsparphyric basalt, diabase, gabbro and chert, in that order of abundance. Broken and completely saussuritized plagioclase crystals are abundant and probably are next to the volcanic rock fragments in abundance. There are also minor fragments of myrmekitically intergrown quartz and plagioclase; minor quartz is also present. Carbonate and chlorite are also common.

Overlying and interfingering with the black shale unit at the top of the sequence on Stag Island is a glassy pillowed basalt unit, called the LOWER BASALT member. This member continues southeastward to Seal Island and is also found on the Duck Islands.

The Duck Islands are not on strike with the main outcrop and therefore there is a number of possibilities for the occurrences of the LOWER BASALT member there: -

(i) An earlier eruptive phase of the LOWER BASALT magma, pre-explosive brecciation, and therefore essentially equivalent to the pale-green, microcrystalline (glassy) unit within the intrusive member. This could possibly be the source for the glassy basalt fragments in the breccia member.

(ii) A part of the LOWER BASALT member that has infilled a depression in the original topography.

(iii) may be faulted in equivalent of the LOWER BASALT member.

(iv) the questionable, but possible, anticlinal structure mentioned in the above section would bring the LOWER BASALT member down in this locality (unfortunately, no reliable top determination could be found on the Duck Islands).

The LOWER BASALT member is a grey to pale green (apple-green) southwest facing pillow basalt unit. It is a pile of closely packed, bulbous and molded pillows (Plate 1) with abundant pillow breccia (Plate 2) (often up to 50% of the exposure). The pillows are generally from 2 to 4 feet in diameter but range from 4 to 5 inches up to 8 feet.

Chilled rims are hard to recognize because of the uniform, glassy nature of the pillows from rim to core. However, a vesicular and slightly more glassy rim, 1/2 inch in thickness, is sometimes recognizable. Brecciated, in-situ pillow rims are also common.

Interpillow material is not common but where present consists of spalled-off pillow rims and pillow breccia fragments in a finer, probably hyaloclastic matrix. Calcite is a common breccia and vein material. A thin lens of black shale containing pyrite and chalcopyrite occurs intercalated with the pillow lavas on Seal Island.

The essentially homogeneous glassy nature from rim to core is an outstanding feature of these pillows and is not known to the writer from any other area. The only truly holocrystalline pillows within this unit were noted on the southern-most shore of the Gunning Islands. The main outcrop (Stag Island) of this glassy pillow member portrays a repeated sequence from glassy-nonporphyritic to glassy - porphyritic with varying proportions of plagioclase and mafic (pyroxene and/or olivine) phenocrysts.

Top determinations from pillows and pillow-breccias are consistently to the southwest.

Occurring on a number of small islands (Bread Box Island, etc.) is an isolated occurrence of massive, fine-grained, sugar-textured, southwest facing, black pillow basalts of the UPPER BASALT member. This member is overlain by PIGEON HEAD Formation and underlain by the LOWER BASALT member of the STAG ISLAND Formation; however, neither contact is exposed.

The basaltic pillows are probably related to the diabase dykes and gabbro plugs which are so extensive in this area (Chapter 3).

The pillows are generally large, averaging about 6 feet, closely-packed and molded against each other. They are generally vesicular and non-porphyritic with chilled margins averaging 1/2 inch in width. Jasper is common as an interpillow material and epidote veins are common but not extensive.

2.2.3. Interpretation

The INTRUSIVE member and the gabbro bodies on Crab and Crow Islands appear to be part of the same sequence, part of which was brecciated during the subsequent explosive activity thus producing the BRECCIA member. The presence of reworked tuff and limestone in the BRECCIA member possibly suggests the development of a shallow marine environment prior to the explosive brecciation which was also a submarine phenomenon as indicated by the local bedding zones.

The linear outline of the BRECCIA member may either be a primary, i.e., indicating a linear fissure, or secondary feature due to sedimentary redistribution. The size, angularity and unsorted nature of the deposit suggests that it is close to its original source area and has undergone minimum lateral transportation.

The bedded but poorly sorted sequence of coarse breccia fragments on the Middle Islands probably represents rapid settling in water whereas the finer bedded, finer grained, arkosic sequence forming the top of the breccia deposit on Stag Island probably represents a greater amount of later transportation.

The sulphide blocks could possibly represent fragments of a larger deposit that was disrupted during the explosive activity. Massive pyrite - pyrrhotite - chalcopyrite lenses in the black shales at the contact with the pillow basalts of the INTRUSIVE member on Stag Island is an indication of possible sources for these blocks.

The occurrence of the arkosic-type breccia debris as horizons within the lower parts of the LOWER BASALT member suggests that the lava-producing volcanic activity was essentially contemporaneous with the last phases of the explosive activity or at least the settling out of the explosive ejecta.

The development of extensive pillow breccias indicates that the submarine eruptions of basalt could not have been at depths greater than 5 km since explosive submarine eruption of basalts is unlikely to occur at depths greater than this (McBirney, 1963). However, the general non-vesicular nature of the

LOWER BASALTS suggests a depth around 4 km. (Moore, 1963, 1965).

2.2.4. Pigeon Head Formation (c. 1,500 feet)

This is a NW-SE trending, southwest dipping and facing, reworked pyroclastic and volcanogenic sediment formation. It is best developed on Pigeon Head and Seal Island Tickle Head where it reaches its maximum exposed thickness. It also occurs on Southern Head where it is only a few hundred feet thick; however, here it is overlain by the PYROCLASTIC member of the BURNT HEAD Formation, which could be possibly included in the PIGEON HEAD Formation. The division was made with the disappearance of extensive black shale horizons characteristic of the PIGEON HEAD Formation and the appearance of lava intertongues and extensive pillow units that are so characteristic of the BURNT HEAD Formation.

The lowermost unit of this formation is best exposed on Pigeon Head. The base is characterized by a baked and silicified, black, cherty, bedded shale with zones of black flinty, conchoidal chert. It is intruded by numerous sills of black basalt and diabase that are traceable into gabbro plugs. Microscopically the shales consist of an altered, carbonated and silicified cryptocrystalline (almost opaque) matrix of probable volcanogenic origin with rare plagioclase crystals or fragments ($\sim$1/8 mm) and the occasional rare fragment of altered basic volcanic. Disseminated euhedral pyrite is probably of diagenetic origin.

The above grades into and is interbedded with thin beds (1/4 inch - 3 inches of grey and fine-grained, poorly graded, sandy-textured pyroclastics. In thin section these beds consist of both fresh and saussuritized plagioclase crystals and crystal fragments and minor altered augite fragments and chips. However, the bulk of the rock is a highly altered (chloritized, carbonated, etc.) cryptocrystalline tuffaceous aggregate that forms the matrix for the larger chips and fragments. Diagenetic (?) pyrite is disseminated throughout the rock. Secondary quartz is common in the matrix.

It grades upwards into fine-grained, bedded, poorly graded green reworked tuffs with rare horizons of black cherty shale. Microscopically, the rock is mainly a cryptocrystalline (almost opaque) aggregate of tuffaceous debris containing secondary quartz, chlorite, epidote, and carbonate. However, there are the occasional lenses and thin beds rich in fragments and chips of dusty, inclusion-filled, andesine and chloritized pyroxene. These coarser beds and lenses are gradational into the above-described cryptocrystalline phases (Plate 3). They contain rare minor rounded to subangular quartz fragments as well as secondary quartz. Disseminated pyrite is common.

A similar section occurs on Seal Island Tickle Head, where again there are many gabbroic intrusions and dykes.

Grey, massive, bedded chert occurs near the base of the sequence and also occurs sporadically throughout the sequence. A discontinuous coarse pyroclastic zone near the base of the sequence on Seal Island Tickle Head contains fragments varying from 1 1/2 inches to microscopic in size. Subrounded to angular and irregular volcanic fragments predominate, and these fragments range from basalt containing quench-textured plagioclase microlites in a black matrix to feldsparphyric type. Angular chert is followed by angular quartz grains and minor, broken, subhedral andesine plagioclase grains in abundance.

Occurring interbedded with the black shales and reworked tuffs are beds (< 1 foot - 20 feet) and discontinuous lenses of grey arkoses containing varying proportions of chert, volcanic, feldspar, quartz and rip-up bed fragments.

Microscopically, the rock contains ~15% cryptocrystalline matrix. Saussuritized, subhedral to euhedral, broken plagioclase (andesine) is the predominant fragment type and has a widely varying ratio to angular and subrounded quartz fragments which often show a distinct resorbtion texture but are occasionally bipyramidal in outline. Chert and rip-up fragments are the most common rock fragments, with minor angular fragments of altered feldsparphyric basalt. The rock fragments are always very subordinate in number to either the plagioclase or quartz fragments (Fig. 2.1).

Minor rounded and elongated, chilled bombs of vesicular to porphyritic green andesite were also noted in some of the reworked tuff horizons. These bombs are generally in the 1 to 2 inch size range.

Slumping and rip-up fragments are common on a bedding scale. In the fine-grained beds current ripples, minor small-scale cross-laminations and scour features are often developed. The top of the sequence often displays soft sediment deformation such as swirling, bending, buckling, rip-up, flowage and load-casting on the contact with the overlying agglomerate of the QUINTON COVE Formation.

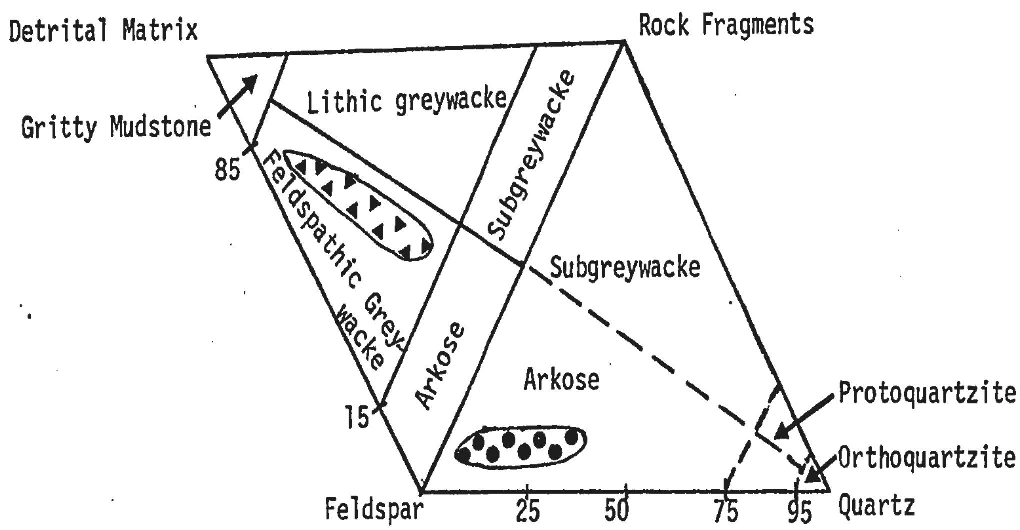


Figure 2.1. (after Pettijohn; Sedimentary Rocks, 1957)

PIGEON HEAD   PARSON'S POINT

Classification of the coarser rock units on the basis of maturity.

2.2.5. Interpretation

The whole formation represents a reworked tuff in a fairly deep water environment. The lack of good grading, cross-bedding, scour features, etc., except on a bedding scale in the finer horizons, suggest that only weak bottom currents were in action.

The coarse, arkosic lenses and beds probably represent influxes of debris-laden currents from up-slope eroding the pre-existing lavas and pyroclastics and ripping and scouring up bed fragments. The plagioclase crystals and crystal-fragments may have been eroded out of existing flows or crystal tuffs. The chert undoubtedly came from the chert horizons that are common in this environment. The quartz may have come from vesicles in lavas; however, the resorbed quartz and the rare bi-pyramidal crystals must have come from quartz-bearing flows and/or intrusions none of which were present until the rare quartz-bearing flows of the PILLOW-ANDESITE member of the BURNT HEAD Formation and/or the SEAL HEAD COMPLEX are emplaced (see Table 1.2).

The microlitic and feldsparphyric basaltic fragments have a ready source in the LOWER BASALT member of the STAG ISLAND Formation. The irregular shape of some of the fragments, along with the overall angularity of all the fragments, suggest a minimum distance of transportation and possibly an explosive origin. The vesicular and porphyritic andesite bombs represent explosive expulsion of magma of the type parental to the overlying PILLOW ANDESITE member of the BURNT HEAD Formation. The absence of load-casting or drop-features in the surrounding pyroclastics suggest that the bombs were deposited with the surrounding tuffs.

2.2.6. QUINTON COVE Formation (c. 3,000 feet)

This is a NW-SE trending, southwest dipping coarse agglomerate horizon with a 20 to 30 feet unit of southwest dipping and facing reworked tuffs occurring about half-way up the formation. It is southeasterly thinning and pinches out before it reaches the Southern Head area. It is conformably overlain by the PYROCLASTIC member of the BURNT HEAD Formation.

The agglomerate consists of a variety of volcanic rock fragments varying from microscopic to 3 feet in size in a fine to medium grained tuffaceous matrix. They are generally subangular to subrounded with rare chilled rims (1/2 inch) noted on a couple of andesitic blocks (bombs?). The blocks have a general size increase towards the southeast.

Except for rip-up fragments (up to 8 x 10 feet) of the underlying PIGEON HEAD Formation in the Seal Island Tickle area, all the fragments are of volcanic origin. The most common fragments are bombs and blocks of epidotized andesite, of green, fine to medium grained andesite and of occasional basalts. Fine-grained, red (oxidized), vesicular and porphyritic andesitic volcanic fragments occur in the Seal Island Tickle area.

Microscopically the epidotized bombs and blocks contain saussuritized andesine plagioclase in the groundmass and as phenocrysts. Groundmass and phenocrystic mafics have been completely altered to epidote. Epidote also occurs in veins and throughout the groundmass. The groundmass also contains secondary quartz.

The green, andesitic bombs and blocks can be divided into two petrographic types. The dominant type is essentially a seriate feldsparphyric andesite. The moderately to extensively saussuritized andesine microlites and phenocrysts are in a chloritized cryptocrystalline groundmass. The red, vesicular and porphyritic volcanics described above belong to this type.

The second type contains saussuritized andesine plagioclase phenocrysts and chloritized-epidotized-clinopyroxene in roughly equal proportions in a fine-grained groundmass of plagioclase and pyroxene. Secondary calcite is common.

The matrix of the agglomerate varies from an altered, completely cryptocrystalline type to fine-grained tuffaceous with varying concentrations of andesine plagioclase crystals and crystal-fragments with and without chloritized clinopyroxene grains. Chlorite and epidote are common.

The reworked tuff horizon is fine-grained, bedded and green. In thin section it grades from medium-grained tuff with plagioclase and clinopyroxene crystal fragments (up to 0.04 inch) and minor lava fragments in a finer-grained, partially chloritized tuffaceous matrix to a cryptocrystalline (almost opaque) equivalent.

2.2.7. Interpretation

The numerous and predominant feldsparphyric volcanic fragments are similar to the lower pillow units of the PILLOW-ANDESITE member of the overlying BURNT HEAD Formation. The general lack of chilled margins and the angularity of these blocks suggest an accessory origin for these blocks. Thus it is suggested that andesitic volcanicity of the PILLOW-ANDESITE type was active prior to and during (occasional bomb), as well as after the deposition of the QUINTON COVE Formation.

The minor occurrence of clinopyroxene-plagioclase-bearing volcanic fragments and clinopyroxene-bearing tuffs, which are very similar to the upper portions of the PILLOW-ANDESITE member, suggest that lavas and/or a magma of this type were not abundant at this time and may have been in the early stages of forming.

2.2.8. BURNT HEAD Formation (c. 5,500 feet)

This NW-SE trending, southwest dipping and facing pyroclastic and pillow lava sequence forms the main outcrop on Long Island. It is found along the west shore from Western Head to Red Point and continues southeastward along strike to the south shore of Long Island (Long Island Tickle) with a NW to SE change in lithology from mainly pyroclastics in the northwest to predominantly pillowed andesites in the southeast. It also increases in thickness to approximately 7,000 feet. It conformably overlies the QUINTON COVE Formation and is overlain by the PARSON'S POINT and the LONG TICKLE Formations.

This formation has been subdivided into two members, mainly because around BURNT HEAD itself it can be readily divided into a lower PYROCLASTIC member and an upper PILLOW-ANDESITE member. However, along strike to the northwest it becomes dominantly pyroclastic (tuff) (Plate 4) with minor lava interfingers; while to the southeast it is mainly pillowed flows with intercalated pyroclastic horizons.

In the Burnt Head area the base of the PYROCLASTIC member is marked by 40 to 75 feet of laminated, black, cherty shale. This is overlain and interbedded with reworked, grey-green laminated pyroclastics but also occurs sporadically as thicker distinctive units throughout the sequence. Microscopically the black cherty scale horizons are also of a tuffaceous nature. Grading from medium grained zones rich in altered andesine in a cryptocrystalline matrix to zones that are completely cryptocrystalline with rare microscopic fragments. There are minor primary quartz grains however, and secondary quartz is quite common. There are abundant highly carbonated and silicified cryptocrystalline lenses or beds with rare plagioclase chips forming siliceous green beds which are interbedded with the tuff and black shale.

The fine-grained, grey-green, laminated and poorly graded tuffs have well-developed slumped flame structures and small scale slumps and scour features. In thin section (Plate 5) the rock is mainly of a cryptocrystalline (almost opaque) tuffaceous nature with the occasional rich zone of turbid and saussuritized andesine plagioclase crystal fragments ranging from microscopic to ~ 0.01 inch. Secondary carbonate and minor secondary quartz occurs in the matrix.

Thin beds (1 to 4 inches) of a medium-grained, black-green feldspar crystal tuff are occasionally interbedded with the rocks in the Burnt Head area and become much more extensive in the Western Head area. Microscopically, these tuffs consist mainly of saussuritized and broken andesine plagioclase crystals or crystal fragments in a fine-grained, chloritized tuffaceous matrix rich in plagioclase chips. Chloritized and epidotized pyroxene fragments and angular feldsparphyric andesite fragments are common. Rare angular chert and minor angular quartz fragments may also be present. Minor secondary quartz also occurs in the groundmass and in vugs. Disseminated pyrite is common.

Discontinuous beds and lenses (up to 5 feet thick) of grey-white chert occur sporadically throughout the member. Microscopically the chert varies from a cryptocrystalline to microcrystalline equidimensional intergrowth of quartz with minor epidote and rare iron oxides (Plate 6).

A distinctive slump-breccia zone varying in width from 1 to 50 feet (averaging 10 feet) occurs in discontinuous zones from Seal Island Tickle to Western Head area. It contains scoured-up fragments of the surrounding tuff, black shale, chert, tuffaceous iron formation, as well as broken plagioclase and volcanic fragments and extensive angular quartz.

Small agglomerate horizons are locally developed. The top of the member in the Burnt Head area consists of interbedded shale and tuff overlain by 20 feet of agglomerate and then 20 feet of shale - tuff with porphyritic andesite interfingers which can be traced into the overlying PILLOW-ANDESITE member.

In the Burnt Harbour area of Cutwell Arm, isolated and broken andesitic pillows, elongated at right angles to bedding and parallel to the schistosity, occur in a coarse and sporadically oxidized tuffaceous matrix (Plate 7). This is suggestive of the classical pillow-lava, isolated pillows, broken-pillows sequence described by Carlisle (1963), except here the tuffaceous matrix is not the finer grained aquagene tuff. Instead the tuff is the coarser equivalent of the above described tuffs and the isolated pillows seem to have fallen or dropped into the unconsolidated tuffs as a result of instability in the pillow pile. Consequent slumping may have resulted in the brecciation of the isolated pillows and even the elongation of the semi-consolidated isolated pillows in the direction of slump movement. Similar occurrences of isolated pillows in a tuffaceous matrix are sporadically developed in the intercalated pyroclastic zones of the PILLOW-ANDESITE member.

Coarse pyroclastic zones are common in the Cutwell Arm area where they are interbedded (10 to 100 feet) with the above described fine-grained tuffs and black shales. These coarse pyroclastic zones often have a flow alignment of scoured up and accidental fragments of bedded pyroclastics and black shale. These coarse tuffs are also rich in fragments of saussuritized and turbid andesine and feldsparphyric lava. There are also a number of angular and partially resorbed quartz grains. Also one fragment of the dacitic Seal Cove Complex was noted.

The matrix is generally a fine-grained chloritized tuffaceous equivalent of the above with moderate to extensive secondary carbonate and minor disseminated epidote and iron oxides.

The tops of these coarse tuff zones generally contain less pyroclastic and shale fragments, but are fairly rich in volcanic fragments, plagioclase and chloritized clinopyroxene fragments.

Minor acid pyroclastic horizons occur sporadically throughout the sequence but are best developed on the west coast where they are approximately 800 feet thick. The lower unitscontain rounded to elongated (3 to 6 inches) vesicular and epidotized bombs in a medium-grained acid matrix. Bombs are rare in the upper units which are often extensively replaced and mineralized with pyrite. Microscopically the rock is a cherty microcrystalline quartz mosaic (Plate 8) with scattered subangular, partially resorbed, bipyramidal quartz grains. The secondary groundmass and vug quartz has an amoeboid, poikilitic texture. There are rare relict plagioclases now represented by carbonate, epidote, albite and silica. Rarer fresh plagioclases have a lower andesine (sodic) composition. Epidote and carbonate are common.

Isolated subrounded blocks (1/2 inch to 2 feet) of limestone similar to the PARSON'S POINT Formation are found in the feldspar crystal tuffs and minor acid pyroclastics at the top of the PYROCLASTIC member in the bottom of Cutwell Arm, and may actually be a facies of the PARSON'S POINT Formation.

The top of the member on the west shore consists of a coarse agglomerate and slump-breccia zone. The slump zone contains fragments of pyroclastics, black shales, tuffaceous iron formation, volcanics, rare limestone fragments and a creamy-white acid volcanic found only as detritus in the LONG TICKLE Formation.

Andesitic dykes and sills occurring throughout this member may be related to the overlying lavas.

The base of the PILLOW ANDESITE member in the Burnt Head area is marked by a number of massive, vesicular andesite flows (2 to 8 feet thick) that are transitional upwards into vesicular and porphyritic, green andesitic pillow lavas. Interpillow material is a green and white chert but is not extensive. Higher in the sequence and southeastward along strike the pillows become larger (averaging 3 to 4 feet, but up to 6 to 8 feet), bulbous, draped and "toed" (Plates 9 and 10). Interpillow material here is generally lower in overall abundance and is mainly red jasper. Isolated pillow and agglomerate zones are sporadically developed.

The pillows show no systematic variation in vesicularity. They are generally more vesicular around their outer circumference and chilled rims about half an inch wide are generally well developed. The flows are generally highly feldsparphyric but may also occasionally be non-porphyritic.

The lava tongues occurring in Cutwell Arm and along the west coast of Long Island are of the same type as described above, but massive flows are also present. Epidotized chert occurs as interpillow material.

Intercalated horizons (several inches to 200 feet) of agglomerate (with rare limestone blocks) and reworked and slump-folded (Plate 11) tuff are common and are best developed along the south shore of Wild Bight and along

Long Tickle. The intercalated reworked tuffs often display soft sediment deformation around and between the pillows forming an interpillow material.

Oxidation and "hematization" of tuffs, isolated pillow matrix and the occasional flow gives rise to discontinuous lenses, pods and zones of "pseudo-iron formation". The oxidation-hematitization of the rocks is rarely gone to completion. Generally the matrix is the most extensively altered and the fragments have a zonal-concentric replacement around their edges (sometimes developed to the center) giving a 'patch-work' pattern.

2.2.9. Interpretation

The formation represents an intertongued and intercalated lava and pyroclastic sequence that undergoes a lateral facies change from dominantly volcanics in the southeast to essentially pyroclastics in the northwest.

The bedding, slumped flame structures, slump folds and slump-breccia horizons suggest the rocks were laid down in fairly quiet water on a slope probably by slow settling from debris laden water and, in the case of the coarser horizons, possibly by turbidity currents. The slump and scoured-up horizons are also suggestive of turbidity action. The action of minor gentle bottom currents is reflected in the fine-grained horizons by small lenses and troughs of redistributed material, minor cross-laminations and current ripples; however, these currents must have been weak and on a small scale since the coarser horizons were not affected.

The flow banded coarse pyroclastics containing numerous scoured-up rock fragment zones in Cutwell Arm may actually be a 'pyroclastic flow' (Fiske, 1963). In fact, the isolated pillows, broken pillows in a pyroclastic and rock-fragment matrix in this area may be such a pyroclastic flow.

The bulk of the pyroclastics—plagioclase-rich tuffs and the feldsparphyric volcanic-rich tuffs—are probably genetically related to the essentially feldsparphyric andesitic PILLOWED-ANDESITE member. Whereas, the upper pyroclastic zones rich in plagioclase-clinopyroxene fragments in a plagioclase-clinopyroxene tuffaceous matrix are possibly related to the late stages of volcanic activity that produced the plagioclase-clinopyroxene andesites in the upper part of the PILLOW-ANDESITE member.

The absence of pumice, glass shards, accretionary lapilli, and vesicular bombs suggest that the debris was of accessory origin, i.e., derived from pre-existing rocks. Moreover, the angularity of the volcanic fragments suggest an explosive origin for these by the explosive brecciation of lava or a partially consolidated magma rather than by erosion. Also the vesicular bombs in the acid pyroclastic horizons reflect explosive volcanic activity.

The pillow lavas often have an "intrusive" relationship into soft, unconsolidated tuffs; however, most of the tuff horizons appear to be deposited over the pillows and the appearance of interpillow red jasper suggests that the flows were exposed to open water before being covered by pyroclastics.

It thus appears that the area of sedimentation was receiving eroded debris from the flanks of the volcano, plus "primary" suspended material, bombs, and ejecta at the same time the flows were being produced. The flows then continued into the basin of the deposition intruding and at the same time being covered by volcanic debris that had an earlier but genetically related origin (Fig. 2.2). In fact, the effusive stage may have triggered the redistribution (erosion) of the earlier volcanic products that were deposited near the volcanic vent.

The isolated subrounded bl cks of limestone mixed with the pyroclastics at the top of the PYROCLASTIC member may mark the beginning of a shallow water or emergent facies.

2.2.10. PARSON'S POINT Formation (c. 200 feet)

This sequence is best developed in Lush's Bight village particularly on Parson's Point. It overlies the BURNT HEAD Formation and is directly overlain by the LONG TICKLE Formation. Outside of Lush's Bight village most of the rocks of this formation are limestone and because of the lenticular and pod-like shape of all the limestone on Long Island, it is assumed that minor unconformities overlie and underlie this formation. It now occupies the trough of a syncline which has its limbs eroded. This may then explain its outcrop pattern.

The base is marked by c. 50 feet of grey-blue, fine to medium grained recrystallized and sparsely fossiliferous (crinoid fragments, brachiopods and gastropods) limestone breccia. The breccia consists of random and unsorted subangular blocks of limestone varying from 1/4 inch to 2 feet in size. The matrix is generally minor and is of a limy-mud carbonate type. There is also a small amount of feldspar crystal tuff as matrix and often squeezed between the limestone fragments. Minor volcanic fragments of an undetermined type are also present in the limestone breccia.

The limestone breccia is overlain by approximately 15 feet of medium grained, graded and cross-bedded feldspathic greywacke (Fig. 2.1). The greywacke contains visible detrital magnetite, feldspar, rock fragments, minor limestone and quartz. Microscopically, the matrix varies from 20% to 80% of the rock and generally is a fine-grained, carbonated and sericitized equivalent of the larger fragments. In places the matrix looks flow-banded and occasionally augens the fragments. Epidote and chlorite also occur in the matrix.

The fragments consist of saussuritized plagioclase, pyroclastics, chert and chloritized and epidotized volcanics of both the feldsparphyric and plagioclase-clinopyroxene type. However, the feldspar fragments always exceed the rock fragments in abundance. Angular and irregular quartz grains are also quite common. Differential weathering of calcareous zones is a common feature of these greywackes.

The slump-folded limestone breccias and massive limestone overlying the greywackes are interbedded with limy, cherty, volcanogenic black shales. This upper interbedded zone can be traced laterally southwest along strike to a 50 feet unit of cherty black shales which contain one poorly preserved brachiopod. Limestone breccia (30 feet) and reworked tuffs overlie the shales. Rare and unidentifiable graptolites occur in these shales.

Extensive slump folding and mixing of the rock types occur on the south tip of Lush's Bight village. There it is also intruded by the SEAL COVE complex.

2.2.11. Interpretation

The large scale and well-developed cross-bedding and the fossil assemblage in the limestone is suggestive of a shallow water environment. This probably indicates the development of a shallow water facies on the top or site of a volcano.

The subangular, unsorted and "jig-saw" like nature of the fragments suggests that the brecciation of the limestone is more of a cataclastic effect than a wave action (fore-reef) feature. It probably represents the shaking-up and brecciation of semi-consolidated limestone in a small lagoonal type basin by tectonic forces active during the life cycle of the volcano (earthquakes, tremors, expulsions, etc.). Blocks of the limestone may have fallen off into the surrounding pyroclastics.

The black shales are also suggestive of a quiet, lagoonal type environment. The sparsity of fossils in both the limestone and black shales suggests that the environment of deposition was probably stagnant and of an enclosed lagoonal type, and the waters were probably polluted with poisonous solutions and gases from the volcano.

2.2.12. SEAL COVE COMPLEX

This complex is best exposed between Red Point and Seal Cove. However, it also occurs cutting the PARSON'S POINT and the LONG TICKLE Formation. Fragments of it are found in the PYROCLASTIC member of the BURNT HEAD Formation and up to about the middle of the LONG TICKLE Formation. Therefore, in the stratigraphic column it has a wide timespan; however, since the main intrusive phase post-dates the PARSON'S POINT Formation, it is placed above this formation.

The complex varies from an intrusive flow-banded dacite to its explosive pyroclastic equivalent. The phases are hard to distinguish and appear to grade into or are a part of each other and are intruded by coeval phases. However, as a generality the main intrusive phase occurs in the northern half of the complex.

The intrusive and/or flow phases vary from aphanitic to coarsely feldsparphyric and form red to dark green in color. This color variation is gradational and may occur on outcrop scale (i.e. 100 feet), but also commonly as a flow-banding feature and as a patch-work discoloration (oxidation) - often giving an agglomeratic appearance. The bands are sometimes autobrecciated resulting in a fragmented appearance which can also be mistaken for pyroclastics.

The pyroclastic phase consists of irregular, angular, rounded and oval fragments of both the red and green (or fragments displaying both) feldsparphyric dacite. The fragments vary in size from microscopic to two feet bombs in the agglomeratic phases. The matrix may be of a finer-grained pyroclastic equivalent of the above or of the intrusive phases. The fragments sporadically occur in bedded, reworked basic tuff of the BURNT HEAD and LONG TICKLE Formations. The agglomerate bombs have pink, chert-like chilled rims, and fragments of this type (generally $<$ 6 inches) are common throughout the complex. Chilled zones of the intrusive - extrusive phase also have this pink, cherty appearance.

The bombs, fragments and generally the matrix of the intrusive phase are microscopically similar. The color variation is generally very faint but is sometimes reflected by a slightly higher opaque iron oxide concentration for the darker zones. The rocks have a seriate porphyritic texture, the phenocrysts being mildly to extensively sericitized plagioclase of An_{28} - An_{35} composition (Plate 12). Flow banding is often prominent around these phenocrysts (Plate 13). The cryptocrystalline groundmass contains plagioclase, chlorite, sericite, minor disseminated iron oxides, and both primary and minor to extensive secondary quartz. Secondary quartz also occurs in vesicles and in patches or knots.

2.2.13. Interpretation

The complex relationships within the body suggest a repeated and prolonged period of magmatic activity associated with the same or similar magma(s), and possibly genetically related to the dacitic plugs and dykes described in Chapter 3 (compare Plates 12 and 17). Likewise, the occurrence of fragments of the complex from the middle of the PYROCLASTIC member to the LONG TICKLE Formation and its intrusive relationships into these formations suggest a prolonged period of activity coeval with and after their formation.

The complex may be interpreted as a near-surface dacitic plug with associated dykes, sills and flows cutting the earlier phases derived from the same magma, and grading into contemporaneous explosive phases, and being cut by later phases.

2.2.14. LONG TICKLE Formation (? 3,000 feet)

This formation overlies the PARSON'S POINT and the BURNT HEAD Formation. It extends southeastward from south of Lush's Bight to east of Milkboy's Cove. It is generally a southwest dipping and facing sequence, however it may be modified by local folding.

The formation is marked by the occurrence of extensive and thick reworked tuff and agglomerate horizons, by common limestone horizons and the occurrence of a fine-grained, cream-white, angular volcanic fragments. This fragment type occurs throughout the formation in both the coarse and fine pyroclastic zones. Microscopically the creamy-white fragments contain extensively saussuritized plagioclase phenocrysts in an altered cryptocrystalline groundmass containing secondary quartz and minor iron oxides. Secondary quartz also occurs in knots.

The tuffaceous matrix is generally the same for both the fine and coarse pyroclastics. It essentially consists of saussuritized plagioclase fragments, altered andesitic rock fragments and possibly relict clinopyroxene now represented by epidote. Chlorite and epidote are also extensive throughout the matrix.

Angular fragments of the SEAL COVE Complex occur along the feldsparphyric black basalt fragments in the tuffs in the Milkboy's Cove area. The feldspar crystal tuffs described from the BURNT HEAD Formation are also found in this area.

The base of the formation is marked by fine-grained, bedded, reworked tuffs interbedded with coarser tuffaceous horizons containing vesicular and porphyritic green andesitic bombs. These bombs have chilled rims and are mineralogically and texturally similar to the interfingered lavas. Microscopically these bombs and lavas consist of completely saussuritized, relict plagioclase phenocrysts and partially resorbed, mottled-textured clinopyroxenes in a chloritized cryptocrystalline groundmass.

The reworked tuffs are graded, have well-developed flame structures (Plate 14) local slump and scour features and cross-bedding. Interbedded with the tuffs are silicified and sometimes oxidized extremely fine-grained volcanogenic sediments. Microscopically the tuffs consist of chloritized clinopyroxene and saussuritized plagioclase fragments and chips.

Air-fall tuff horizons consisting of angular andesite fragments (1/10 inch to 4 inches) in a carbonate and limy-tuffaceous matrix occur just west of Milkboy's Cove and also south of Lush's Bight.

Fine-grained, white, recrystallized, silicified and fossiliferous limestone is common in the lower parts of the sequence along the south coast. The limestone occurs both as distinctive limestone lenses up to 20 feet thick and as minor limestone horizons between flows and within pyroclastics.

The fossils have been tentatively identified by Dr. R.H. Flower of the New Mexico Bureau of Mines as indicating a possible Middle Ordovician age (Strong and Kean, 1972).

<u>Fossils</u>

Nautiloid Cephalopods (orthocones)

(Several) Conularid Spp.

? Leperditiid

Crinoid columnals

The abundant crinoid columnals are generally around 1.5 mm in diameter but may be quite large. The one specimen of ostracode Leperditia is c. 6 mm long, flattened and broken. Since muscle scars and eye tubercles have been obliterated, it was assigned by Flower to Leperditiidae on the general external morphology. The conularoids all appear to belong within the genus <u>conularid</u>.

The cephalopods are the most interesting and at least one of those examined by Dr. Flower is one of the rod-bearing members (Flower, 1964, p.113) of the family Baltoceratidae (Plate 15) which has a stratigraphic range of

Lower Canadian into the Wilderness Stage. However, the rod-members of this family have a shorter range, being sparingly developed in the Cassinian, and ranging through the Whiterock, Chazy and Wilderness Stages.

Agglomerate, massive and pillowed flows intermixed with reworked tuffs are more abundant higher in the sequence. The agglomerates are generally of two types which occur both together and separately. The first is a "bomb-agglomerate" (Plate 16) containing round to oval,generally vesicular and porphyritic,green andesitic bombs of the type described above. The second, equally abundant type, is a coarse pyroclastic containing numerous angular to subrounded fragments (<1 inch to 1 foot) of the above described creamy-white volcanics and of dark-green to black, feldsparphyric to non-porphyritic volcanic. This volcanic has an aphanitic groundmass and sometimes has chilled rims. Microscopically these dark-green volcanic fragments contain saussuritized plagioclase phenocrysts and microphenocrysts in a black cryptocrystalline matrix rich in chlorite. These feldsparphyric fragments increase towards the top of the sequence and are the same as massive flows and pyroclastic horizons on the west shore near Long Point.

Also in the vicinity of the Long Island Pluton, the agglomerate occasionally contains subrounded blocks of coarse-grained, feldspar-augite porphyritic gabbro of the same nature as the gabbro phase of the Long Island pluton. Also pyroxene and minor plagioclase crystal tuffs occur in this area. Microscopically these tuffs consist of crystals and crystal fragments of chloritized clinopyroxene and saussuritized plagioclase in a chloritized, cryptocrystalline tuffaceous matrix.

The intertongued and intercalated lava may be massive and pillowed. The lavas are andesitic and vary from very vesicular and porphyritic to essentially non-vesicular and non-porphyritic. The tops of the flows are often oxidized and hematitized, especially in the areas where there are limestone lenses.

2.2.15. Interpretation

The reworked tuffs were deposited on a gentle slope by gravity settling and by bottom currents. The air-fall pyroclastics indicate an emergence, but the presence of pillow-lava, reworked tuffs and limestone lenses probably indicate only a partial emergence and possibly an increase in volcanic activity.

The presence of the gabbroic blocks in the agglomerate possibly suggest that the magma source and emplacement of the gabbro phase of the LONG ISLAND Pluton was pre-deformation; whereas, the main intrusive phase occurred post-deformation.

2.3. Summary

For a more detailed discussion refer to the "interpretation" section at the end of the descriptions of each formation.

The sequence represents a submarine volcanic-clastic pile of island arc affinity that shows a decrease in water depth stratigraphically upward, i.e. with decrease in time (see Fig. 2.2).

The field relationship of the dykes, gabbro and pillowed basalts of the INTRUSIVE member at the base of the sequence suggests they are genetically related and represent the earliest phase of volcanic activity. This complex was then explosively brecciated (BRECCIA member) and reworked in a developing island arc environment. This brecciation may be related to the essentially uninterrupted and vast outpourings of pillowed basalts (UPPER and LOWER BASALT member) that now overlie and finger into the breccia. This must have occurred at depths less than 5 km since explosive submarine eruption of basalt is not possible at depths greater than this (McBirney, 1963) and in fact may be about 4 km since it is at this depth that vesicularity practically disappears (Moore, 1963, 1965) and in the LOWER BASALT member vesicularity is at a minimum.

After and partly contemporaneous with the dying stage of basaltic volcanism, there was an influx of pyroclastic material of andesitic derivation heralding the development of andesitic activity in a nearby explosive volcanic source area. This pyroclastic material was deposited mainly by gravity settling from debris-laden water and by turbidity currents. The material was probably derived from upslope deposits plus ejecta still in suspension from the original explosions ("primary-suspended" material). There was a minimum of strong bottom current activity at this stage.

Contemporaneous with the deposition of the material (PYROCLASTIC member) genetically related andesitic lavas were being erupted (PILLOW-ANDESITE member). These flows therefore have an intertonguing and interbedded relationship to the pyroclastics.

Continued volcanic activity resulted in deposition surpassing subsidence and compaction,thereby resulting in a shallow water environment. It is in this environment that the limestone and limestone breccias and cross-bedded greywackes of the PARSON'S POINT Formation developed, as did also the limestone lenses and air-fall tuffs of the LONG TICKLE Formation.

However, submergence must have occurred again to produce the pillow lavas, agglomerates and reworked tuffs of the LONG TICKLE Formation.

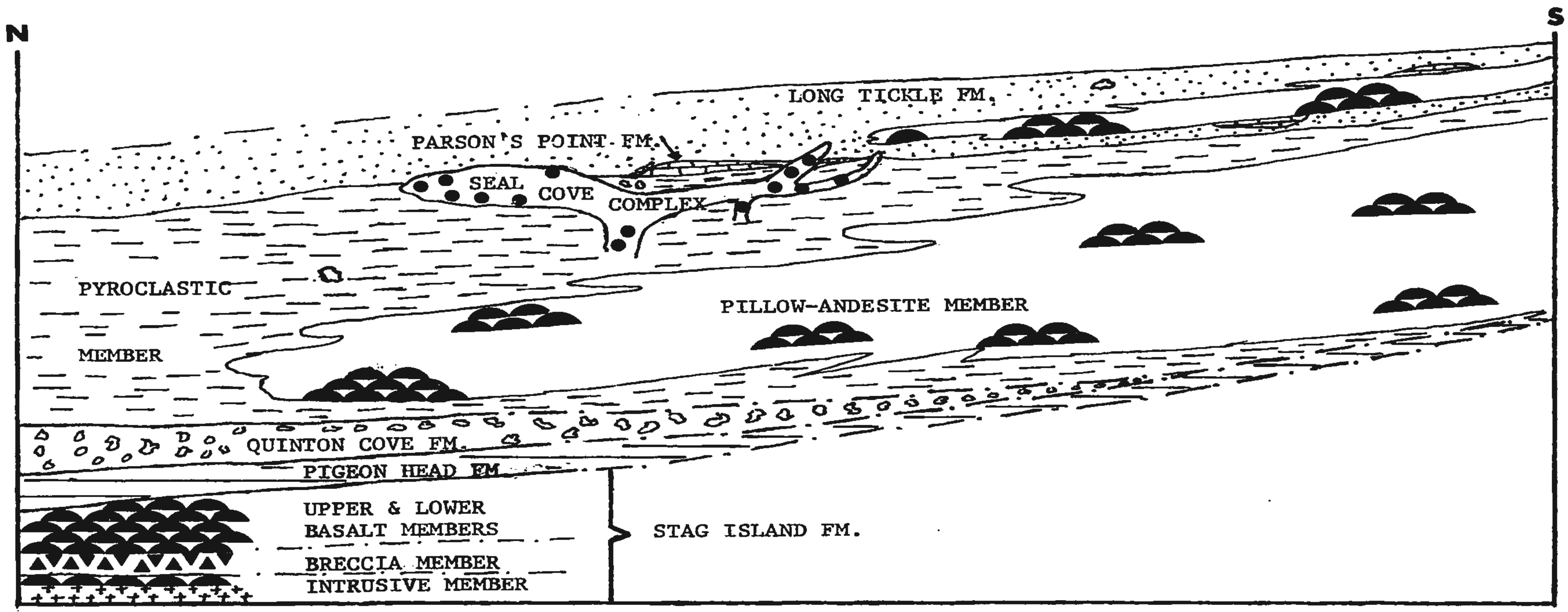


Figure 2.2. Schematic N-S section through Long Island, prior to folding, faulting and igneous intrusion. (Dashed lines represent inferred or projected geological contacts.)

3. INTRUSIVE IGNEOUS ROCKS

3.1. Introduction

Intrusive igneous rocks in the form of dykes, sills, small stocks, and plugs are abundant in the map area. They range from basic to acidic in composition and the dykes and sills show a considerable range in thickness from 1 foot to 150 feet. Generally the basic intrusions are concentrated in the lower parts of the succession; the granodioritic rock to the middle of the section and the common quartz-feldspar porphyry (Soda-Granite Porphyry, Espenshade, 1937) is common throughout the whole succession but with a higher concentration in the central portion near the granodiorite.

The intrusive sequence is discussed in the general order of decreasing age (Fig. 3.1). As previously discussed in Chapter 2, the Seal Cove Complex also represents an intrusive complex of very early age (penecontemporaneous); however, it is here regarded as part of the volcanic sequence and described in Chapter 2.

3.2. Dacitic Plugs, Dykes, Flows

These intrusions are cut by the quartz feldspar porphyries and also by dark green diabase dykes which are brecciated by the Long Island Pluton (see Fig. 3.1).

The plugs are generally small ($<$500 feet in diameter) and vary from massive, aphanitic to feldsparphyric with an aphanitic groundmass.

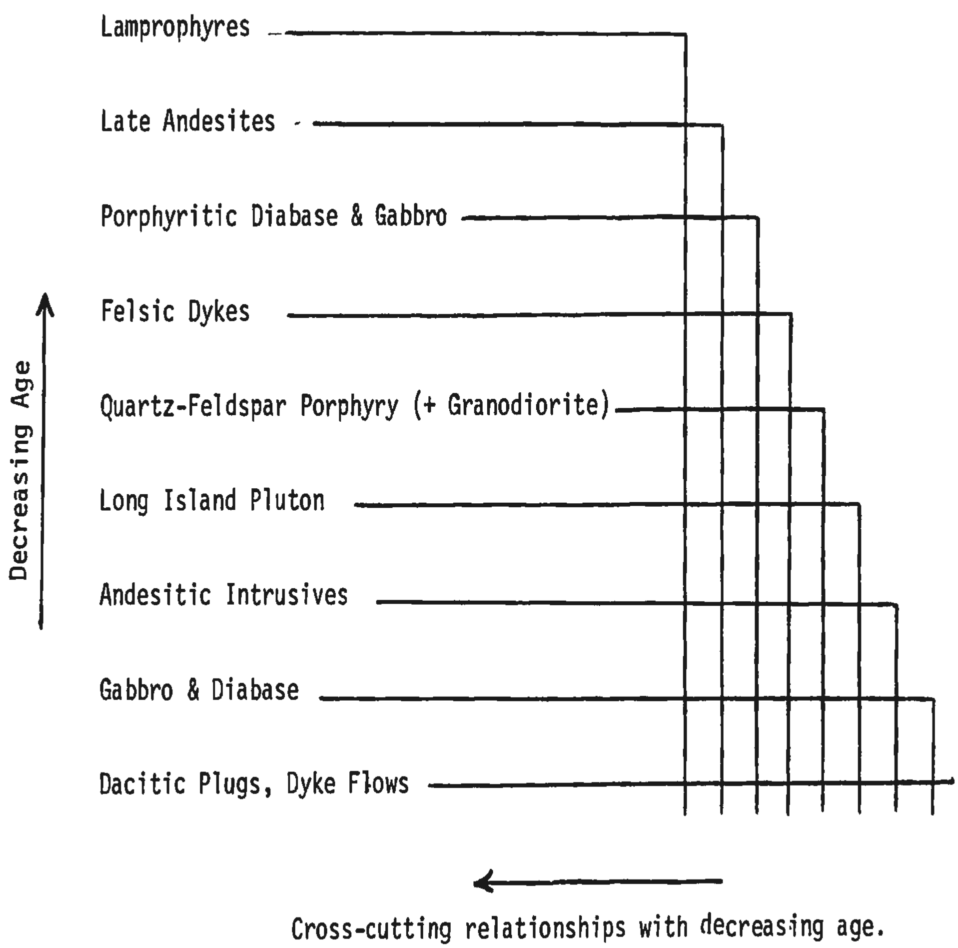


Figure 3.1. Schematic representation of observable and deduced age relationships between the main intrusive rocks in the Long Island area.

Dykes of this dacite occur in the Southern Head area as thick (up to 40 feet), grey to green, flow-banded, sometimes columnar-jointed bodies varying from feldsparphyric to non-porphyritic. This flow-banding and a flow-brecciation is well developed in the Doolan Folly area where the dacites are also extensively pyritized and faulted. It is the flow-banded, flow-brecciated dacites in the Doolan Folly area that gives the rocks a flow or lava appearance.

Microscopically (Plate 17) the rock consists of isolated phenocrysts and microphenocrysts of sericitized plagioclase ($\sim An_{25-30}$). There are also minor microphenocrysts of alkali feldspar and phenocrysts of partially resorbed quartz. Quartz also occurs as a primary groundmass mineral. The groundmass consists of a finely intergrown mesh of quartz and feldspar with minor opaques and patches of chlorite (? mafics). Secondary groundmass and vein quartz is also present. According to Moorehouse's classification (1959) these rocks are dacites.

3.3. Gabbro and Diabase

The gabbro and diabase represent plutonic and hypabyssal equivalents of one magma and can be traced into each other. Although they occur mainly in the Pigeon Head area, the gabbro can be traced in a SE direction to Indian Island where the largest of the gabbro bodies occur. The diabase occurs mainly as sills (5 feet - 100 feet) intruding the lower units of the PIGEON HEAD Formation and as minor isolated diabase dykes (1 foot - 5 feet) throughout the whole Long Island succession. These Pigeon Head diabase dykes are occasionally feldsparphyric and gradually grade into grey-green, medium to coarse grained gabbro.

Microscopically the rocks range from hypidiomorphic-granular to diabasic in texture. The plagioclases are of andesine composition ($\sim An_{40}$) and have rare normal zoning. They have undergone a turbid, moderate to extensive saussuritization. The augites are rarely twinned and most commonly altered to chlorite, particularly along cleavages. The coarse, extensively saussuritized gabbros sometimes have a myrmekitic intergrowth of quartz and deuterically altered plagioclase. There is also considerable secondary quartz and carbonate. Magnetite is common and often occurs in skeletal form. Minor groundmass alkali feldspar was noted in a few samples.

3.4. Andesitic Intrusives

Dark green, vesicular, sometimes porphyritic andesitic dykes and sills (up to 20 feet thick) are found sporadically throughout the pyroclastic and agglomeratic members of the QUINTON COVE and BURNT HEAD Formations. They are early in the intrusive sequence and are probably genetically related to the gabbroic and diabasic phase of intrusion and/or to the pillowed andesite member of the BURNT HEAD Formation.

Microscopically they consist of a felty-textured, fine-grained, altered groundmass rich in secondary calcite, chlorite and amoeboid quartz. There is possibly minor primary quartz in the groundmass also. Microlites and microphenocrysts of saussuritized (carbonate, epidote, sericite, etc.) andesine ($\sim An_{34}$) are common. There are also minor phenocrysts and microphenocrysts of chloritized and epidotized augite. Magnetite and sphene occur as accessories.

A 100 - 150 feet thick, columnar-jointed sill on Southern Head is texturally and mineralogically similar to these andesitic bodies and is therefore probably related to them.

3.5. Long Island Pluton

3.5.1. General Description

This semicircular stock, about 5000 feet in diameter, in the southwest tip of Long Island intrudes and metamorphoses the deformed pyroclastic rocks of the LONG TICKLE Formation, i.e. it is post-deformation in age, and on both the northern and southern contact there is an increase in metamorphic grade towards the pluton.

The southern contact shows an inward gradation from the regionally metamorphosed, lower greenschist facies basic pyroclastics to an amphibolitized inner contact aureole and country rock xenoliths. Microscopically this is reflected by an increase in the chloritization of the pyroclastic matrix and the basic fragments and crystals (Plate 18) as the contact is approached. Eventually actinolite-tremolite appears but is not extensive (Plate 19). The amphibolitized country rock and xenoliths consist of recrystallized, i.e. equidimensional hornfels - textured, green hornblende, quartz and albite (Plate 20). This hornfelsing does not obliterate the regional schistosity but often there is a poorly developed, incipient segregation banding of the hornblende and silica, thus strongly amplifying the amphibolite appearance.

The northern contact consists of c. 150 feet wide zone of highly deformed and recrystallized intermediate pyroclastics and agglomerates giving rise to distinct but discontinuous, lenticular bands or pods defined by the black flattened fragments and/or bombs in a white-weathering, grey matrix. The dark bands or pods are mainly chlorite and chloritized mafics. The larger pods may be augened by the grey matrix; however, the thin dark bands often augen crystal fragments.

The gray matrix is essentially recrystallized, equidimensional quartz and feldspar. Large, broken, strained, sericitized and quartz-replaced crystals of andesine occur throughout this matrix and are augened by the quartz-feldspar matrix and by stringers of green chlorite that define the schistosity (Plate 21).

The schistosity parallels the distinct banding defined by the mafic and silicic zones. The banding probably represents original bedding that has been modified by a flattening parallel or subparallel to the plane of the bedding. An alternative explanation of the banding is that it actually represents a composite fabric (Kennedy, pers. comm.), i.e., polyphase deformation, thereby suggesting an external source for these rocks. However, there is no microscopic or megascopic evidence for this. Also over a distance of 400 - 500 feet the highly deformed rocks can be traced into relatively undeformed rock of the same lithology, i.e. pyroclastics containing fragments and bombs of feldsparphyric lava in a cryptocrystalline, sometimes feldsparphyric matrix. It may be noted that similar feldsparphyric volcanic fragments are found in the LONG TICKLE Formation along the south coast of Long Island.

These contact rocks appear to represent regionally deformed rock with a near vertical to subvertical schistosity subparallel to the bedding (observable in other parts of Long Island). Superimposed effects of the thermal and pressure metamorphism of a forcefully injected pluton may possibly amplify the regional deformation with accompanying segregation of mafic and silicic minerals, similar to the amphibolitization noted on the southern contact.

The pluton itself represents a multiphase (5) intrusion. In general, the darker (i.e. more basic) rocks represent the older phases of intrusion. Each phase of the intrusion contains xenoliths of the earlier phase(s). This gives rise to complex intrusive-breccia relationships. There are also xenoliths of the amphibolitized country rock (pyroclastics and lava); grey, recrystallized PARSON'S POINT type limestone; and partically amphibolitized diabase dyke fragments. The fragment range from angular to rounded, may have a 'jig-saw' relationship and often have clear resorbtion textures along thin edges and fractures. The rounded appearance is often due to this resorbtion. The diorite fragments in the granodiorite matrix show the most distinct resorbtion textures.

The number of xenoliths decreases away from the contacts and the body in general becomes more homogeneous - being mainly of the granodiorite phase. The phases from oldest to youngest are discussed below.

3.5.2. Basic Phase

This phase does not have an intrusive relationship, occurring as xenoliths (1/10 inch - 4 inches) in all the later phases; however, the original intrusive phase may now be represented by a twenty foot zone of this near the southern contact. Microscopically, the rock consists of a pleochroic, green-brown hornblende pseudomorphic after clinopyroxene which is sometimes preserved in the cores of the hornblende. Chlorite and actinolite-tremolite are also common constituents. Much of the chlorite is an alteration product of the hornblende. The texture is ophitic to subophitic with occasionally poikilitically intergrown in the hornblende (pyroxene originally) a completely altered (chlorite, ? antigorite) mineral with olivine outline, and fracture. Magnetite is also concentrated along the rim and fractures of this mineral (Plate 22), and it is taken to be olivine.

The plagioclase ($\sim An_{40}$) constitutes less than twenty modal percentage of the rock and is usually saussuritized. Magnetite is disseminated throughout the rock. Minor quartz (? secondary) may occur in the interstices. Secondary calcite is common.

3.5.3. Dioritic Phase

This occurs as a definite intrusive phase into the earlier basic rocks and is intruded by the later phases. It is a medium-grained, grey rock rich in hornblende and plagioclase with common quartz. Basic pegmatite patches with hornblende up to 2 inches long are common.

The texture is generally hypidiomorphic-granular. Extensively sericitized twinned and zoned plagioclase makesup 30 - 40% of the rock. Green, subhedral hornblende is the next most common mineral and is quite often altered to chlorite, especially along cleavages. Anhedral quartz occurs in the interstices and ranges from 2 to ~10%. Minor brown biotite and rare orthoclase also occur. Opaque iron oxides occur disseminated throughout the rock.

3.5.4. Granodioritic Phase

This phase differs from the dioritic phase by possessing a smaller percentage of hornblende, i.e., lighter in color.

Subhedral to euhedral, sericitized, andesine ($\sim An_{40}$) makes up approximately 40% of the rock. Green chloritized hornblende, quartz, orthoclase and accessory biotite and minor apatite occur in that order of abundance.

3.5.5. Aplitic Phases (2)

There are at least two sets of aplite dykes or veinlets several inches thick that crisscross all phases of the plutons. Despite their general crisscrossing pattern they have a prevalent 40 - 60^{o} W strike.

They weather a pinkish-white and generally have aplitic texture, however occasionally distinct feldspar, biotite and quartz phenocrysts are recognizable.

Microscopically the rock consists of microphenocrysts of quartz, alkali feldspar and sericitized, twinned and zoned euhedral plagioclase and minor brown biotite in a fine-grained equidimensional mesh of quartz and feldspar.

The quartz-feldspar porphyry dykes (see below) that are so abundant in this area cut the thick pluton in a N 40 - 50^{0} W direction. A three feet thick lamprophyre dyke also cuts the pluton in the same general direction.

3.5.6. Chemistry

Chemical analyses of five samples representing the basic, gabbroic (dioritic) and granodioritic phases from the Long Island Pluton are given in Table A-II, Appendix II. This pluton, as does other stocks associated with volcanic assemblages throughout the Notre Dame Bay area, has an overall calc-alkaline affinity (Kean, 1971) (see Figure A-II, Appendix II).

3.6. Quartz-Feldspar Porphyry

3.6.1. Dykes

These porphyritic dykes and sills, called soda-granite porphyry by Espenshade (1937), are common throughout Long Island, but are concentrated in the northern part around the granodioritic plugs (Section 3.6.2.). They range in width from 2 feet to 150 feet. They also occur as multiple dykes which generally have parallel contacts but may occasionally have cross-cutting relationships.

In hand specimen, they are characterized by numerous large phenocrysts of plagioclase, less commonly quartz, and often biotite in a grey aphanitic groundmass. The second phase of a multiple dyke is generally of the same mineralogy and texture as the first; however, as a rule the second phase contains more biotite, and occasionally, as in the Doolan Folly area, the first phase contains K-feldspar. These dykes in some cases contain fine-grained basic inclusions.

Microscopically the dykes have a seriate porphyritic texture and felsophyric matrix. The quartz phenocrysts are rounded and partially resorbed. The euhedral, normally zoned, turbid and sericitized plagioclase phenocrysts fall within the oligoclase-andesine range (averaging $\sim An_{35}$). There is minor anhedral alkali feldspar (orthoclase) and green-brown chloritized hornblende. However, biotite is the principal mafic mineral, and it often has a ragged appearance and chlorite alteration. The groundmass consists of a fine-grained, dense intergrowth of quartz, feldspar, occasional biotite and occasionally extensive hornblende. Pyrite and apatite occur as accessories.

3.6.2. Stocks

In the Cutwell Arm - Red Point area there are a number of small stock-like bodies ($<$ 1/4 square mile) that may represent the cupolas of a larger unexposed body beneath. These stocks are generally medium-grained, equigranular, pink to grey-white, granodiorite bodies.

The quartz-feldspar porphyry dykes described above were not seen cutting these bodies. This, plus the fact these bodies are mineralogically similar to the dykes, suggest a genetic relationship between them.

Microscopically they are hypidiomorphic granular and contain subhedral and twinned, sericitized oligoclase, and partially resorbed, rounded quartz as the principal minerals. Biotite where present, is extensively chloritized. Orthoclase is also present, but is subordinate to the other minerals.

3.7. Minor Intrusions

3.7.1. Early Basaltic Dykes

These fine-grained, grey-green dykes (c. 2 feet thick) are found in two isolated occurrences cutting the andesitic dykes (section 3.4.) in the Seal Island Tickle area.

Microscopically they consist of highly altered, slender plagioclase laths in a devitrified, altered and recrystallized brown glassy matrix. Anomalous-blue chlorite, carbonate and minor secondary quartz occur in the matrix.

Megascopically and microscopically these dykes resemble the LOWER BASALT member of the STAG ISLAND Formation and may genetically represent the late intrusive products of the magma.

3.7.2. Late Felsic Dykes

These dykes (< 1/2 foot to 5 feet) are found only on the northern islands. They often occur in association with, but cross-cutting the quartz-feldspar porphyry dykes described above.

These dykes are buff-colored, aphanitic and generally non-porphyritic except for rare quartz phenocrysts. Microscopically they consist of a cryptocrystalline groundmass rich in quartz and feldspar and extensive carbonate. Occasionally, there are a few microphenocrysts of completely altered unidentifiable plagioclase. Quartz may also be present as anhedral phenocrysts.

3.7.3. Porphyritic Diabase and Gabbro

These diabase dykes and associated small fine-grained gabbro plugs occur cross-cutting the quartz-feldspar porphyry dykes on the northern islands. They are fine-grained, massive, black, vesicular dykes with minor large plagioclase phenocrysts.

The texture is intergranular with brown, partially chloritized (along cleavages and margins) augites occupying the interstices between the randomly oriented, apparently unaltered, plagioclase laths (Plate 23). Magnetite is disseminated throughout the rock. Secondary calcite occurs in the groundmass.

One chemical analysis of the gabbro phase is presented in Table A-II Appendix II. The rock has a silica-undersaturated composition, i.e., it is nepheline normative.

3.7.4. Late Andesites

The true age of these dykes could not be established; however, they do cut the quartz-feldspar porphyries. They occur mainly in the Wild Bight area and to a lesser degree about the south shore. They are generally vertical to subvertical and N-S trending and range from 1 to 5 feet in thickness. They commonly form a dyke swarm of five or more. They are fine-grained, green, vesicular, andesitic to almost dacitic rocks.

Microscopically they are a microcrystalline, felty-textured, interwoven mesh of altered plagioclase, and secondary calcite. The rock was probably originally of andesitic-dacitic composition.

3.7.5. Lamprophyre Dykes

Two lamprophyre dykes were noted in the map area - a three foot wide NE-SW trending one cutting the Long Island Pluton and a two foot wide N-S trending one cutting the pillow lavas in the Stag Island area. Espenshade (1937) named these dykes as the latest in the intrusive sequence for the Pilleys Island Map area. Their distribution seems to be more or less sporadic and not confined to any particular locus. A lamprophyre dyke from the Sullivan Pond area, Springdale, has been dated by Brinex (H.R.Peters, pers. comm.) using K/Ar as 438 ± 12 m.y.; likewise a trap lamprophyre dyke from Pilleys Island has been dated as 362 ± 14 m.y. Wanless et al. (1964) dated lamprophyre dykes to the east of the map area as 144 ± 12 m.y.

The lamprophyres are dark greenish grey to black in color and generally dip almost vertical with a jointing normal to their trend. Because of their resistance to weathering and erosion they stand out over the surrounding rocks.

Microscopically they consist of stubby euhedral to subhedral groundmass augite and a few augite microphenocrysts that often are chloritized. The matrix is essentially a mesostasis of blue chlorite, carbonate and quartz. There is also grey-green, fibrolamellar, lath-shaped chlorite.

Secondary carbonate and to a lesser extent quartz, also occur as cavity, fracture, and vesicle fillings. Magnetite and apatite occur as accessories.

3.8. Diatremes

There are two prominent diatremes on Long Island and they appear to be of different ages.

3.8.1. Older Diatreme

This older and smaller diatreme is found on Southern Head. Here a 2 - 3 feet wide breccia zone stands vertically in a 150 feet high cliff. It contains fragments of all the surrounding rock, namely, pyroclastics, black shales, green lava or dyke rock and clastic fragments. The fragments are generally subangular or subrounded and some have a 'jig-saw' relationship. They range in size from 1/10 inch to $>$1 foot. The matrix is generally a finer and chloritized equivalent of the fragments but quartz sometimes forms the matrix.

Near the top of the cliff poor exposure, faulting and inaccessibility makes relationships obscure, however, the diatreme is not seen cutting the overlying columnar jointed sill (Section 3.4.) anywhere.

3.8.2. Younger Diatreme

The larger and younger of the two is found on Western Head. This diatreme has a mushroom shaped vertical section and a circular top or cross-section (c. 100 - 150 feet radius). It contains angular to sub-rounded fragments showing a 'jig-saw' relationship. The fragments range from a few inches to five or six feet in size (Plate 24). The fragments are from the surrounding agglomerate, tuff, ash, volcanics and quartz feldspar porphyry. They show no sorting and a quartz feldspar porphyry dyke can be traced from the country rock into the diatreme where it is brecciated and displaced and then back into the country rock. However the contact of the diatreme with the country rock is knife-sharp. The matrix is white quartz.

3.8.3. Discussion

The older and smaller diatreme or breccia located on Southern Head may actually be a faulting or shearing effect (cf. Farmin, 1954; Coe, 1966; Bryant, 1968). This is suggested by the fact that the matrix is a fine-grained equivalent of the larger fragments and by the linear shape of the breccia zone and is supported by the extensive faulting in this area.

Such a tectonic breccia zone would be favourable for the migration and localization of secondary fluids and thus may result in local zones of silicified (quartz) matrix.

The Western Head diatreme, however, is no doubt of igneous explosive origin. The mushroom-shape, razor-sharp contacts, unsheared nature and igneous matrix is definite proof of this. As described in section 3.8.2., this diatreme contains quartz feldspar porphyry fragments and therefore is of a relatively young age in the sequence.

3.9. Pre-Deformation Ultramafics

On Pigeon Island, approximately half-way along the south coast of Long Island, there is an occurrence of a highly-sheared and highly weathered recrystallized carbonate rock. Because of its insular occurrence and the shearing and faulting in this area, its relationship to the surrounding andesitic pillow lavas cannot be fully established; however, its foreign nature may suggest intrusion.

Occurring within this grey, recrystallized, magnesite-rich (determined by XRD) rock are occasional, subrounded (up to 1 foot) blocks of fine-grained, black or dark green, chloritized nature.

Microscopically the rock consists of magnesite with disseminated magnetite. Actinolite-tremolite was also noted disseminated throughout the rocks and concentrated along fractures. There were also zones of quartz-albite masked by carbonate. Veins of magnesite also cut the host rock.

Trace element chemistry shows that Ni and Cr read off the calibrated scale of the x-ray fluorescent unit, i.e. $>$1000 ppm, while Zr, Sr and Rb were not detected. The presence of magnetite, magnesite and the chemistry of the body suggest that it may have been an ultramafic plug.

4. STRUCTURE

4.1. Introduction

The Long Island area is underlain by an essentially south-dipping, south-facing sequence of volcanic rocks. Small-scale, open synclinal-anticlinal folds are sporadically developed throughout the sequence, particularly in the Lush's Bight and Wild Bight areas and to a lesser extent along the south coast. A locally developed cleavage (S_1) is associated with these folds, and cleavage-bedding intersections and angular relationships suggest that the sequence is now occupying the south limb of a westerly plunging anticline. Minor crenulations and kink bands refold this S_1 cleavage; however, there is evidence that these later features are not related to any regionally developed second-phase deformation.

Small faults are common throughout the southern half of the island, and the south coast is interpreted to be bound by a large E-W fault, the Long Tickle Fault. Structural cross-sections are given in Figure 4.3.

4.2. Fabrics

A penetrative cleavage or schistosity having a general E-W, subvertical to vertical attitude is inhomogeneously and generally poorly developed in the Long Island area. The inhomogeneity of the deformation is reflected by the occurrence of adjacent zones of weakly deformed rock and strongly flattened and penetratively cleaved rocks. The cleavage is generally more strongly developed in the less competent coarse tuffaceous zones than in the fine-grained, thin-bedded, massive tuffs and the massive pillow lavas. Blocks and bombs in the coarse pyroclastics, isolated-pillows and some massive pillows are sometimes flattened in the plane of cleavage, thereby defining an S-fabric (S_1, Flinn, 1965). Some pillows and fragments also show a minor elongation in the plane of cleavage, therefore, the fabric is actually a L-S fabric with S>L (Flinn, 1965). Although reliable "strain gauges" are usually lacking, the above suggest that the strain has a K value of about 1 (Flinn, 1962), i.e. it approximates to plane strain.

Microscopically the cleavage in the fine-grained tuffs is recognized with difficulty as a fine-grained chlorite (actinolite-tremolite) banding.

In the southern part of Long Island (particularly the Wild Bight and the South coast areas) extreme shearing and faulting have given rise to shear zones with a shear-cleavage. This shear-cleavage often parallels or subparallels the regionally developed penetrative cleavage (S_1), thereby intensifying or obscuring the S_1 cleavage.

4.3. Folds

4.3.1. Slump Folds

Preconsolidation slumps are common and sporadically developed throughout the sequence. In all cases observed these folds have no genetically related cleavage, the cleavage, if present, being generally non axial planar, and they are disharmonic and chaotic with widely divergent fold axes, and are generally associated with slump-breccias and other soft sediment deformation features.

The two areas of strongest development are in the Wild Bight area (Plate 11) and along the south side of Lush's Bight Village. In the Wild Bight area, the slump-folded tuffs are interbedded and interfingered by numerous porphyritic pillowed andesites, the flow and emplacement of which may have possibly triggered the slumping. The Lush's Bight area represents a relatively shallow water environment in which semi-consolidated limestones were brecciated by tectonic activities such as earthquakes, tremors, explosions, etc. These same mechanisms may have been partially responsible for the slump folding and slump brecciation in this area.

4.3.2. Tectonic Folds

4.3.2.1. Local Folds

Tectonic folds are rare, even in interbedded structurally inhomogeneous rocks, probably because of the controlling influence of the thick competent piles of lava. However, a fold as shown in figure 4.1. plunging 45^{0} west is found on Red Point, and folds as depicted in figure 4.2. are common in the Wild Bight area. These open synclinal - anticlinal flexure type folds (Figure 4.2.) have an east or west plunge $\leq 45^{0}$ and are of the first order, i.e., they do not fold the regional penetrative cleavage (S_1) and are interpreted from the cleavage bedding relationships to be genetically related to the regional (S_1) fabric.

Similar small scale synclinal - anticlinal folds are developed along the south shore of Long Island. Genetically related larger scale folds of this type are developed in the Lush's Bight area, the Southern Head area and along the south shore.

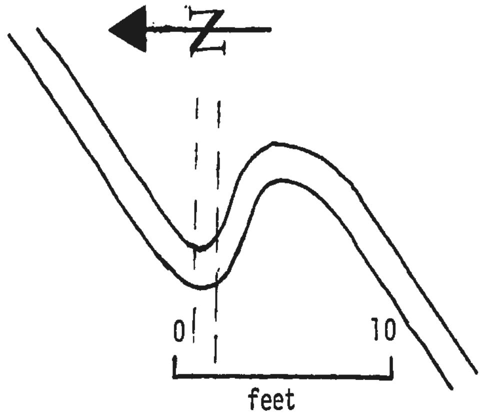


Figure 4.1. Fold noted near Red Point, west coast of Long Island.

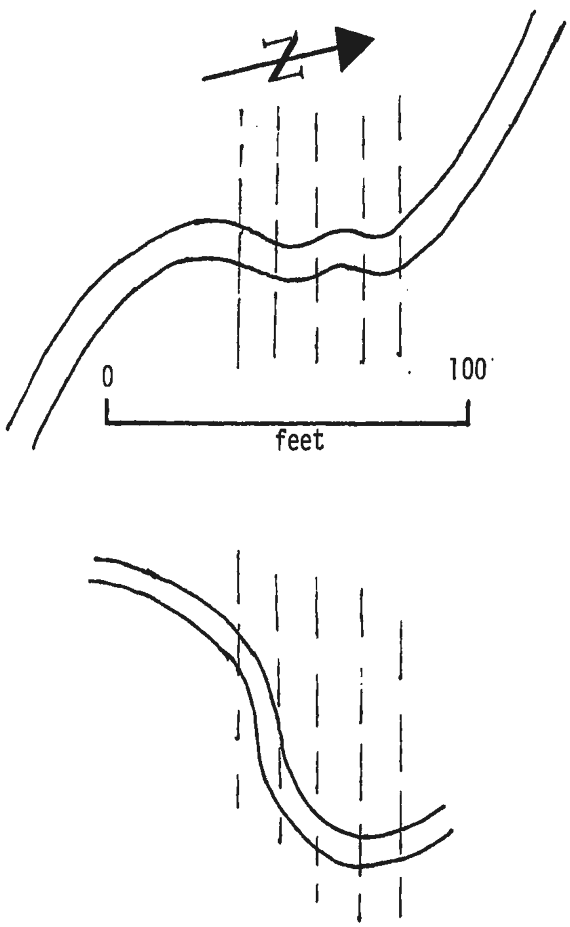


Figure 4.2. Typical folds of the Wild Bight area, Long Island. Dashed lines represent cleavage traces.

4.3.2.2. Regional Folds

As stated above, the Long Island area consists essentially of a south-facing, south-dipping volcanic pile with no repetition by folding, except by the minor local folds discussed above. This is deduced from sedimentary and pillow tops and consistent cleavage - bedding relationships. The cleavage - bedding intersections indicate that a major fold plunges moderately W to NW and the angular relationships and fold-types of figure 4.1. suggest that the succession is on the south limb of a moderately tight anticline, the wavelength of which must be in the order of ten miles. As previously discussed in Section 2.2.2., the questionable reversal in stratigraphic "tops" (i.e. NE facing) near the base of the BRECCIA member of the STAG ISLAND Formation and the occurrence of the LOWER BASALT member on the DUCK ISLANDS, may actually mark the north limb of the anticline.

4.3.2.3. Kink Bands

Minor subhorizontal, E-W trending kink bands, folding or kinking the S_1 cleavage and the shear-cleavages, are developed in the highly sheared fault zones of the Wild Bight area. Because of their spatial relationships to these fault and shear zones, these kinks are interpreted to be genetically related to the faulting and shearing. Their subhorizontal axes, as does that of the rare slickensides associated with faulting, suggests that σ_1 (maximum stress) was subvertical during faulting.

Minor small scale crenulation of the S_1 fabric was also noted near the southern contact of the Long Island Pluton. These crenulations are interpreted to be a result of the forceful intrusion of the pluton.

4.4. Faults

4.4.1. NW and NE Fault Systems

There are two prominent sets of faults marked by strong lineaments in the Long Island map area, a NE-SW set and a NW-SE set making an acute angle intersection. This may be suggestive of a conjugate set of faults. Rarely can any major displacement be mapped; however, minor dextral displacements of a few inches to tens of feet (20 feet - 30 feet) are often mappable on the NE-trending set. In the Stag Island area there is a mappable displacement of four hundred feet on the NE-trending set.

These post-folding faults have a subvertical, oblique-slip movement. Rare slickensides on the NE-trending set plunge 50^{o}SW in a subvertical plane.

4.4.2. East - West Faults

East-west faults - lineaments are subordinate in number or size to the NW and NE fault system. One such E-W fault gives an horizontal dextral displacement of c. 2,000 feet between the sulphide block zone near the base of the BRECCIA member of the STAG ISLAND Formation on Little Stag and Crow Islands.

A major E-W lineament forms Long Island Tickle. This lineament was first referred to as a fault by Strong (1972). He suggested it was one of a system of block faults that could be employed to explain and tie together the

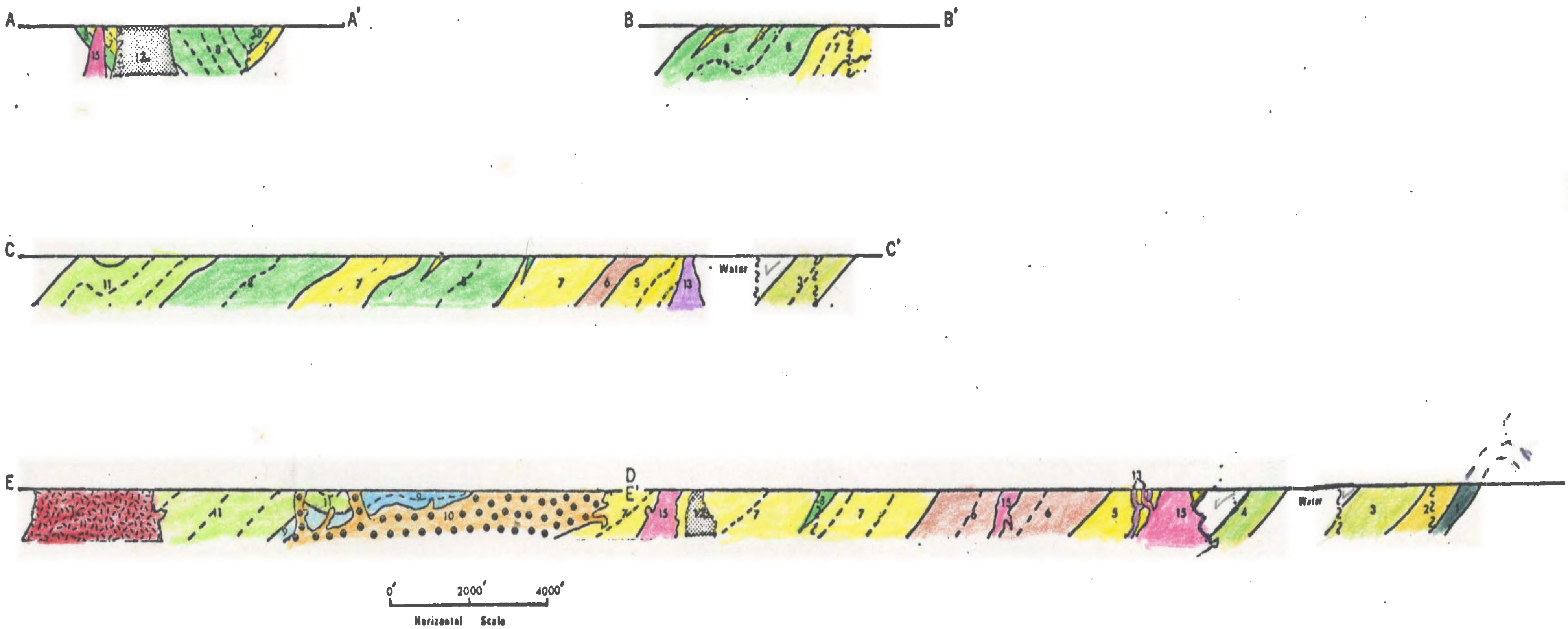


Figure 4.3. Structural cross-sections through Long Island. 1 - INTRUSIVE member; 2 - BRECCIA member; 3 - LOWER BASALT member; 4 - UPPER BASALT member; 5 - PIGEON HEAD formation; 6 - QUINTON COVE formation; 7 - PYROCLASTIC member; 8 - PILLOW-ANDESITE member; 9 - PARSON'S POINT formation; 10 - SEAL COVE COMPLEX; 11 - LONG TICKLE formation.

isolated occurrence of different stratigraphic levels of ophiolites in the Pilley's Island - Long Island area.

This lineament separates strikingly different lithologies - "sheeted dykes" and hornblende gabbros on the south (Pilley's and Brighton Islands) and tuffs, agglomerate, limestone and flows on the north (LONG TICKLE Formation), is marked by extensive shearing, fracturing, faulting, rotation of strikes, minor folds, rare slickensides, high degree of alteration and steep cliffs. From this evidence it is reasonable to assume that the lineament represents a major fault and that the "Long Island volcanics" (CUTWELL GROUP) could indeed be faulted against "oceanic" crust (Strong, 1972).

The relationship of the E-W faults and lineaments to the NW and NE - trending systems is not well established, but they seem to be cutting the NW, NE faults and therefore younger.

4.5. Age of Deformation

It has generally been accepted that the main deformation in the Lush's Bight Group took place in middle or late Ordovician times. This conclusion is based on the fact that near King's Point gently folded red beds tentatively palaeomagnetically correlated (Neale, in prep.) with the Silurian Springdale Group, unconformably overlie steeply dipping and cleaved Lush's Bight Basalts (MacLean, 1947; Neale and Nash, 1963).

However, most stratigraphic evidence from the Central Mobile Belt shows no great structural or stratigraphic break between Ordovician and Silurian rocks, but rather a mild Silurian transgression with a continuous record of deposition from the medial Ordovician to early Silurian times (Williams, 1969;

Horne & Helwig, 1969). The absence of Silurian rocks north of the Luke's Arm Fault (Lobster Cove Fault) is thus a reflection of the exposure of generally older rocks from deeper structural levels (Horne and Helwig, 1969). Marten (1971) therefore suggested a post-Silurian, probably Devonian age for the deformation in the Lush's Bight Group and proposed a decrease in the intensity of deformation up the succession, i.e., the less deformed rocks occupy a higher structural level.

5. PETROLOGY

5.1. Introduction

This chapter deals only with the extrusive rocks, with the exception of the INTRUSIVE member of the STAG ISLAND Formation. The petrography of the intrusive rocks is dealt with in Chapter 3, and of the pyroclastic rocks in Chapter 2. Table 5.1 gives a summary of both the igneous and metamorphic mineralogy of each formation discussed below. Table 5.1 (p. 85) gives the mineralogical basis for defining and distinguishing basalt and andesite.

5.2. Petrography

5.2.1. STAG ISLAND Formation

INTRUSIVE member: The fine-grained, dark green diabase dykes, screens and pillowed basalts all have similar mineralogy and equigranular texture. The original clinopyroxenes have been completely altered to chlorite, epidote and/or fibrous actinolite-tremolite. No original plagioclase can be recognized in these fine-grained varieties; however, the medium-grained dykes and screens are rich in An_{45} plagioclase (up to 40%) which has been moderately saussuritized. Fibrous and granular green chlorite occurs as replacement of pyroxene.

Quartz and chlorite occur in vesicles and often there is extensive secondary amoeboid quartz in the groundmass. Extensively silicified basaltic pillows often have a dacitic appearance in hand specimen.

Minor opaque minerals and secondary calcite are also present.

LOWER BASALT member: The bulk of the pale grey-green pillows and pillow breccias of this member are characterized by a devitrified glassy matrix from rim to core. The glass has a devitrified texture, is generally brown or grey in color and is often rich in chlorite and/or masked by secondary carbonate, and generally contains moderately to extensively saussuritized, quenched-textured (skeletal) microlites of plagioclase (Plate 25). Minor microphenocrysts of saussuritized and carbonated plagioclase, chlorite replacements of olivine and epidotized clinopyroxene (Plate 26) sporadically occur. Phases or zones of the flows are coarsely vitrophyric with variable proportions of chloritized and epidotized clinopyroxene, chloritized and (?) serpentinitized olivine and extensively saussuritized plagioclase. The plagioclase phenocrysts and microphenocrysts are locally replaced and veined by albite (Plate 27).

Iron oxides occur as disseminations. Secondary carbonate and epidote are common as vein and vug material. Calcite also occurs as megascopic veins. Secondary quartz is also present in some cases.

The rare crystalline phases consist of fine-grained, felty-textured, equigranular epidotized and chloritized pyroxene and saussuritized plagioclase.

An estimated average range of the original modal mineral content is as follows: Plagioclase (phenocrysts, microphenocrysts, microlites) 5-50%

Mafics (Mainly chloritized cpx) 0 - 15%

Opaques 1 - 3%

Matrix 15 - 95%

The petrography suggests the rapid eruption of a basaltic magma containing phenocrysts of mainly plagioclase, less clinopyroxene and less olivine at or near liquidus temperatures of about 1150°C (cf. Tilley, Yoder and Schairer, 1964-65, 1965-66). Upon eruption, rapid cooling permitted only the crystallization of plagioclase (microlites) and occasionally groundmass clinopyroxene.

UPPER BASALT member: These rocks are equigranular, diabasic-textured with groundmass plagioclase and epidotized and chloritized clinopyroxene. There are also rare glomeroporphyritic patches of plagioclase and rare clinopyroxene microphenocrysts.

The groundmass plagioclase displays clear quench textures, e.g. skeletal, and are of generally albite-oligoclase composition; however, some determinations also give sodic andesine composition. The vein-like nature of some groundmass plagioclase suggests an albitization effect. An original calcic plagioclase is also suggested by the occasional epidote grains and patches throughout and in the cores of the albitic plagioclases. The plagioclase crystals are generally fresh and clear, apart from these isolated epidote patches.

Iron oxides and minor sphene also occur in the groundmass. Minor quartz veins were noted, as were microscopic and megascopic epidote veins. Calcite, however,is not common.

As estimated original average modal composition is as follows:

Plagioclase (phenocrysts and microphenocrysts)	- 12%
Clinopyroxene	- 5%
Matrix (microlites and alteration products)	- 80%

Opaques	- 1%
Accessories	- 2%

5.2.2. BURNT HEAD Formation

PILLOW-ANDESITE member: The bulk of this member, i.e. from its base to very near its top, is petrographically homogeneous and varies randomly in the degree of alteration.

The lavas are generally seriate feldsparphyric with an intersertal texture (Plate 28). The plagioclase phenocrysts are of average andesine composition (An_{40-50}), in some cases showing poorly developed normal zoning and vary from moderately to completely saussuritized. The plagioclase microphenocrysts ($<$0.02 inches) and groundmass microlites are also of andesine composition and vary from moderately saussuritized to fresh with a turbid and dusty appearance. One sample contained quartz phenocrysts.

The groundmass, besides containing plagioclase microlites, is black and fine-grained to cryptocrystalline. The cryptocrystalline-subopaque nature often seems to be a result of extensive microcrystalline chlorite (original glass?). It also contains disseminated iron oxides, minor epidote grains and patches, carbonate patches and veins, and rare secondary quartz.

Some specimens are completely carbonated and contain sericite. Chlorite and quartz occur in vesicles and calcite veining is extensive.

The lavas near the top of the member contain microphenocrysts of clinopyroxene (augite) in addition to the plagioclase. The augites are in some cases fairly fresh but are generally chloritized and epidotized.

The groundmass consists of chloritized and epidotized clinopyroxene, turbid plagioclase and disseminated iron oxides. The chloritization of the groundmass varies from moderate to extensive, resulting in a light to dark green color.

Secondary quartz is common in the groundmass and also in vesicles with chlorite.

An estimated range of mineral composition is as follows:

Plagioclase (Phenocrysts, microphenocrysts, microlites)	- 10 - 60%
Clinopyroxene	- 0 - 5%
Opaques	- 2%
Accessories	- 5%

5.2.3. LONG TICKLE Formation

This is also a feldsparphyric andesite. The seriate=textured saussuritized plagioclases are of andesine composition. There is also minor groundmass and microphenocrystic clinopyroxene.

The groundmass is fine-grained to cryptocrystalline containing chlorite, epidote, carbonate and disseminated iron oxides.

Calcite also occurs extensively in fractures, cracks and vesicles.

5.2.4. Discussion

A summary of the igneous and metamorphic mineralization of each formation is given in Table 5.1. below.

Megascopically the lavas were divided into basalts and andesites by texture and color. The highly porphyritic nature and the absence of a predominate glassy matrix in the andesites appears to be the main textural difference between these groups. However, the basalts contain minor olivine and more clinopyroxene than do the andesites. Plagioclase is the dominant mineral in both, occurring as phenocrysts, microphenocrysts and in the groundmass; however, there is less evidence of albitization in the andesites although they are strongly saussuritized.

The present mineral assemblage is characteristic of the lower greenschist metamorphic facies.

TABLE 5.1.

Summary of the Igneous and Metamorphic Mineralogy of Extrusive Rocks of Long Island.

Formation	Original Igneous Mineralogy		Present Metamorphic Mineralogy
	Phenocrysts (microphenocrysts) (in order of abundance)	Groundmass	
STAG ISLAND			
(i) INTRUSIVE member	--	clinopyroxene, plagioclase (~An_{45}), opaques	chlorite, epidote, actinolite-tremolite, calcite.
(ii) LOWER BASALT member	Plagioclase Clinopyroxene Olivine	glass, plagioclase microlites, opaques	chlorite, epidote, (?)serpentine, calcite, albite
(iii) UPPER BASALT member	Plagioclase (clinopyroxene)	plagioclase, clinopyroxene opaques, sphene	chlorite epidote calcite
BURNT HEAD	Plagioclase Minor clinopyroxene	plagioclase microlites, opaques	chlorite, epidote, calcite
LONG TICKLE	Plagioclase Minor clinopyroxene	plagioclase, (minor) clinopyroxene opaques	chlorite epidote calcite

5.3. Petrochemistry

5.3.1. Introduction

Approximately three hundred specimens of lavas and flows were collected. These samples were representative of the sampled area and an attempt was made to avoid collecting altered, sheared and amygdaloidal samples so as to keep contamination to a minimum.

Sixty representative samples were selected for analysis, with the exclusion of any showing strong petrographic evidence of alteration. These sixty specimens were then analysed for trace elements (Rb, Sr, Zr, Ba, Ni, Cr, Cu, Zn, Co) and then plotted against Sr (Figure 5.1.). Sr was chosen as the abcissa because it had a wide range of concentration (i.e. to spread the data out) and not on any petrological basis.

The twenty-nine specimens showing the least scatter were then selected for major element analysis (SiO_2, Al_2O_3, TiO_2, CaO, MgO, Na_2O, K_2O, MnO, P_2O_5, FeO, Fe_2O_3). These data, along with their C.I.P.W. norms, are presented in Table 5.2. Adjustments were made for oxidation (calculate Fe_3 with Fe_2) and hydration, i.e. loss on ignition, Table 5.2. (recalculate totals to 100%) (Irving and Barager, 1971) in calculating the norms and plotting diagrams. The twenty-nine analysed samples were plotted on all diagrams except Figures 5.6 and 5.8. See Figure 5.2 for sample locations.

5.3.2. Chemistry

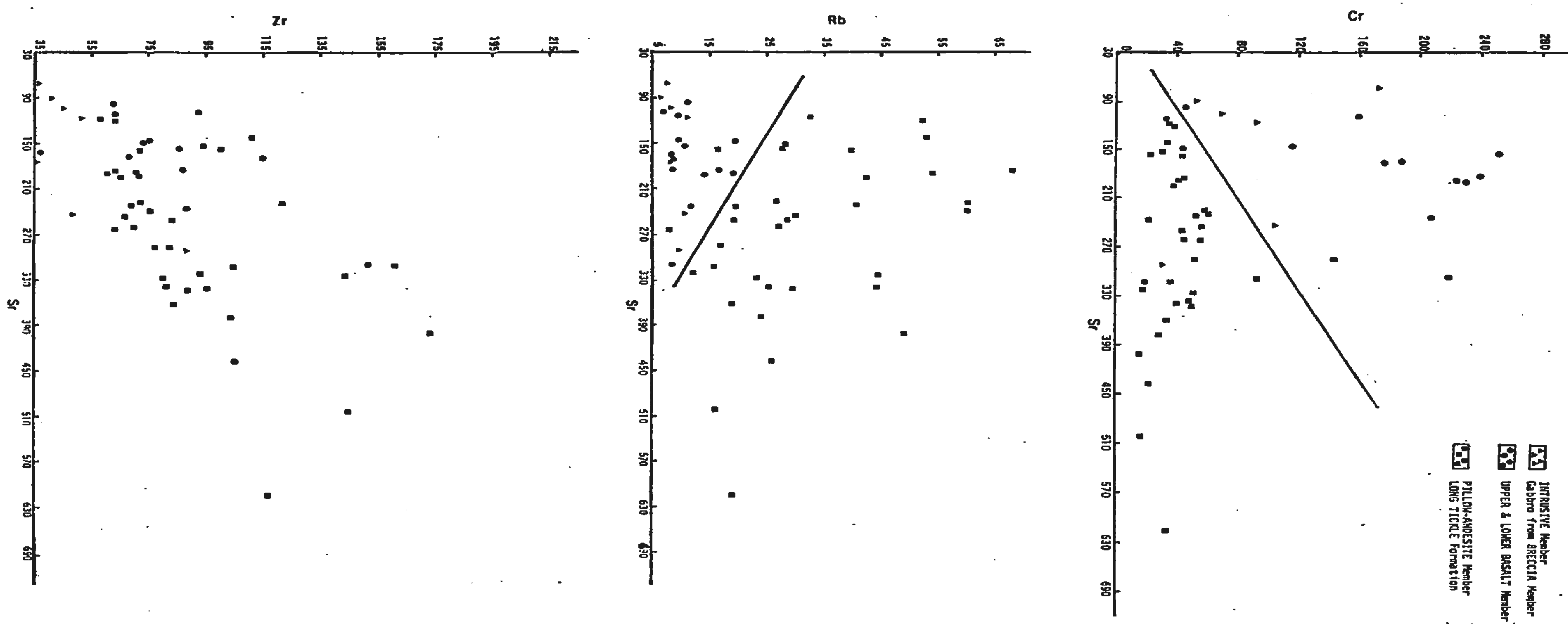
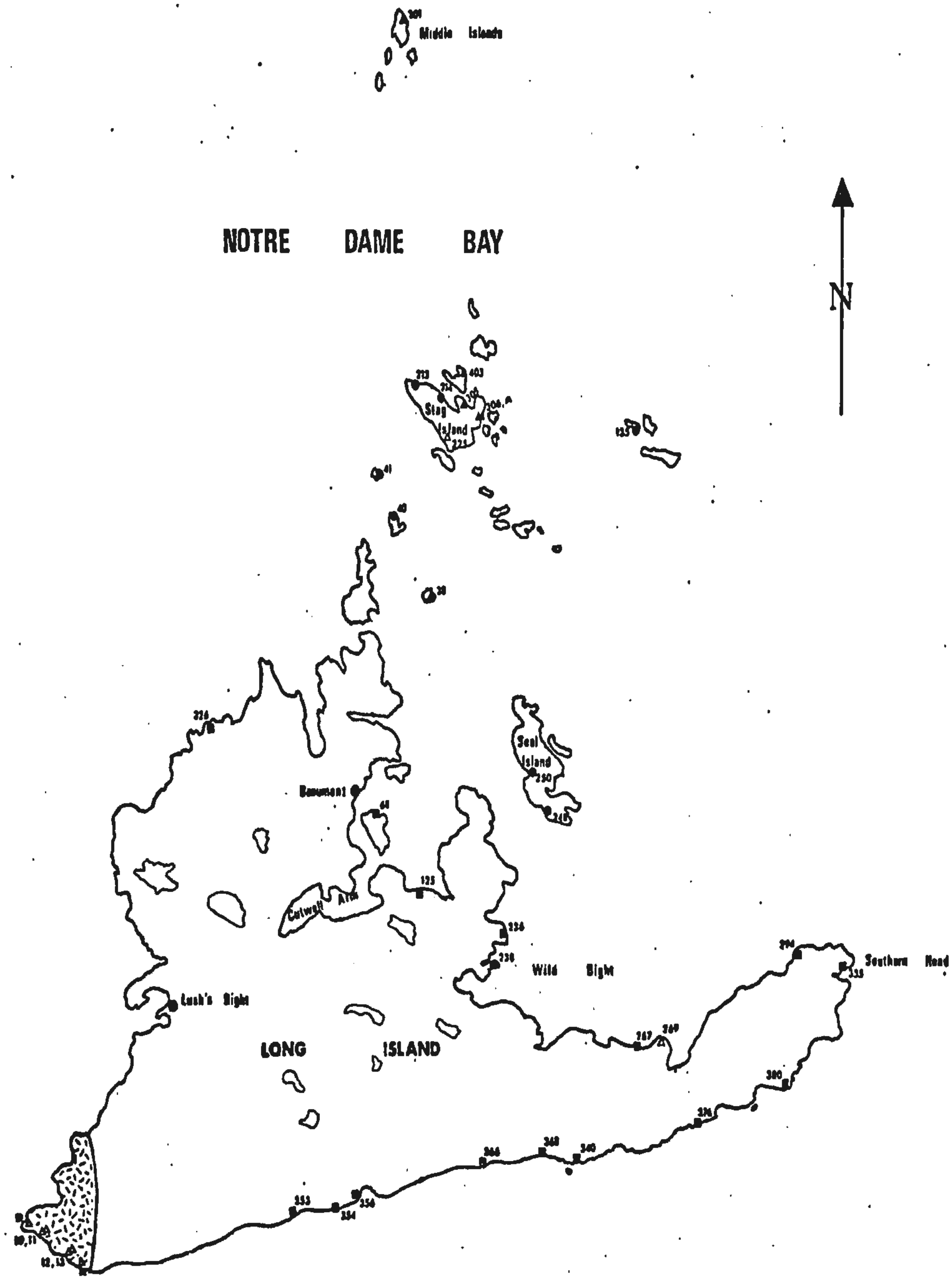


Figure 5.1. Zr, Rb, Cr vs. Sr diagram showing the scatter of points and the general subdivision of the Long Island rocks into two groups.



Scale
1 " = 6,800'

Figure 5.2. Sample location map. Solid symbols represent analyses given in Table 5.2; open symbols represent analyses of intrusive rocks given in Table A-II, Appendix II.

TABLE 5.2.

Chemical analyses of rocks from Long Island, Newfoundland

INTRUSIVE MEMBER AND BRECCIA MEMBER

	403B* (Pillowed Basalt)	306* (Diabase Dyke)	306A (Diabasic Screen)	305 (Gabbro Block)	301 (Gabbro Block)
SiO_2	53.60	56.50	47.00	49.80	50.50
TiO_2	0.83	1.24	1.00	0.20	0.20
Al_2O_3	14.64	13.60	15.50	15.40	15.80
Fe_2O_3	1.44	13.20+	13.10+	0.69	0.99
FeO	8.13	n.d.	n.d.	5.36	4.75
MnO	0.23	0.14	0.12	0.14	0.11
MgO	6.04	3.32	6.75	7.50	9.50
CaO	5.78	8.00	5.45	10.70	8.63
Na_2O	3.94	0.71	4.27	3.75	3.98
K_2O	0.48	0.15	0.12	0.52	0.35
P_2O_5	0.15	0.20	0.31	0.28	0.11
L.I.**	6.20	2.30	5.00	3.97	4.17
Total	101.46	99.36	98.62	98.31	99.09
Q	2.05	22.02	-	-	-
Or	2.98	0.92	0.76	3.26	2.18
Ab	35.02	6.20	38.67	30.34	35.51
An	21.91	34.55	24.38	25.12	25.54
Ne	-	-	-	1.82	-
Aug	5.97	4.03	1.99	24.40	15.21
Hy	30.04	29.26	4.33	-	1.33
Ol	-	-	27.06	14.21	19.56
Mt	-	-	-	-	-
Ilm	1.66	2.43	2.03	0.40	0.40
Ap	0.37	0.60	0.77	0.44	0.27
Rb	11	10	6	11	6
Sr	116	293	104	244	175
Ba	39	-	31	58	40
Zr	52	88	45	38	31
Cu	141	43	33	62	80
Zn	83	194	96	62	57
Cr	93	29	69	104	535
Ni	33	15	31	59	107

* - Altered specimen
** - Loss on Ignition

n.d. - not determined
\+ - total Fe as Fe_2O_3

TABLE 5.2. (Cont'd)

LOWER BASALT MEMBER

	250B (Basalt)	248 (Basalt)	214 (Basalt)	213 (Basalt)	135 (Basalt)
SiO_2	49.30	48.80	51.60	48.70	46.80
TiO_2	1.49	1.80	1.00	1.17	1.41
Al_2O_3	14.00	14.50	13.85	15.02	16.40
Fe_2O_3	1.53	1.41	1.36	2.04	3.78
FeO	7.61	8.10	8.36	7.31	8.31
MnO	0.14	0.15	0.12	0.19	0.21
MgO	6.79	5.90	4.88	5.78	6.07
CaO	8.30	9.60	10.00	11.60	9.18
Na_2O	3.88	4.70	4.60	3.80	4.00
K_2O	0.11	0.23	0.14	0.28	0.50
P_2O_5	0.11	0.37	0.11	0.40	0.41
L.I.**	7.50	4.63	1.81	3.20	2.71
Total	100.76	100.19	97.83	99.49	99.78
Q	-	-	-	-	-
Or	0.69	1.43	0.86	1.72	3.04
Ab	35.25	33.26	38.91	27.69	30.72
An	21.97	18.65	17.45	24.04	26.08
Ne	-	4.56	0.91	3.12	2.25
Aug	17.67	23.76	28.02	27.46	14.76
Hy	10.92	-	-	-	-
Ol	10.19	13.86	11.61	12.68	13.76
Mt	-	-	-	-	5.64
Ilm	3.04	3.58	1.98	2.31	2.76
Ap	0.27	0.90	0.27	0.97	0.98
Rb	9	9	8	10	14
Sr	168	308	167	156	192
Ba	107	202	52	150	120
Zr	115	151	67	85	71
Cu	77	42	41	69	67
Zn	84	89	82	87	95
Cr	177	218	182	251	230
Ni	58	164	89	90	102

* = Altered Specimen
** = Loss on Ignition

TABLE 5.2 (cont.)

	UPPER BASALT member			PILLOW-ANDESITE member	
	38E (Basalt)	40* (Basalt)	41 (Basalt)	340E (Andesite)	376D (Andesite)
SiO_2	53.20	58.80	48.30	53.60	50.80
TiO_2	1.20	1.12	1.27	0.82	0.67
Al_2O_3	15.30	14.40	14.50	18.40	19.10
Fe_2O_3	3.60	3.50	7.04	3.29	2.17
FeO	6.97	5.80	9.50	5.95	5.79
MnO	0.10	0.80	0.14	0.14	0.12
MgO	5.28	4.60	5.30	3.45	2.89
CaO	6.34	3.34	4.96	9.40	7.67
Na_2O	5.20	4.20	5.28	4.30	5.40
K_2O	0.26	0.81	0.25	0.07	0.78
P_2O_5	0.17	0.37	0.32	0.25	0.19
L.I.**	3.10	2.90	2.54	2.50	4.46
Total	100.72	100.64	99.40	102.17	100.04
Q	-	11.95	-	-	-
Or	1.58	4.96	1.54	0.42	3.61
Ab	45.23	36.78	40.91	36.56	41.62
An	18.14	14.64	15.74	30.85	27.50
Ne	-	-	3.01	-	3.46
Aug	10.89	-	6.51	12.67	9.45
Hy	9.80	27.10	-	16.74	-
Ol	11.61	-	29.02	0.63	12.55
Mt	-	-	-	-	-
Ilm	2.34	2.20	2.51	1.57	1.34
Ap	0.41	0.89	0.77	0.58	0.46
Rb	10	19	10	8	19
Sr	113	149	113	286	263
Ba	117	121	117	186	233
Zr	63	68	63	77	63
Cu	36	66	36	116	53
Zn	75	93	75	92	91
Cr	33	44	33	144	36
Ni	30	16	30	49	24

* = Altered specimen
** = Loss on ignition

TABLE 5.2 (cont.)

PILLOW-ANDESITE MEMBER

	294B (Andesite)	326 (Andesite)	335 (Andesite)	366D (Andesite)	380B* (Andesite)
SiO_2	50.90	53.12	47.20	55.20	44.40
TiO_2	1.06	0.90	0.80	0.86	0.70
Al_2O_3	14.83	17.52	19.95	18.50	16.80
Fe_2O_3	1.96	2.25	1.75	3.38	1.69
FeO	10.67	8.19	7.76	4.51	6.43
MnO	0.23	0.15	0.15	0.15	0.17
MgO	2.90	5.44	2.48	1.78	2.68
CaO	6.07	6.74	7.39	6.41	11.40
Na_2O	3.05	1.76	2.48	3.37	4.31
K_2O	0.83	1.04	2.70	1.60	0.71
P_2O_5	0.27	0.72	0.25	0.24	0.23
L.I.**	6.00	0.98	9.06	2.80	9.42
Total	98.77	98.81	101.97	98.80	98.94
Q	4.79	10.65	-	8.31	-
Or	5.31	6.30	17.22	9.89	4.69
Ab	27.90	15.26	22.63	29.81	19.74
An	26.30	29.43	37.78	31.61	27.31
Ne	-	-	-	-	11.88
Aug	3.73	-	-	-	29.05
Hy	29.11	31.86	7.70	17.94	-
Ol	-	-	12.29	-	6.09
Mt	-	-	-	-	-
Ilm	2.18	1.75	1.64	1.71	1.49
Ap	0.68	1.71	0.63	0.58	0.60
Rb	28	30	68	49	20
Sr	154	343	186	402	234
Ba	550	415	736	640	404
Zr	94	88	63	174	69
Cu	148	62	52	47	74
Zn	137	94	95	94	93
Cr	32	49	45	16	54
Ni	23	24	31	14	40

* = Altered specimen
** = Loss on Ignition

TABLE 5.2. (cont.)

PILLOW-ANDESITE Member

	68B (Andesite)	125 (Andesite)	236E (Andesite)	238 (Andesite)	267A* (Andesite)
SiO_2	44.60	52.40	60.10	46.00	51.10
TiO_2	0.70	0.57	0.73	0.81	0.48
Al_2O_3	18.20	16.80	16.71	21.48	15.60
Fe_2O_3	1.01	1.30	0.97	2.63	1.81
FeO	8.03	7.47	2.05	9.11	5.34
MnO	0.15	0.12	0.06	0.17	0.13
MgO	4.30	3.40	3.04	3.36	3.60
CaO	7.71	7.20	2.72	4.60	9.00
Na_2O	4.50	2.08	4.72	3.72	2.50
K_2O	1.01	1.61	1.50	1.83	1.90
P_2O_5	0.18	0.25	0.27	0.27	0.30
L.I.**	7.91	8.20	5.40	4.90	8.90
Total	98.30	101.40	98.27	98.88	100.66
Q	-	8.54	14.84	-	3.91
Or	6.62	10.23	9.47	11.55	12.26
Ab	25.08	18.91	42.61	33.58	23.09
An	29.33	34.11	17.80	22.46	28.09
Ne	9.26	-	-	-	-
Aug	9.83	2.12	-	-	15.48
Hy	-	24.30	12.65	5.10	15.41
Ol	17.94	-	-	18.95	-
Mt	-	-	-	-	-
Ilm	1.47	1.16	1.46	1.64	0.99
Ap	0.46	0.62	0.67	0.67	0.76
Rb	30	42	45	40	53
Sr	246	195	309	231	143
Ba	249	548	440	574	543
Zr	67	65	161	69	110
Cu	86	12	29	22	31
Zn	91	97	63	100	86
Cr	56	39	93	53	34
Ni	28	26	57	22	27

* =Altered specimen

** = Loss on Ignition

TABLE 5.2 (Cont'd)

	368B (Andesite)	LONG TICKLE Formation 353 (Andesite)	354A* (Andesite)	356C (Andesite)
SiO_2	50.12	57.20	44.80	46.70
TiO_2	0.70	0.67	0.77	0.77
Al_2O_3	18.00	17.80	21.54	22.60
Fe_2O_3	1.83	2.15	2.51	2.80
FeO	8.18	4.29	6.75	6.00
MnO	0.18	0.12	0.17	0.12
MgO	4.02	2.05	3.21	3.10
CaO	7.60	7.15	6.13	8.78
Na_2O	3.37	3.70	2.25	2.94
K_2O	0.61	0.37	3.15	1.10
P_2O_5	0.30	0.22	0.70	0.46
L.I.**	4.00	2.10	7.07	3.90
Total	98.91	97.82	99.05	99.27
Q	-	13.27	-	-
Or	3.81	2.29	20.32	6.85
Ab	30.13	32.69	20.76	26.81
An	34.02	32.10	28.17	42.68
Ne	-	-	-	-
Aug	3.16	2.92	-	-
Hy	25.42	14.87	10.85	8.99
Ol	1.32	-	11.12	10.84
Mt	-	-	-	-
Ilm	1.41	1.33	1.59	1.54
Ap	0.74	0.53	1.77	1.23
Rb	19	12	60	26
Sr	361	320	236	437
Ba	326	366	645	546
Zr	84	93	76	105
Cu	74	42	82	73
Zn	98	84	113	115
Cr	33	19	22	21
Ni	16	10	19	18

* = Altered specimen
** = Loss on Ignition

5.3.2.1. Variation Diagrams

Major element oxides and trace elements have been plotted against SiO_2 (Figures 5.4 and 5.5) in order to compare elemental abundances and possible trends. However, as described in Section 5.2., the lavas show petrographic evidence of alteration which would have modified their original chemical composition.

There have been numerous descriptions of the chemical effects of greenschist metamorphism, including migration of just about all the elements under one set of conditions or another (e.g. Vallance, 1960, 1965; Smith, 1968; Cann, 1969; Reed and Morgan, 1971; Smitheringale, 1972; Jolly and Smith, 1972), and it is almost certain that some such changes have taken place in the Long Island lavas. Although such features as albitization, chloritization and epidotization suggest the nature of such changes, it is practically impossible to determine their extent and therefore be able to correct for them. In these diagrams and subsequent discussions the only corrections made were for oxidation (loss on ignition) and hydration (cf. Irving and Baragar, 1971).

Frequency distribution diagrams for the field and petrographic subdivisions (Table 5.1) are given in Figure 5.3. These diagrams show a wide range of silica content, but some analyses can be eliminated because of secondary introduced quartz (Section 5.3.2.2) thereby placing the SiO_2 range between 48-58%. The combined frequency diagram (Figure 5.3.d.) best shows the essentially unimodal distribution of these lavas with a concentration near the upper basalt - lower andesite SiO_2 range and a tapering off towards the higher silica range.

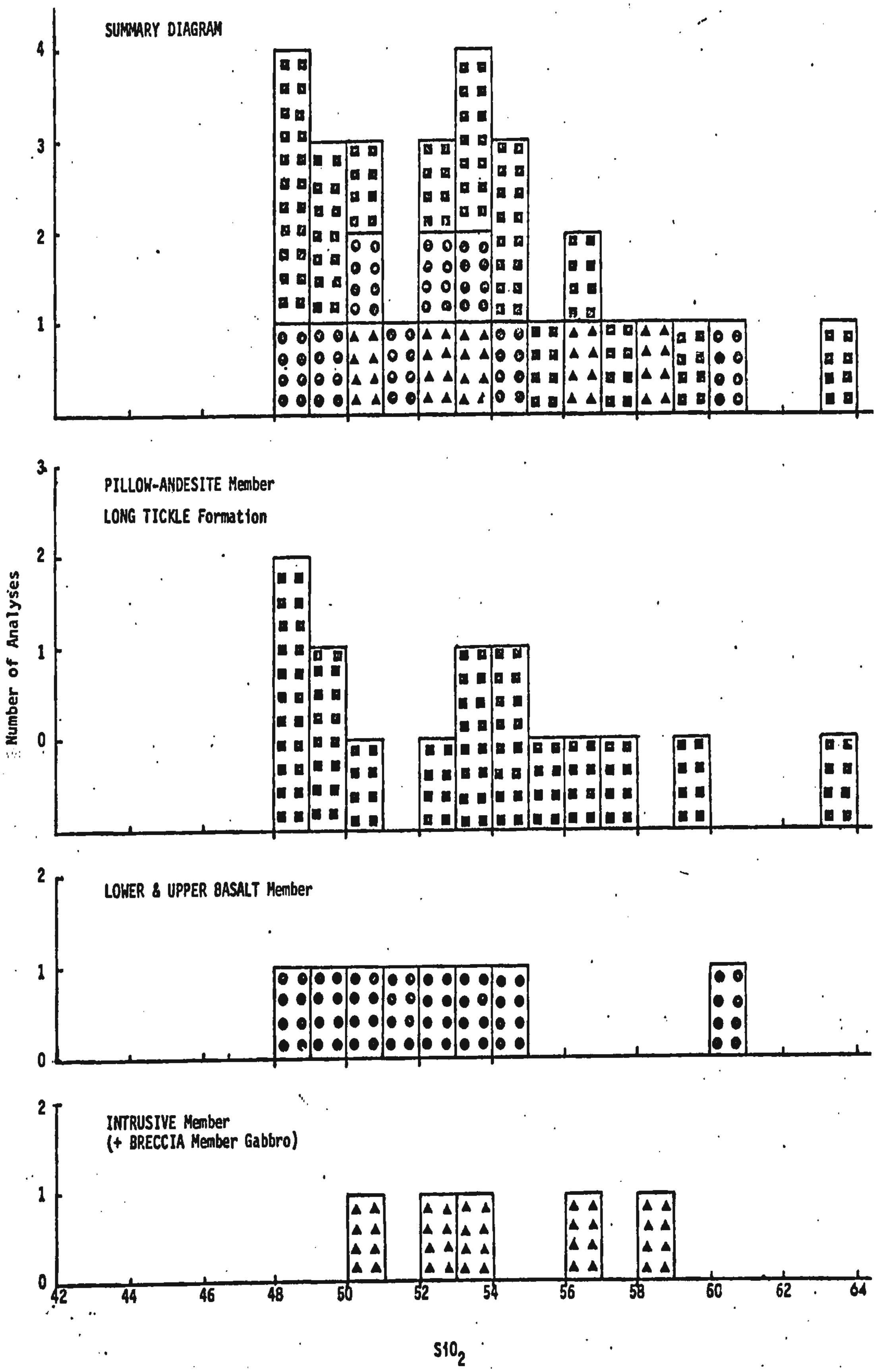


Figure 5.3. Frequency distribution of SiO_2 in the Long Island rocks.

Despite possible metamorphic alteration of the original chemistry, it is clear from the diagrams (Figures 5.4, 5.5, 5.6, 5.7, and 5.8) that the Long Island volcanic rocks fall into two chemically distinct groups. One group includes the INTRUSIVE member and the LOWER and UPPER BASALT members of the STAG ISLAND Formation and is here collectively called the BASALT group or grouping; the other is called the ANDESITE group or grouping and includes the PILLOW-ANDESITE member and the LONG TICKLE Formation.

The ANDESITE grouping generally shows a wide scatter, particularly in Figures 5.4 and 5.5, and consequently some points plot within the field of the BASALTS. However, most of these points can be eliminated because of various secondary chemical effects.

Of the samples plotted, specimens 40, 403, and 306 (dykes) can be eliminated from the BASALT group because of secondary introduced quartz. Samples 267, 380, 354, and 340 can be eliminated from the ANDESITE group because of extensive alteration (carbonate, saussurite, sericite, chlorite, epidote) and/or other introduced minerals. Thus the wide scatter within each grouping is most likely the result of secondary alteration effects. With this in mind one can discuss the two chemically distinct groups in terms of the variation diagrams.

On the major element and trace element diagrams (Figures 5.4. and 5.5) the ANDESITE group consistently plots as a more differentiated suite than the underlying BASALT group, i.e., the ANDESITE group has less CaO, MgO, Fe_2O_3, TiO_2, Cr, Ni and more K_2O, Al_2O_3, Rb, Sr and

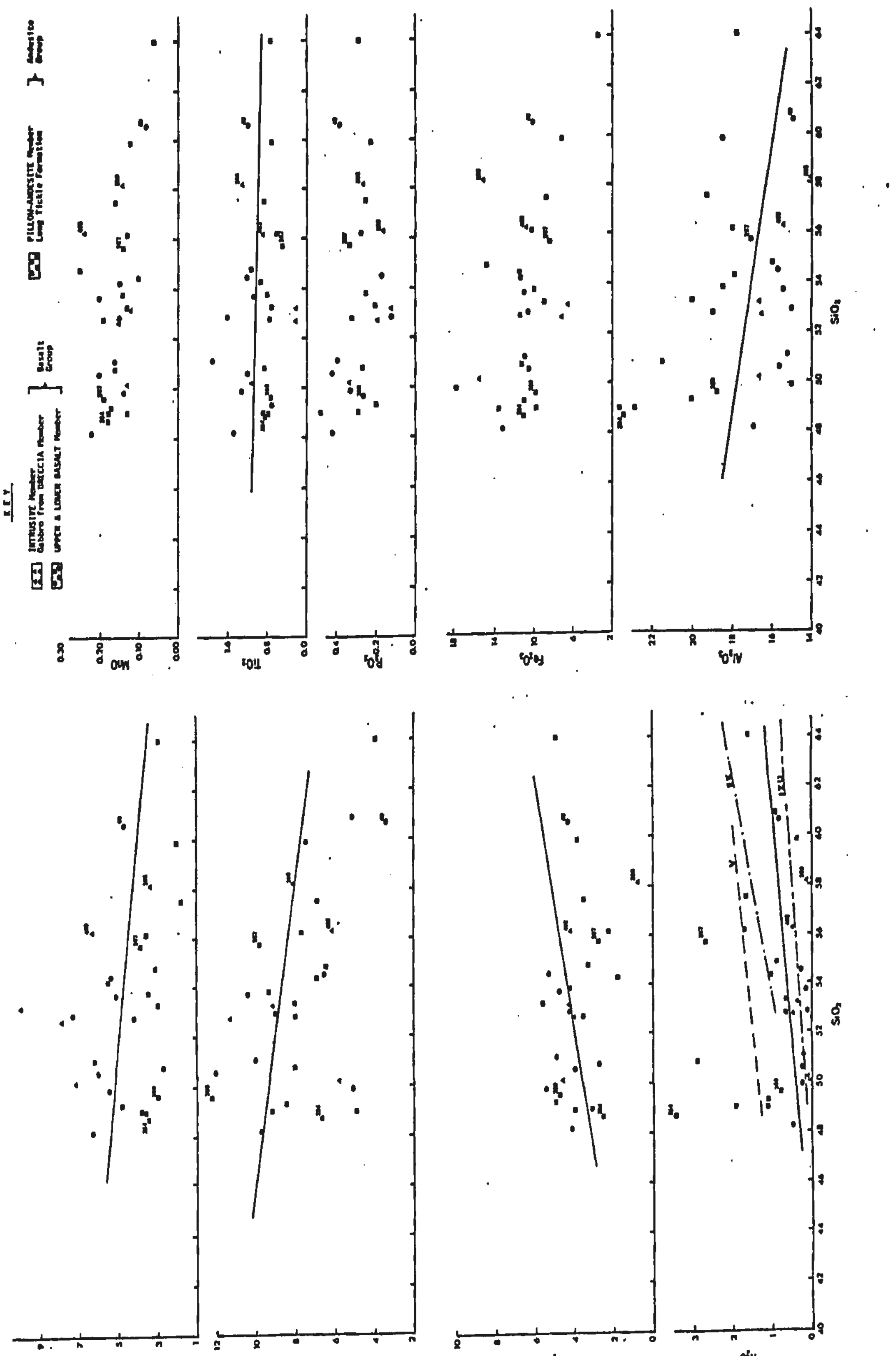


Figure 5.4. Major oxides vs. SiO_2. Solid line represents approximate division between the two groups discussed in the text. IZU = Izu Islands and peninsula (tholeiitic association); V = mt. Victory, EK = Eastern Kamchatka (calc-alkaline association).

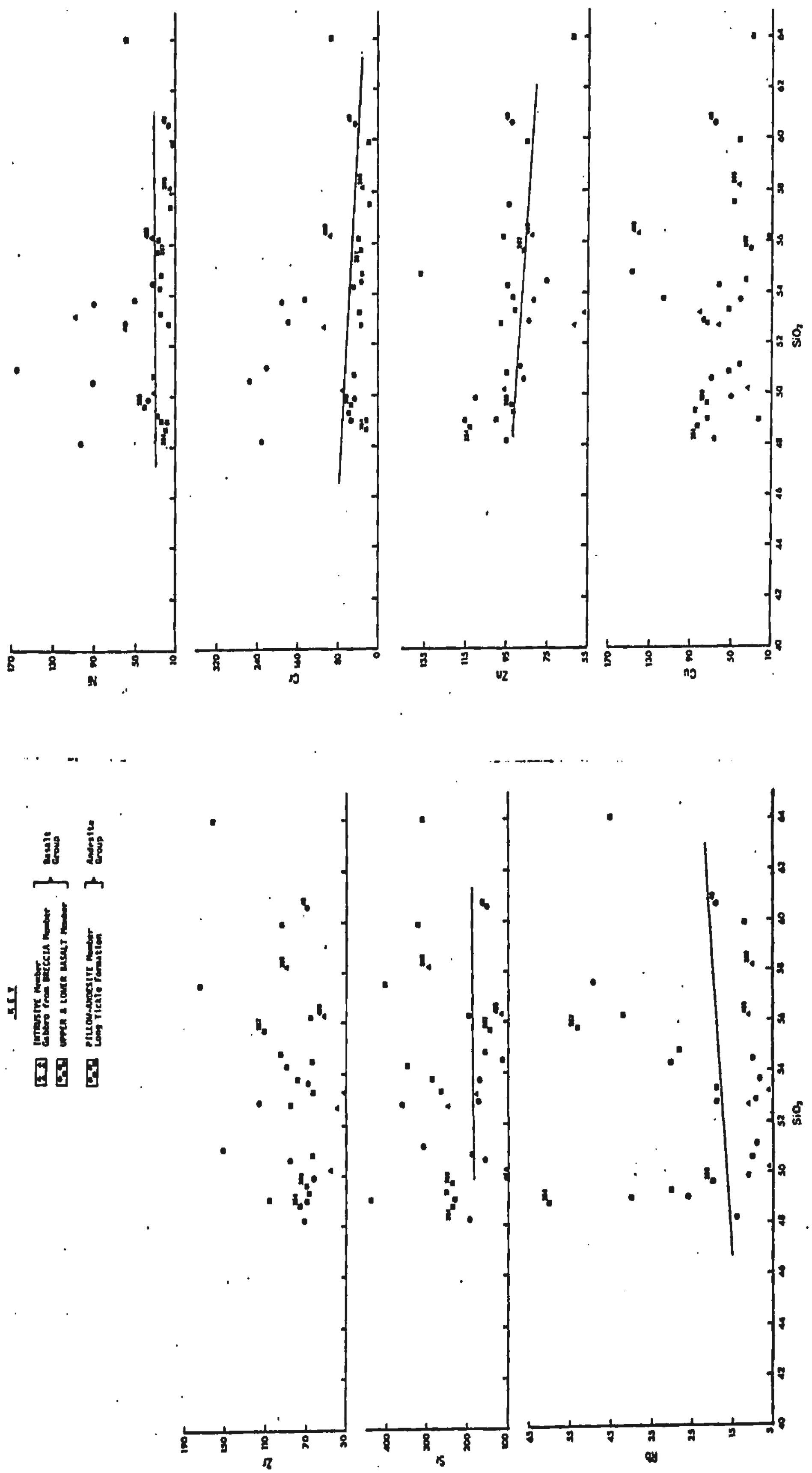


Figure 5.5. Trace elements vs. SiO_2. Solid line represents approximate division between groups.

Zn than the BASALT group (see also Figure 5.6).

The UPPER BASALT member of the BASALT grouping shows a transition between the two groupings for the elements Cr, Ni, and Ca. For Cr and Ni it plots in the high Ni and Cr range of the ANDESITE field, while for Ca it plots low in the ANDESITE field; however, this is probably partly due to albitization, as suggested by the petrography.

The only other exception to this general rule is Na_2O. It is higher in the BASALT group than in the ANDESITE, i.e., the reverse of an igneous differentiation process. However, as discussed in Section 5.2, the BASALTS show strong evidence of albitization, possibly because of their greater depth (cf. Marten, 1971).

On the FMA - CNK diagram (Figure 5.7) the lavas have an andesitic affinity (Kuno, 1960) and it is worth noting that the FMA trend for the calc-alkaline rocks from the Solomon Islands (Jakeš and Smith, 1970) divides the Long Island lavas into the two chemically distinct groups discussed above.

On the total Fe vs MgO plot (Willmott, 1972) (Figure 5.8) again there are two chemical groupings corresponding to the lower basaltic and upper andesitic sequences on Long Island.

5.3.2.2. Alteration

It is clear that the Long Island lavas fall into two distinct and consistent chemical (and petrographic) groups. It was also noted

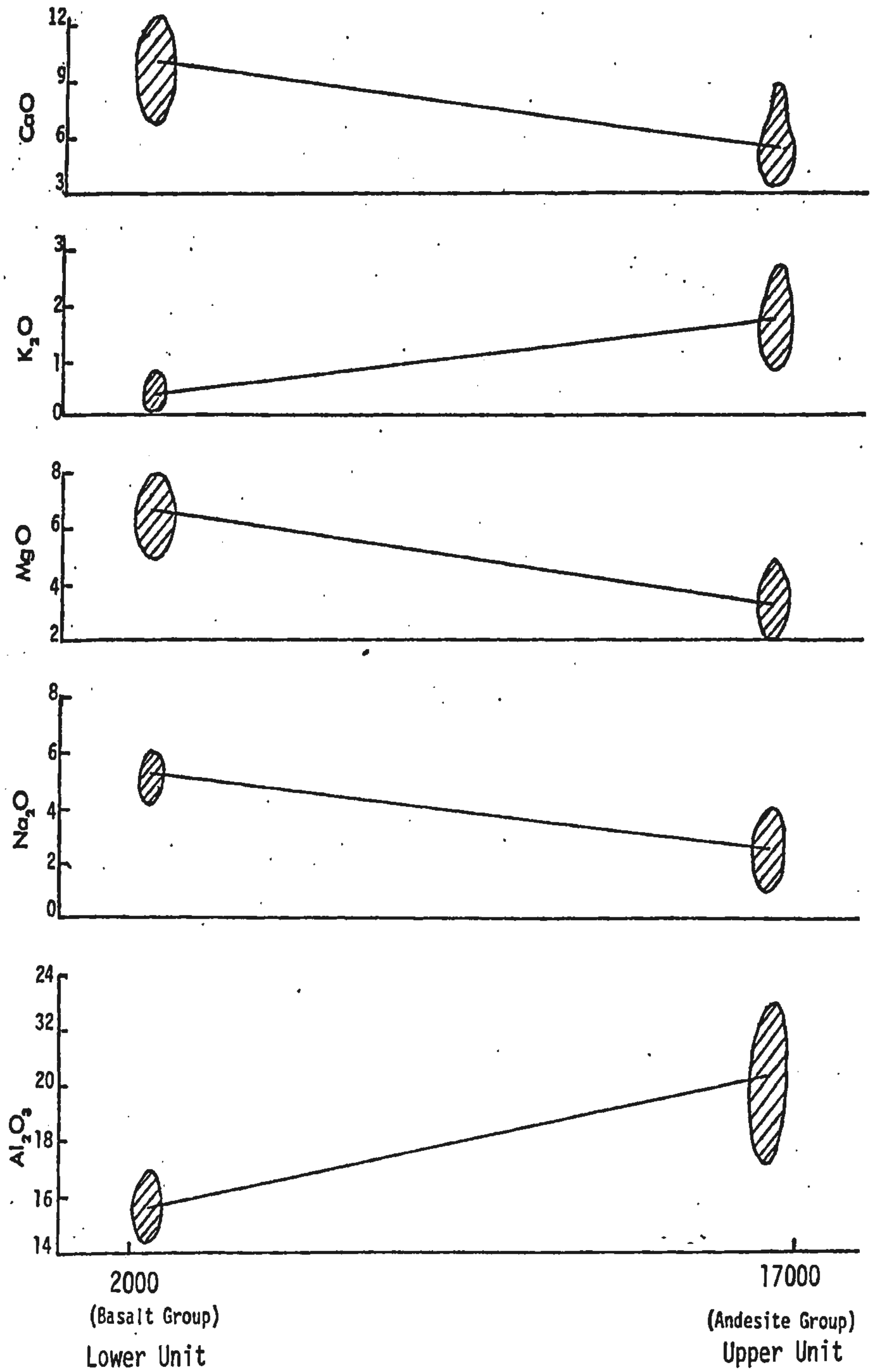


Figure 5.6. This diagram shows the difference in major element chemistry of the Long Island rocks between the basal glassy basalts and the upper porphyritic andesites.

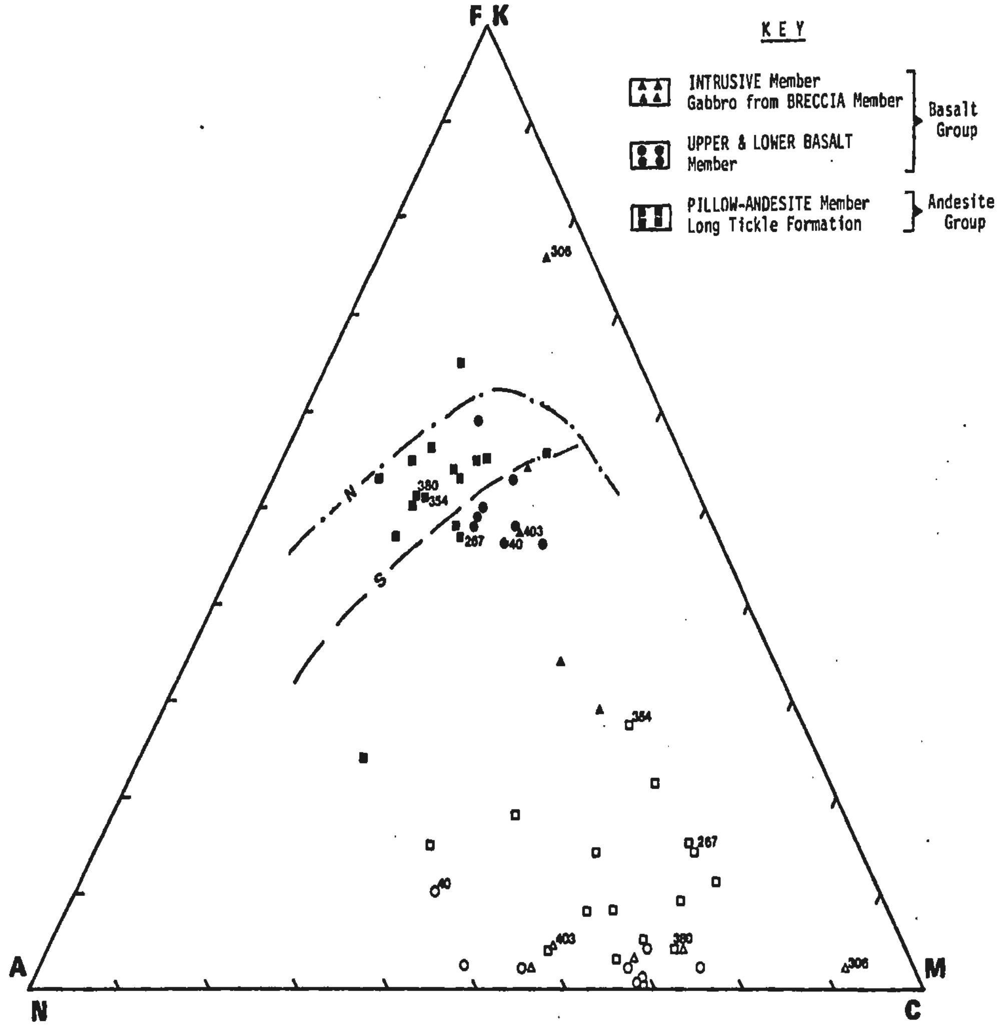
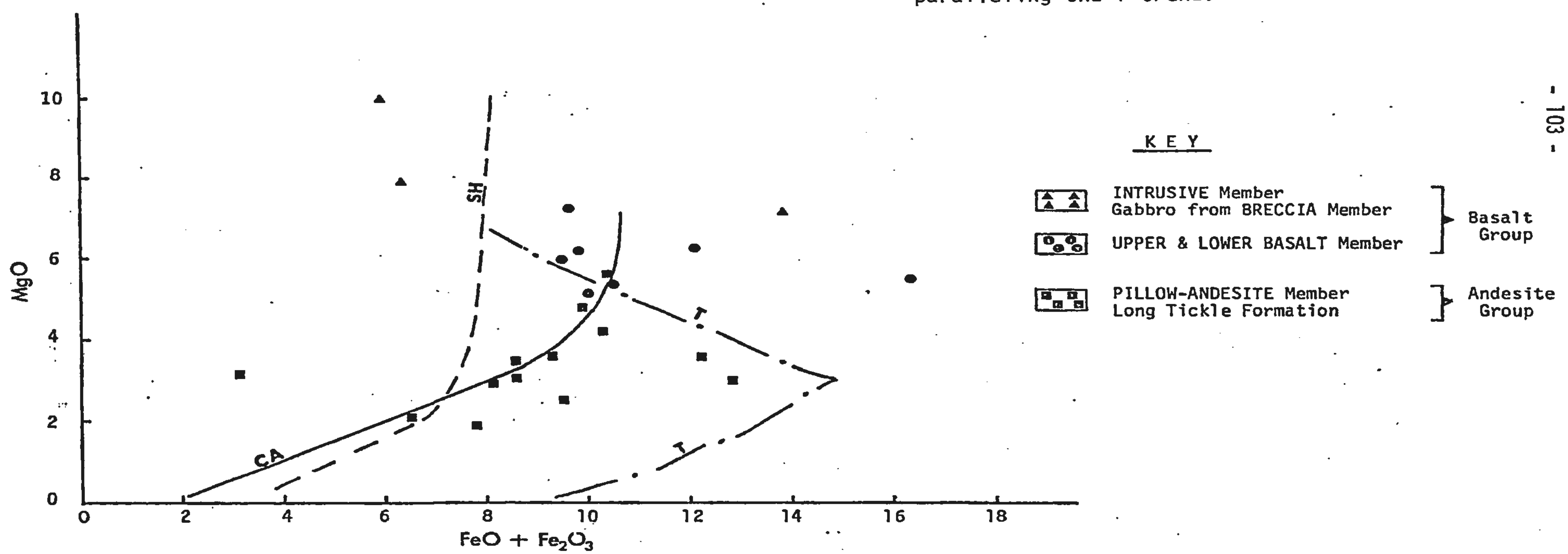


Figure 5.7. F.M.A. (total iron as FeO:MgO:total alkalis), solid symbols and C.N.K. ($CaO:Na_2O:K_2O$) open symbols, diagrams for the Long Island rocks. For comparison the trend of calc-alkaline rocks from the Solomon Islands and Bougainville Islands (S), and tholeiitic rocks from New Guinea (N) are given. (After Jakes and Smith, 1970.)

Figure 5.8. (after Willmott, 1972). Total Fe vs. MgO. CA = calc-alkaline association; SH = Shoshonite association, T = tholeiitic association. Note that the ANDESITE GROUP plots along the Ca-trend; whereas the BASALT GROUP has a scatter roughly paralleling the T-trend.



that within each group there may be considerable scatter due to secondary superimposed alteration effects that are petrographically detectable. The possibility exists then that the chemical grouping is a further reflection of chemical alteration. However, the strongly consistent nature of the chemical grouping is the best argument for its primary origin.

If due to secondary alteration, this alteration must have been very systematic over a distance of c. 15,000 feet. Smith (1968) described systematic alteration or alteration domains (Ca-enriched and Ca-depleted with a corresponding enrichment or depletion in sympathetic and antipathetic elements) on an outcrop scale. If one could envisage systematic complimentary alteration domains developing on the scale of tens of thousands of feet, one could expect to find as Smith and Vallance (1960, 1965) did, that throughout and across domains Na, K, total Fe and Mg all vary concordantly, their variation being antipathetic to that of Ca while Al_2O_3 varied sympathetically with Ca. However, this does not hold true for the Long Island rocks (Figure 5.6). In the Long Island rocks where CaO is high, so is MgO and total Fe (Figure 5.8) while K_2O and Al_2O_3 is low. Na_2O is an exception since there is evidence (section 5.2) that the basalts have probably been enriched in Na. Furthermore, a K-metasomatism in the andesites, complimenting a Na-enrichment in the basalts is not supported by the overall chemistry or the petrography (no sanidine or orthoclase replacing calcic plagioclase, and only very minor sericite associated with saussuritization).

It must be pointed out that the above discussion assumes constant conditions of alteration. However, such a consistent and systematic chemical pattern corresponding to stratigraphic levels within the Long Island sequence, if not primary, must have formed under very similar, consistent and persistent alteration processes active through a pile c. 15,000 feet thick. It is more reasonable to suggest that the chemical groupings represent an original igneous chemical difference due to differentiation and is now modified and partially obscured by secondary effects within an essentially isochemical system (cf. Cann, 1969; Reed and Morgan, 1971; Smitheringale, 1972).

5.3.2.3. Interpretation

The K/Rb ratios (Figure 5.9) for these rocks are slightly higher than the "normal" value of 230 indicated by Taylor, 1966. However, Gast (1968) and Jakeš and Gill (1970) would consider these K/Rb ratios (Figure 5.8) as being characteristic of island-arc environments and in particular the calc-alkaline association, as opposed to the high, generally > 1,000, K/Rb ratios for "oceanic" rocks.

The odd behaviour of the samples with < 10 ppm Rb in Figure 5.9 is probably a reflection of the lower limits of detection and accuracy of the analytical methods. For example, a difference of 2 to 5 ppm lower Rb would eliminate the low ratios for most of these samples.

Cann (1970) demonstrated that Zr/Ti ratios in "oceanic" tholeiites had specific values which did not appear to be affected by spilitization

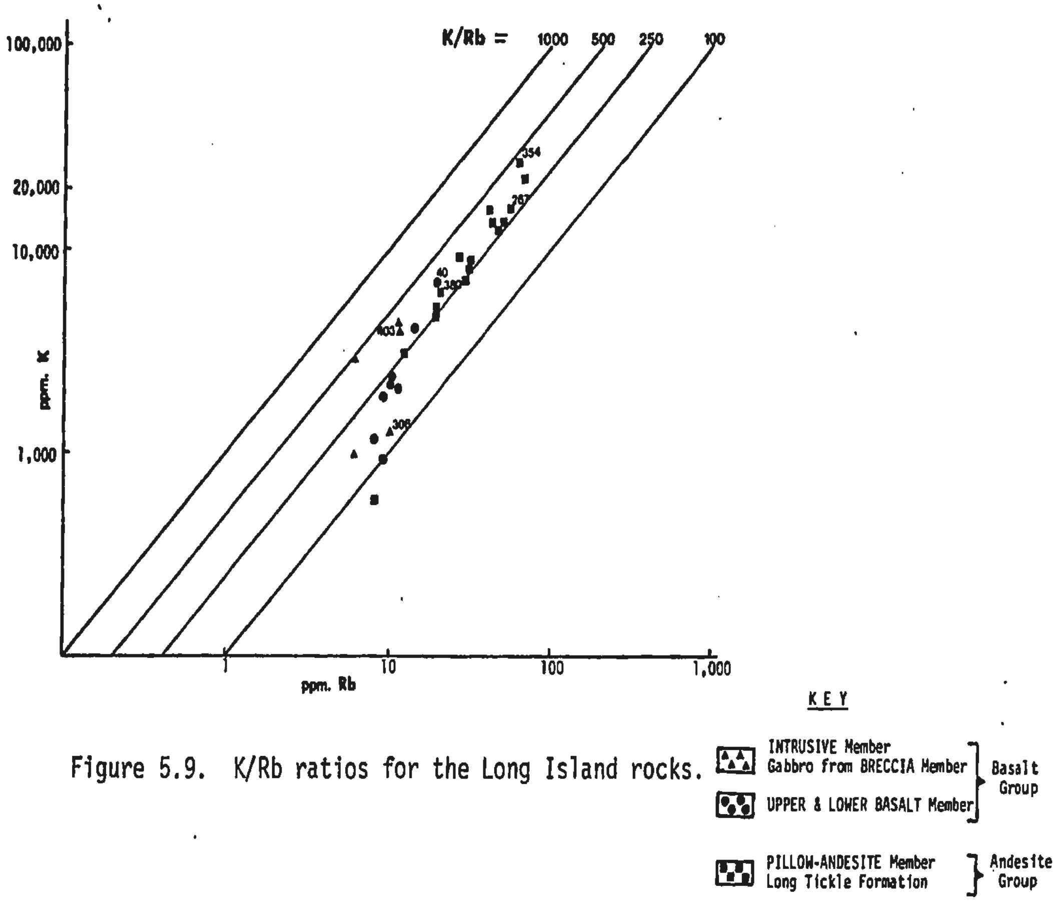


Figure 5.9. K/Rb ratios for the Long Island rocks.

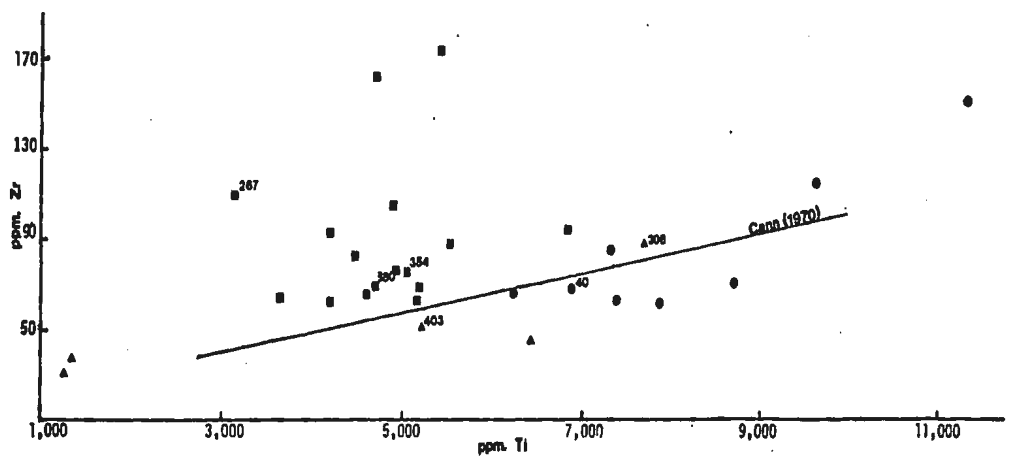


Figure 5.10. Zr/Ti ratios for the Long Island rocks, compared to ocean tholeiites (after Cann, 1970).

or greenschist metamorphism. As seen in Figure 5.10, the Long Island lavas do not correspond with "oceanic" ratios, in fact they suggest either a different original chemistry from "oceanic" tholeiites or a different alteration process. The former suggestion is given preference since Strong (personal communication) has found that the "oceanic" sheeted-dykes and lavas found in adjacent Pilley's Island area (Strong, 1972) which presumably underwent similar grades and degrees of alteration, are in accord with Cann's (1970) findings.

Figure 5.11, total alkalies vs. SiO_2, shows that the Long Island rocks have a transitional nature from tholeiitic to alkalic. This transition is controlled neither by stratigraphic level in the pile nor by variation in the primary igneous mineralogy. It is therefore interpreted to be a secondary, superimposed alteration effect, particularly since the alkalies are so highly variable.

It seems to follow then that from the stratigraphic, petrographic and chemical evidence the Long Island area is not of oceanic affinity but instead of island-arc affinity. With this conclusion, the two chemical groups corresponding to stratigraphic levels, i.e. a temporal variation, takes on a new meaning.

This stratigraphic or temporal variation in chemistry is characteristic of modern island arcs (Gill, 1970; Jakeš and Gill, 1970; Donnelly et al., 1970; Jakeš and White, 1972). There is also a similar lateral change from island-arc tholeiites on the oceanic (convex) side through calc-alkaline rocks to shoshonitic rocks on the basinal (concave) side of modern island arcs (Jakeš and White,

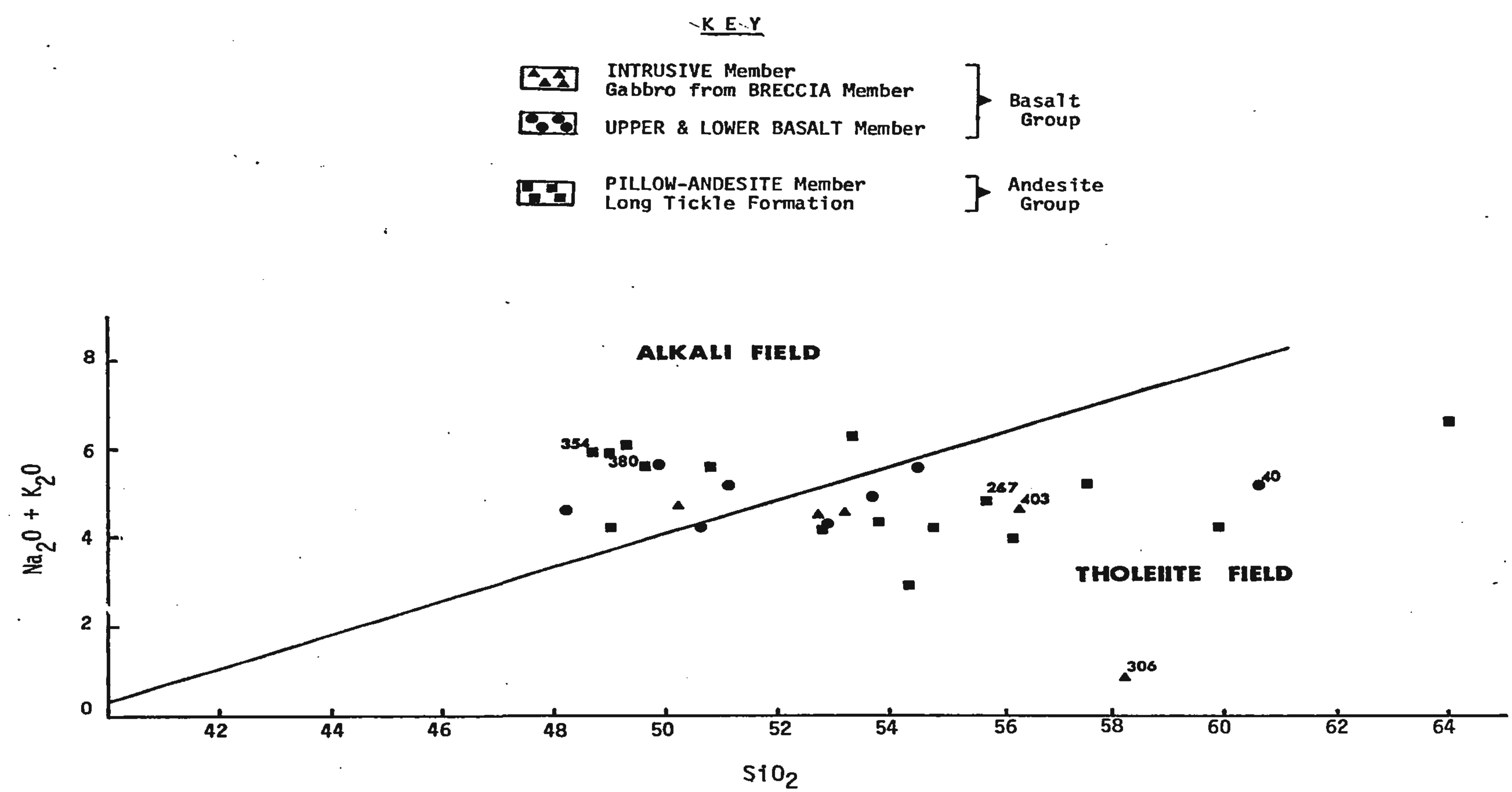


Figure 5.11. (after MacDonald and Katsura, 1964). Total alkalis vs. SiO_2

1972). A discussion of these chemical variations has been given in Section 1.6.2.

Comparing the chemistry of the BASALT group (INTRUSIVE member; UPPER and LOWER BASALT members) as given in Table 5.2. with that of Jakeš and White (1972) (Table 5.3) for volcanic rocks of island arcs, it is seen that they compare favourably with rocks of the island arc tholeiitic basalts. Their low K_2O content and low K_2O vs. SiO_2 slope (Figure 5.4) also agrees with this. Furthermore, on the total Fe vs. MgO diagram (Figure 5.8) these rocks plot as a distinctive group approximating the trend of the island arc tholeiitic association (Willmott, 1972). However, it must be pointed out that the LOWER BASALT member in particular has a predominant silica-undersaturated composition, i.e. nepheline normative. However, this may be a secondary feature since there is petrographic evidence of albitization and there is no overall consistency to this feature throughout the BASALT grouping.

The lower MgO, CaO, Cr, Ni, overall higher SiO_2 and higher K_2O, Rb and Sr, suggest that the stratigraphically higher PILLOW-ANDESITE member and the flows and agglomerates of the LONG TICKLE Formation are more differentiated than the underlying BASALT Group.

Figure 5.4 (K_2O vs. SiO_2) gives a scattered, nondistinct, pattern for these rocks; however, the points do fall within the field of the calc-alkaline series (Jakeš and Gill, 1970).

Figure 5.8, total Fe vs. MgO gives a strong calc-alkaline association trend for these rocks. Within the calc-alkaline association their chemistry compares favourably with that of low-Si andesites (Taylor, 1969; Jakes and Smith, 1970). They actually have characteristics of both the low-Si and low-K andesites (compare Tables 5.2. and 5.3.). Moreover, petrographically these rocks are very similar to the low-Si andesites of the calc-alkaline association found on Eastern Papua.

The highly variable Al_2O_3 content (17.8 - 22.8) is also characteristic of low-silica, variable K andesites of calc-alkaline affinity.

The andesite rocks of the PILLOW-ANDESITE member and the LONG TICKLE Formation, that collectively make up the chemically defined ANDESITE group, appear to be low-silica andesites of the calc-alkaline association.

5.4. Conclusions

Despite all the reservations about metamorphic alteration of the original chemistry, it does confirm what was deduced from the lithology, stratigraphy and petrography -- that the Long Island volcanic succession represents a volcanic pile of island arc affinity.

With further reservations, it is proposed that the succession can be petrologically, as well as stratigraphically, divided into a lower and upper sequence representing a differentiation process.

Furthermore, the succession has a chemical variation from the lower to the upper sequence akin to the variation from island arc tholeiites to the calc-alkaline rocks in modern island arcs.

TABLE 5.3A

(modified after Jakes and White, 1972)

Major Element Abundances in Volcanic Rocks of Island Arcs*

	Island arc tholeiites			Calc-akline rocks						Shoshonitic		
	Basalt	Tholei-itic andesite	Tholei-itic dacite	High-Al basalt	Low-Si andesite	Low-K andesite	Andesite	High-K andesite	Dacite	Sho-shon-ite	Latite	Abyssal tholei-ite
	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	51.57	27.40	79.20	50.59	54.54	59.05	59.64	58.52	66.80	53.74	59.27	49.34
TiO_2	.80	1.25	.23	1.05	1.13	.69	.76	.76	.23	1.05	.56	1.49
Al_2O_3	15.91	15.60	11.10	16.29	16.26	17.07	17.38	16.20	18.24	15.84	15.90	17.04
Fe_2O_3	2.74	3.48	.52	3.66	2.31	3.90	2.54	2.93	1.25	3.25	2.22	1.99
FeO	7.04	5.01	.90	5.08	5.40	2.57	2.72	3.28	1.02	4.85	3.19	6.82
MnO	.17	-	-	.17	.12	.15	.09	.09	.06	.11	.10	.17
MgO	6.73	3.38	.36	8.96	6.97	3.25	3.95	4.14	1.50	6.36	5.45	7.19
CaO	11.74	6.14	2.06	9.50	7.50	7.09	5.92	5.59	3.17	7.90	5.90	11.72
Na_2O	2.41	4.20	3.40	2.89	3.64	3.80	4.40	3.64	4.97	2.38	2.67	2.73
K_2O	.44	.43	1.58	1.07	1.49	1.27	2.04	2.67	1.92	2.57	2.68	.16
P_2O_5	.11	.44	-	.21	.23	.20	.28	.25	.09	.54	.41	.16
H_2O	.45	-	-	.81	1.31	.64	1.08	1.47	.26	1.09	1.44	-

* Examples are from Melanesia -- see exact locations on following page.

TABLE 5.3A (cont.)

1. Tholeiitic basalt, Lake Dakataua, Talasea, New Britian (Lowder and Carmichael, 1970).
2. Tholeiitic andesite, Viti Levu, Fiji (Gill, 1970).
3. Tholeiitic dacite, Saipan (Taylor, 1969).
4. High-Al basalt, north slope of Mt. Trafalgar, Cape Nelson, East Papua (Jakes and Smith, 1970).
5. Low-Si andesite, south slope of Mt. Trafalgar, Cape Nelson, East Papua (Jakes, 1970).
6. Low-K andesite, Mau Quarry, Viti Levu, Fiji (Jakes, 1970).
7. Andesite, lava dome of Mt. Lamington, East Papua (Jakes and White, 1969).
8. High-K andesite, northwestern slope of Mt. Trafalgar, Cape Nelson, East Papu (Jakes and Smith, 1970).
9. Dacite, Savo volcano, Guadalcanal, Solomon Islands (Jakes and White, 1969).
10. Shoshonite, Gumnach River, Mt. Hagen, New Guinea Highlands (Jakes and White, 1969).
11. Latite, Tambul, Mt. Giluwe, New Guinea Highlands (Jakes and White, 1969).
12. Abyssal tholeiite (Engel, 1965).

TABLE 5.3B - Trace Element Abundances in Volcanic Rocks of Island Arcs.

	Island-arc tholeiites			Calc-alkaline association			Shoshonitic association		
	Basalt	Andesite	Dacite	Basalt	Andesite	Dacite	Basalt	Andesite	Dacite
SiO_2	52%	58%	63%	52%	58%	63%			
Rb	5.0	6.0	15	10	30	45	75	100	120
Ba	75	100	175	115	270	520	1000	850	900
Sr	200	220	90	330	385	460	700	850	850
K/Rb	1000	890	870	340	430	380	200	200	200
Ni	30	20	1	25	18	5	20	-	-
V	270	175	19	255	175	68	200	-	-
Cr	50	15	4	40	25	13	30	-	-
Zr	70	70	125	100	110	100	50	150	200

Data in p.p.m.

Data in Table 5.3B were compiled from different sources and do not correspond to rocks in Table 5.3A. Trace element values are preferred values which emerge from compilation of data of other authors, namely: Prinz, 1968; Taylor, 1968; Taylor et al., 1969; Jakes and Gill, 1970; Gill, 1970; and unpublished data by these authors.

6. ECONOMIC GEOLOGY

6.1. Introduction

The study area lies at the northernmost end of the "Central Mineral Belt" of Newfoundland, a term coined by Snelgrove (1929) and now taken as synonymous with the "Central Mobile Belt" referred to previously.

Fogwill (1965) prepared a compilation of the mineral occurrences, prospects and producing and former producing mines on the Island of Newfoundland (Figure 6.1). However, this map is now out-of-date and currently the only producing mines in the Notre Dame Bay region are all on the Baie Verte Peninsula. Two base metal mines (copper) are operated by Consolidated Rambler Mines Limited - Rambler Mine and the Ming Mine (8). The only other mine produces asbestos and is operated by Advocate Mines Limited (5).

The base metal mineralization of central Newfoundland is concentrated in the Lower Paleozoic volcanic rocks (Williams, 1963), and as discussed in Section 1.4 these rocks are divided by a major east-west lineament known as the Luke's Arm Fault (known in the Pilley's Island area as the Lobster Cove Fault). Likewise the base metal mineralization of this region can be separated into two major types by this fault (Strong and Peters, 1972). Those north of the fault contain essentially pyrite and chalcopyrite with pyrrhotite sometimes abundant over pyrite. Examples of these are the deposits at Whalesback, Little Bay, Tilt Cove and Betts Cove. They are found in basic volcanic rocks now thought to be Ordovician oceanic crust (ophiolitic), although many of them are in highly deformed chlorite schist zones (Peters, 1967; Kennedy

3. Parsons Pond
St. Paul's Inlet
4. Brownings Mine
Simms Ridge
Unknown Brook
5. Advocate Mines Ltd.
6. Goldenville Mine
7. Terra Nova Mine
8. Consolidated Rambler
Mines Ltd.
9. Tilt Cove Mine
10. Betts Cove Mine
11. Mount Misery
Betts Cove
12. Rogues Harbour
Stocking Harbour
13. Silverdale
Wheeler
14. Colchester Mine
McNeily Mine
Old English Mine
15. Randell Jackman
16. Sterling
Sullivan
17. British Nfld. Explor. Ltd.
18. Atlantic Coast Copper Corp. Ltd.
19. Miles Cove Mine

22. Gullbridge Mines Ltd.
23. Lockport Mine
24. Fortune Harbour
25. Moreton's Harbour
26. Sleepy Cove
Wild Bight
27. Cobbs Arm
28. Gander Bay
29. Second Pond
Frist Pond
30. Wesleyville
31. Pelly-Shaw Nfld. Ltd.
32. La Manche
33. Wabana Mines
34. Kelligrews
Manuels
Chapel Arm
35. Nfld. Minerals Ltd.
36. Newland Enterprises Ltd.
37. St. Annes Peninsula
Oderin Island
38. Nfld. Fluorspar Ltd.
39. Old Baldy
40. Rencontre East
41. Salmonier Cove Pond
42. Hermitage Peninsula

Pomley Cove
45. Third Basin
Conne Basin
46. Great Bend
47. Burnt Hill
48. Great Burnt Lake
49. Grey River
50. Cinq Cerf
51. La Poile
52. Asarco Buchans Mine
53. Victoria Mine
54. Tulks Hill
55. Steel Mountain
56. Hooker - Flat Bay
57. Flintkote Co. of Canada
58. Indian Head
59. Aquathuna
60. Shoal Point
61. Lewis Brook Mine
62. Springer's Hill
Chrome Point
Blow-me-Down
63. North Star Cement Ltd.
64. York Harbour
65. Mount Gregory
66. Deer Lake

Figure 6.1 (after Fogwill, 1969). Generalized geology and 66 mineral deposits and occurrences of Newfoundland.

and DeGrace, 1972). The only preserved primary features indicate an original volcanic exhalative origin (Upadhyay and Strong, in press). These deposits are similar to the deposits found in ophiolite suites, termed the "Cyprus-type" deposit by Strong and Peters (1972).

Those found south of the fault are polymetallic or complex Cu, Pb, Zn, Ag, Au deposits (e.g. Buchans, Pilley's Island, Catchers Pond) and are generally found in acid to intermediate pyroclastics — generally in dacitic horizons. Tatsumi's (1970) descriptions of the polymetallic Kuroko-type deposits of calc-alkaline island arc volcanism resemble these deposits in all aspects (Strong and Peters, 1972).

6.2. Mineralization

6.2.1. Long Island

Disseminated pyrite is the most common sulphide observed on Long Island. This is generally associated with granodioritic intrusions but is also found in the black shales and interpillow jasper. Extensive massive pyrite occurs as fracture and breccia filling near the top of the acid pyroclastics on the west coast of Long Island.

Fine-grained detrital magnetite also occurs as thin lenses and disseminations in the PARSON'S POINT Formation.

Oxidation and hematitization of pyroclastics and minor lavas give a pseudo-iron formation in many localities throughout the pile.

6.2.2. Oil Islands

Although these two small islands, lying west of Lush's Bight Village were not mapped in detail, two mineral prospects were examined. Both prospects lie on the northeast coast of the easternmost island and both have been test pitted by prospectors early in this century.

Prospect 1. Chalcopyrite, pyrite and minor galena occur in quartz veins cutting dark green massive andesitic lava. The veins are generally approximately 1/4 inch wide and some veins can be traced for a meter or so; however, the veining is not extensive. Malachite staining is common.

Prospect 2. This prospect is in highly sheared, extensively pyritized agglomerate. Mineralization occurs as a fracture filling, as a replacement of fragments and as dissemination. Minor chalcopyrite was noted.

6.2.3. Seal Islands

This island is located just east of Cutwell Arm. The test-pitted prospect occurs at Seal Island Harbour on the east coast of the Island. Pyrite and malachite staining (no chalcopyrite seen) occurs in extensively sheared and altered green pillow lavas and a thin horizon of fractured and sheared black shales.

6.2.4. Little Stag Island Area

Except for a pyrite - pyrrhotite (minor chalcopyrite) horizon occurring at the contact between pillowed basalts and black shales across the tickle from Stag Island, the mineralization in this area is in the form of sulphide and minor magnetite blocks (1/4 in. to 3 ft.) in a diatreme of breccia deposit

(BRECCIA member of the STAG ISLAND Formation).

The subangular blocks have a random size distribution but on both Little Stag and Crow Island they occur near the base of the deposit.

The chemistry of some of the blocks is shown in Table 6.1, and a comparison to the Pilley's Island sulphide showings may be made by comparing with Table 6.2.

TABLE 6.1

Analyses of Samples From Stag Island Diatreme.

Sample No.	Dominant Mineralogy	% Cu	% Pb	% Zn	% Ni	% Ba	% Fe	Ag oz./ton
1	Magnetite (minor pyrite)	0.02	ND	..01	TR	.02	56.0	0.29
2	Pyrite (chalcopyrite)	1.55	.01	.02	TR	ND	-	0.09
3	Pyrite, magnetite chalcopyrite	1.00	TR	.01	TR	ND	42.0	0.09
4.	Pyrrhotite, pyrite chalcopyrite	12.00	TR	.24	.01	ND	-	.73
5	Pyrite, chalcopyrite, sphalerite	1.55	TR	4.70	.01	ND	-	.35
6	Pyrite Chalcopyrite	1.80	TR	.06	TR	ND	-	.06
8	Pyrrhotite Chalcopyrite	2.90	TR	.18	TR	ND	-	.09
10	Pyrrhotite Chalcopyrite	2.50	TR	.31	.01	ND	-	.38

TABLE 6.2

Analyses of Samples from Pilleys Island

	S %	Cu %	Pb %	Zn %	Ag oz./ton
1.	38.6	1.20	3.3	4.8	--
2.	34.41	0.08	0.58	4.4	--
3.	36.1	3.36	0.84	15.0	1.24

1. No. 5 dump of Old Mine.
2. Henderson showing.
3. Bull Road showing.

6.2.4.1. Mineralogy of the Rocks

In general, pyrite, chalcopyrite, pyrrhotite, sphalerite and magnetite occur in that order of abundance. However, some blocks consist essentially of one mineral, eg. magnetite.

The following descriptions are based on the observations of 11 polished sections of blocks.

Pyrite is the most common sulphide and was found in all specimens and generally is the dominant sulphide but occasionally is subordinate to pyrrhotite. The pyrite often occurs in euhedral cubes and often displays a "stockwork" (piecemeal) brecciation (Figure 6.2). It also occurs in a massive subhedral to anhedral form (Figure 6.3). Brecciation of this has given rise to crushed-pyrite zones (Figure 6.3).

Chalcopyrite occurs as vein material in the crushed-pyrite and "stockwork" breccia zones. Chalcopyrite also occurs replacing pyrite.

An ill-defined colloform texture defined by the pyrite can be observed in both hand specimen and polished section of specimen No. 3 (Table 6.1). Dehydration and compaction gives a brecciated texture to this specimen.

Pyrrhotite was recognized in five of the polished sections. It occurs in a massive and a disseminated form. It contains inclusions of chalcopyrite and is embayed by chalcopyrite. Its relationship to pyrite is not clear.

In many cases the pyrrhotite is partially altered to fine-grained marcasite (cf. Ramdohr, 1969, p. 593, Figure 415E, p. 827) giving a 'cellular' or 'tubular' texture (Figure 6.4). Rarely the pyrrhotite is completely altered to marcasite and pyrite.

Chalcopyrite varies markedly in amount but is present in all specimens examined. It occurs as inclusions in both the pyrite and pyrrhotite, and it involves (embays) them also. It also forms veins and fills the interstices between the pyrite grains. Chalcopyrite also occurs as inclusions and blebs and with an invading relationship to sphalerite (Figure 6.5).

Sphalerite was found in only two polished sections. Generally it displays a sharp boundary against both pyrite and chalcopyrite, however, as seen in Figure 6.5 it also has an invading relationship to pyrite.

Magnetite was observed in two polished sections. One section is

Figure 6.2 (x10) Euhedral and brecciated pyrite (white) veined and replaced by chalcopyrite (yellow). Gangue (grey)

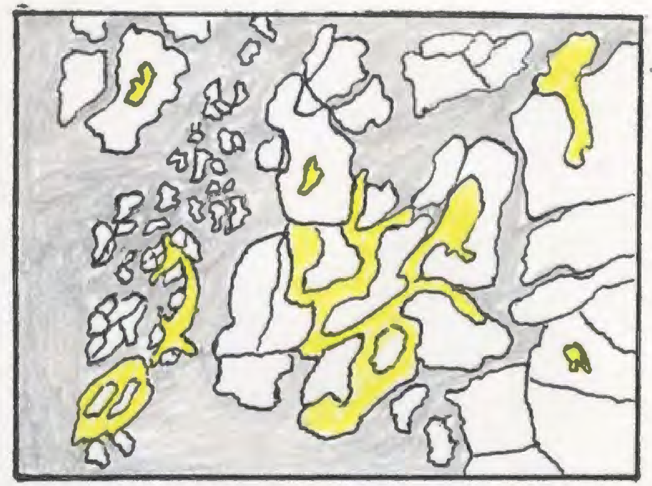


Figure 6.3 (x10) Anhedral, subhedral and massive pyrite (white). Crushed pyrite zone on the left. Chalcopyrite (yellow). Gangue (grey).

Figure 6.4 (x10) Pyrrhotite (orange) being altered to marcasite (blue) along margins and fractures. Chalcopyrite (yellow). Gangue (grey).

Figure 6.5 (x20) Shows relationship between pyrite (white), chalcopyrite (yellow) and sphalerite (black). Gangue (grey).

essentially all magnetite in a massive, amaeboid texture containing very rare pyrite inclusions. In the other it occurs with both pyrite and chalcopyrite. The chalcopyrite often has an invading relationship to the magnetite and contains inclusions of magnetite.

Minor ilmenite occurs as dark-grey, lath-like zones within the magnetite, i.e. as exsolution lamellae.

6.2.4.2. Discussion

Kanehira and Bachinski (1968) described identical textures and mineralogy for the Whalesback ores. These blocks are also chemically similar to the mineralization north of the fault, i.e. ophiolite sulphides or Lush's Bight terrain mineralization.

This then suggests primary oceanic crust origin for the blocks in the Stag Island diatreme (BRECCIA member). However, since these blocks represent fragments of an explosively-disrupted mineralized zone that lies at a lower stratigraphically level, there may also be polymetallic blocks present representing an incipient island arc or 'Kuroko type' deposit.

The SW dipping and facing directions of this BRECCIA member indicate that the source area for these blocks lies to the northeast, i.e., under the sea. However, as discussed in Section 2.2.2, the fragments in the diatreme have travelled a minimal distance and therefore the source area must be in close proximity, both horizontally and vertically.

6.3. Conclusion

Of the three mineral occurrences discussed the Oil Islands prospects and the Stag Island area warrants further investigation. The Seal Island prospect was rather barren except for minor pyrite, although the black shale horizons within basaltic pillow lavas are a favourable geological environment.

Prospect 2 on the Oil Islands appears to be of a secondary replacement nature. It is mainly pyrite with minor chalcopyrite. However, the chalcopyrite - galena occurrence (Prospect 1) in quartz veins is of interest and may warrant further test-pitting and detailed geological mapping.

The sulphide blocks in the Stag Island diatreme (BRECCIA member) is of the greatest interest. It should possibly be remapped on a scale of 1 inch = 50 feet, with particular emphasis on the stratigraphic and size distribution of the mineralized blocks. A ground magnetic and gravity survey might also be useful in delineating any anomalous zones. Submarine sampling of the surrounding area might also be worthwhile.

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Plate 1. Basaltic pillow lavas of the Lower Basalt Member of the STAG ISLAND Formation. Note the scarcity of interpillow material. Stag Island.

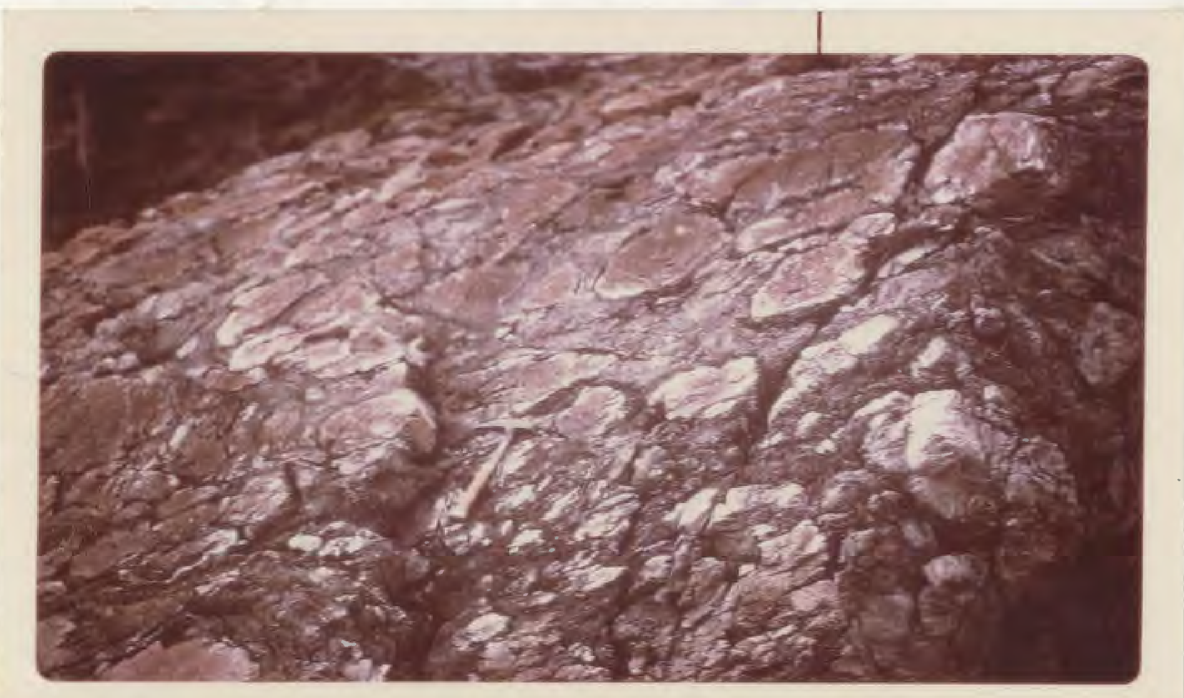


Plate 2. Pillow-Breccia developed in the LOWER BASALT Member. Northern end of Stag Island.

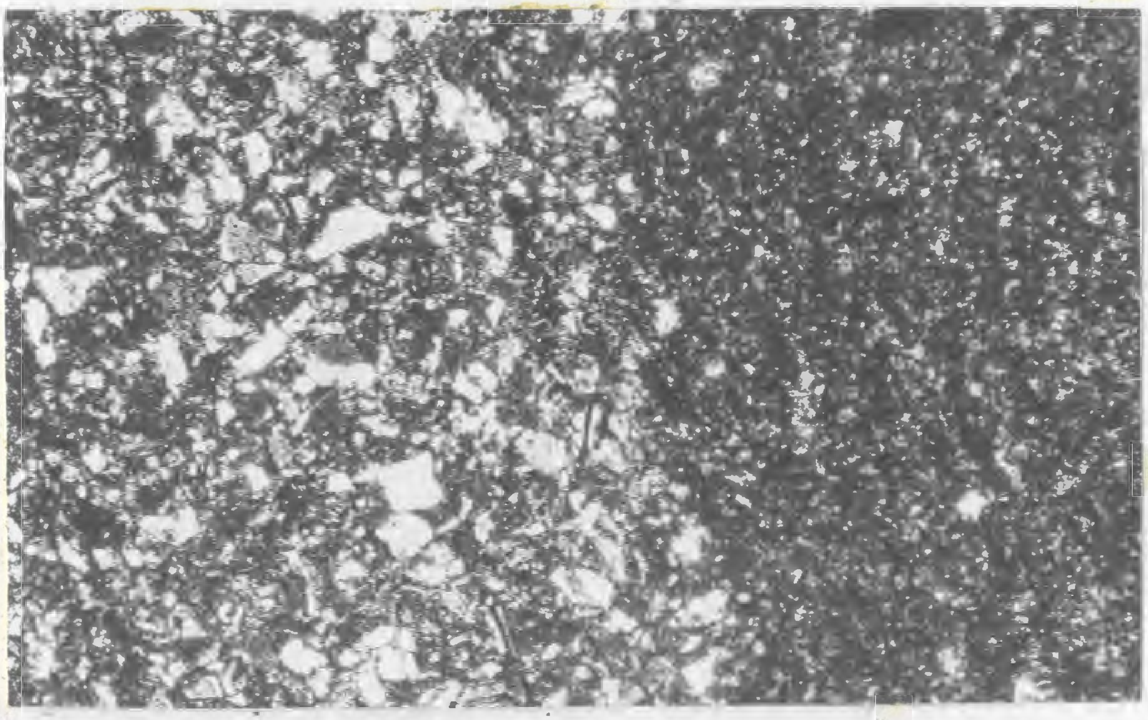


Plate 3. Photomicrograph showing grading in reworked tuff from the PIGEON HEAD Formation (x38). Pigeon Head, x-nicols.

Plate 4. Reworked and bedded tuff in the PYROCLASTIC Member of the BURNT HEAD Formation. Western Head area.

Plate 5. Photomicrograph of reworked tuff from the PYROCLASTIC Member (x38), Cutwell Arm. Plane polarized light.

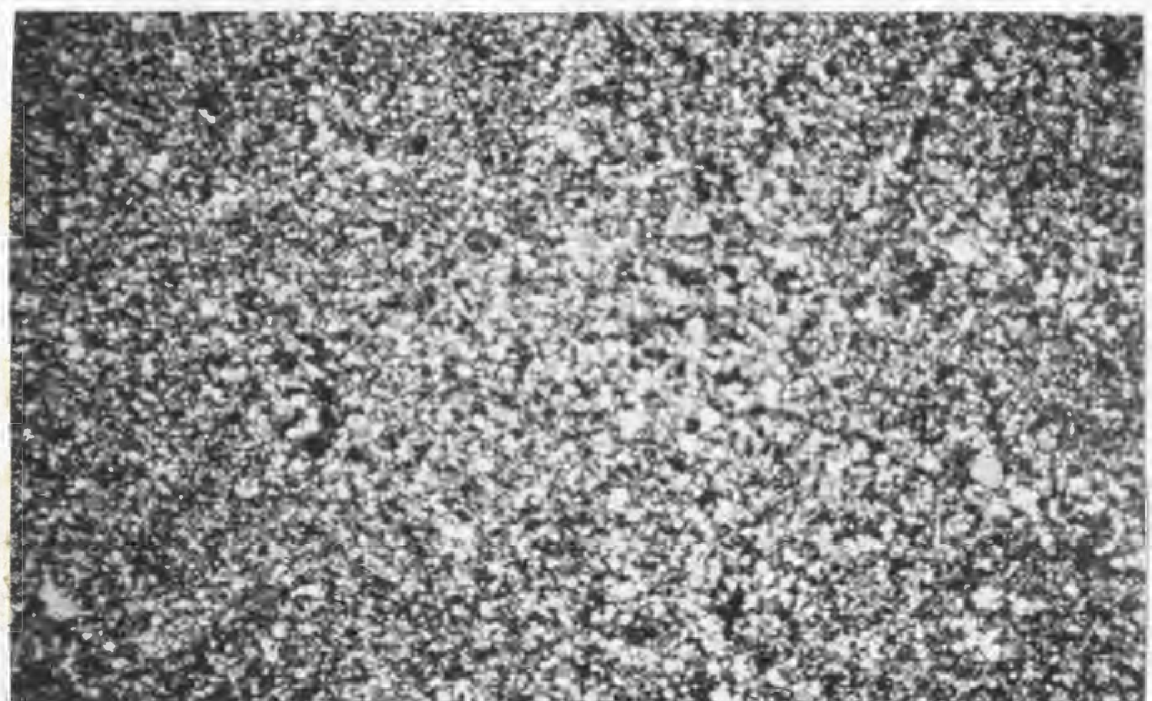


Plate 6. Photomicrograph of chert from the PYROCLASTIC Member (x38), Cutwell Arm, x-nicols.

Plate 7. Isolated andesite pillows in a tuffaceous matrix in the PYROCLASTIC Member, Burnt Harbour, Cutwell Arm.

Plate 8. Photomicrograph of acid pyroclastics in the PYROCLASTIC Member (x38), Flint Islands area, west coast of Long Island, x-nicols.

Plate 9. Typical andesite pillow lavas of the PILLOW-ANDESITE Member, Wild Bight.

Plate 10. Typical andesite pillow lavas of the PILLOW-ANDESITE Member, Wild Bight.

Plate 11. Slump folded tuffs of the PYROCLASTIC Member. This particular horizon occurs intercalated between andesite pillow lavas, Shagg Cliff, Wild Bight.

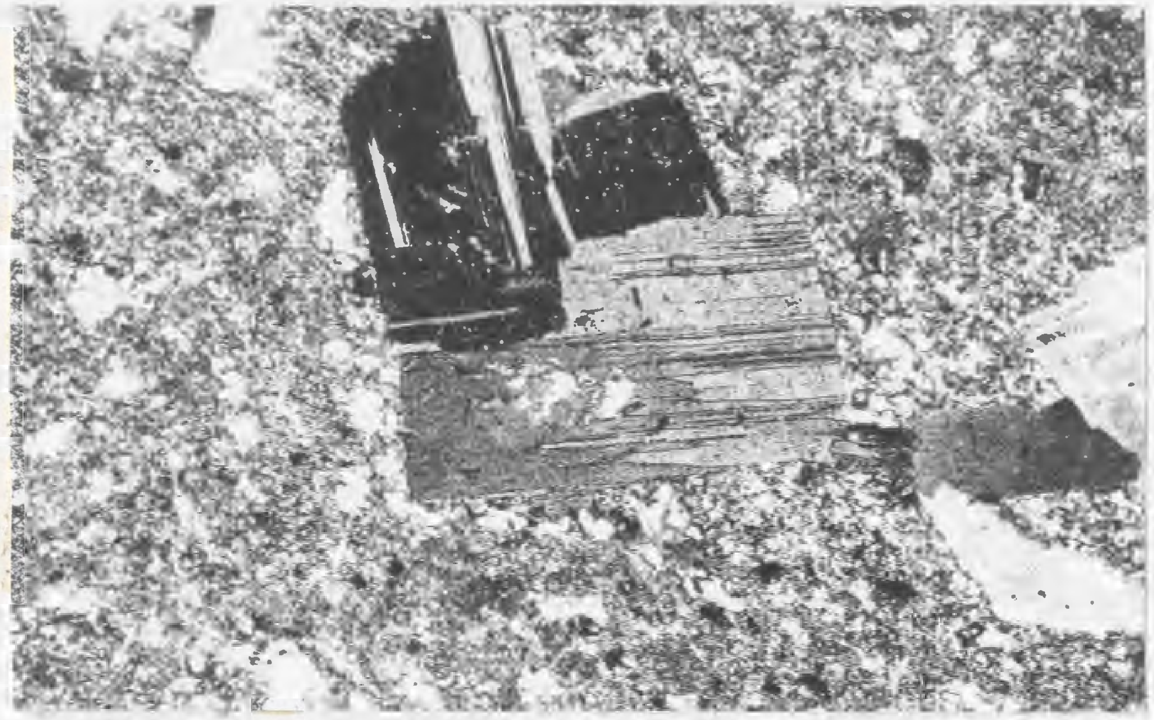


Plate 12. Photomicrograph of the SEAL COVE COMPLEX dacite showing the typical plagioclase phenocrysts and silicified groundmass (x38), Seal Cove area. x-nicols.

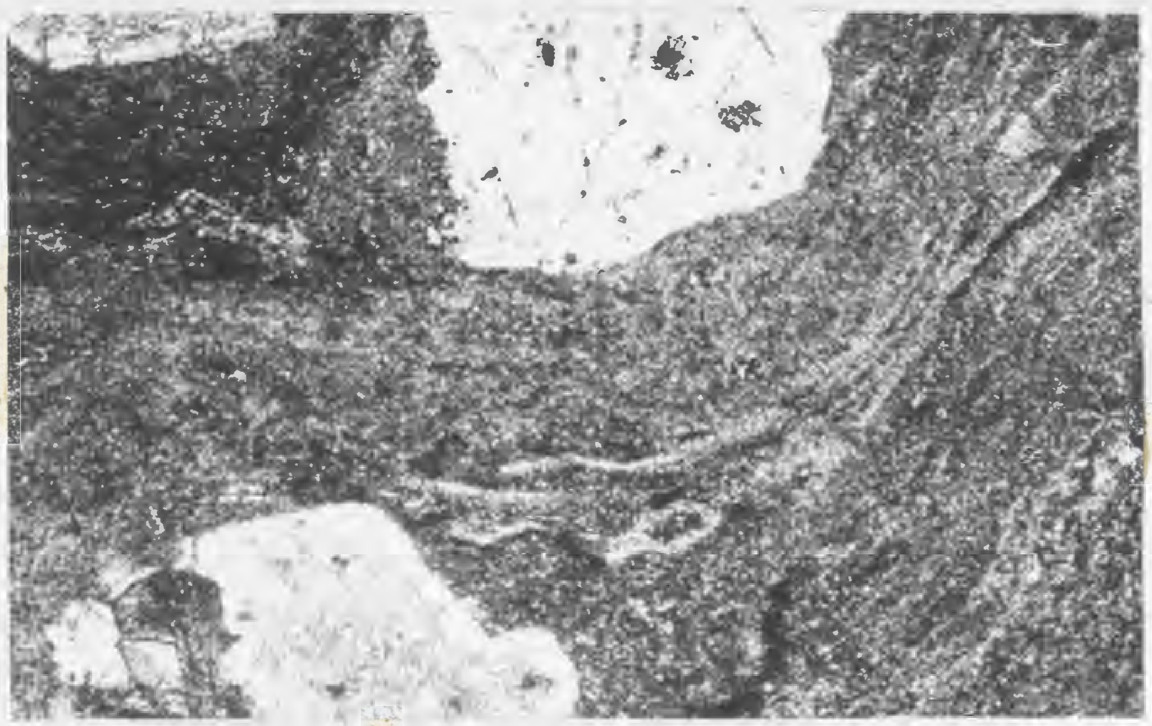


Plate 13. Flow-banding in the SEAL COVE Complex (x38), Seal Cove area. Plane polarized light.

Plate 14. Graded tuffs from the LONG TICKLE Formation showing well-developed flame structures. Milkboy's Cove area.

Plate 15. Cephalopod in a limestone lens, west of Milkboy's Cove, (~2,000 feet).

Plate 16. Bomb agglomerate from the LONG TICKLE Formation. About 4,000 feet west of Milkboy's Cove.

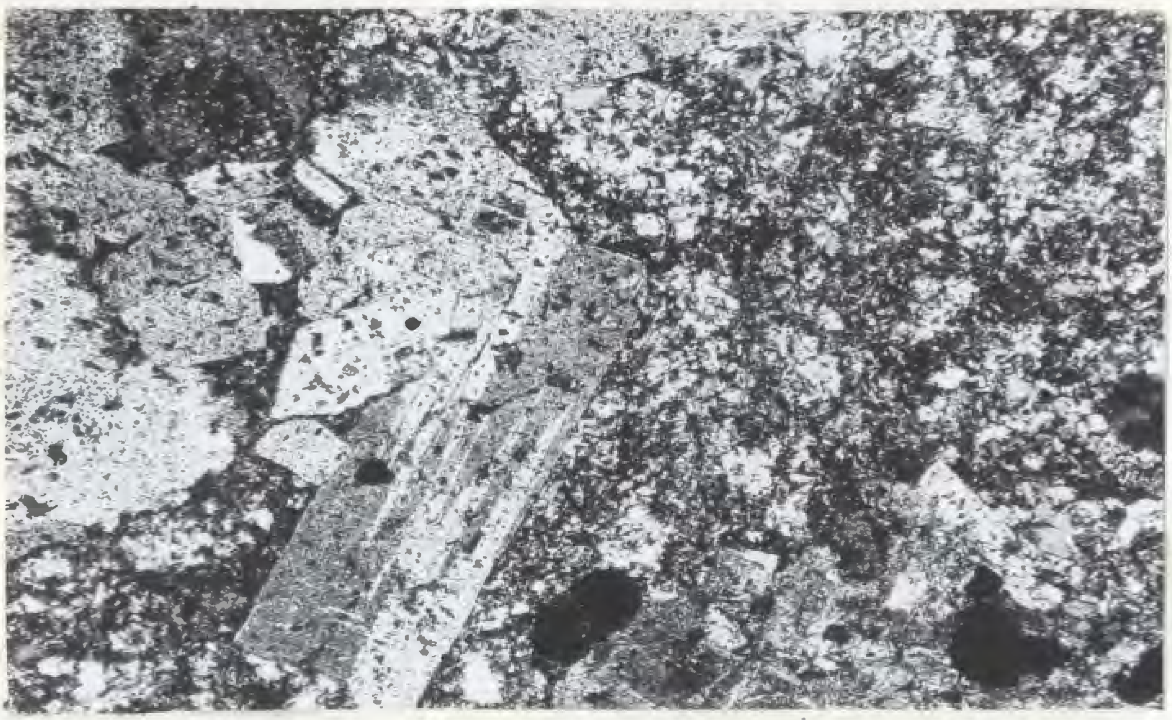


Plate 17. Photomicrograph of a dacitic plug (x38). Southern Head areas. x-nicols.

Plate 18. Photomicrograph of chloritized pyroclastics 250 feet east of the Long Island Pluton (x38), x-nicols.

Plate 19. Fibrous actinolite-tremolite developed in tuffs, 50 feet east of the Long Island Pluton. (x150), x-nicols.

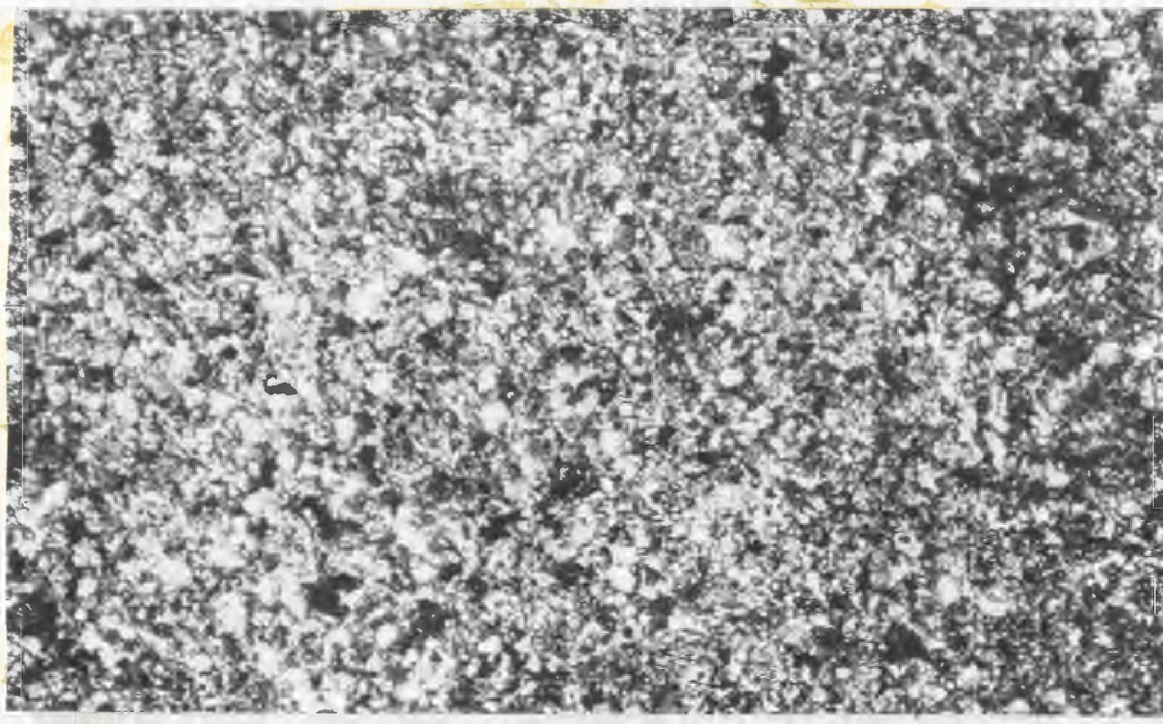


Plate 20. Recrystallized and amphibolitized country rock on the south contact of the Long Island Pluton (x38). Light minerals are feldspar and quartz; dark minerals are green hornblende. X-nicols.

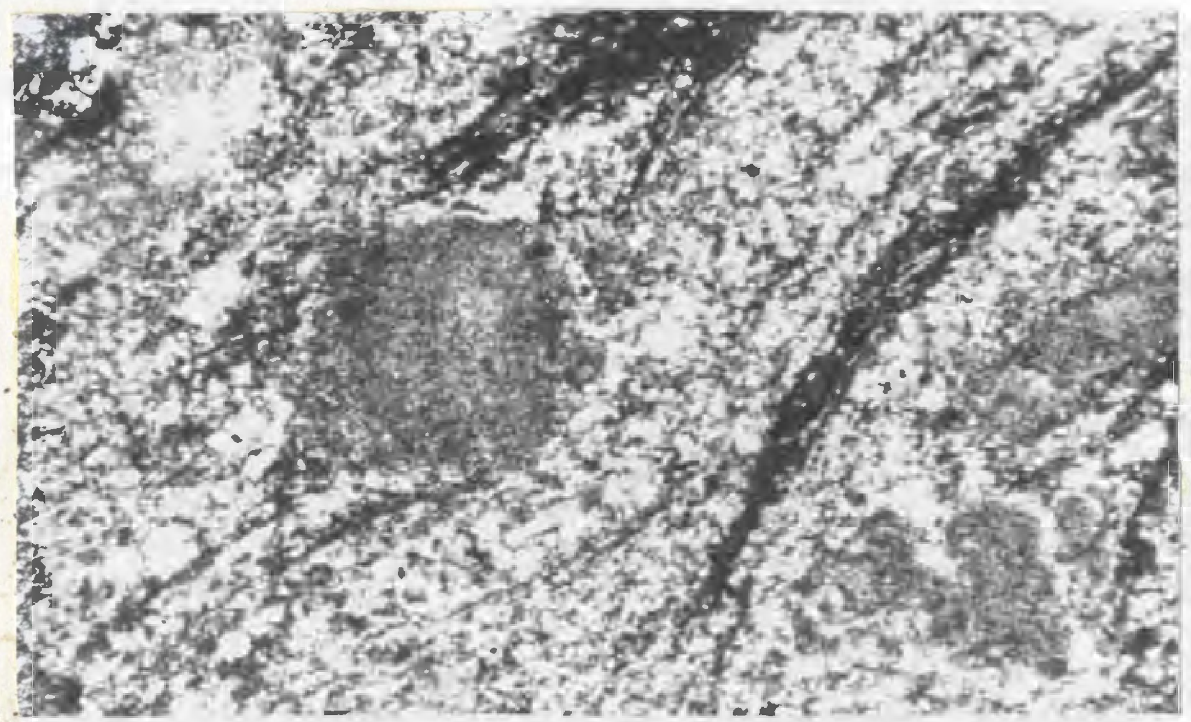


Plate 21. Recrystallized and schistose pyroclastics from the north contact of the Long Island Pluton (x38). The schistosity is defined by the thin bands and stringers of chlorite and chloritized mafics (dark bands). X-nicols.

Plate 22. Photomicrograph of poikilitically included olivine in amphibole pseudomorphing pyroxene, from the basic phase of the Long Island Pluton (x38), 1,500 feet east of the Southwest tip of Long Island. X-nicols.

Plate 23. Photomicrograph of the late diabase dykes (x38). Note the intergranular texture, i.e. pyroxene occupying the interstices between the plagioclase. Stag Island area. X-nicols.

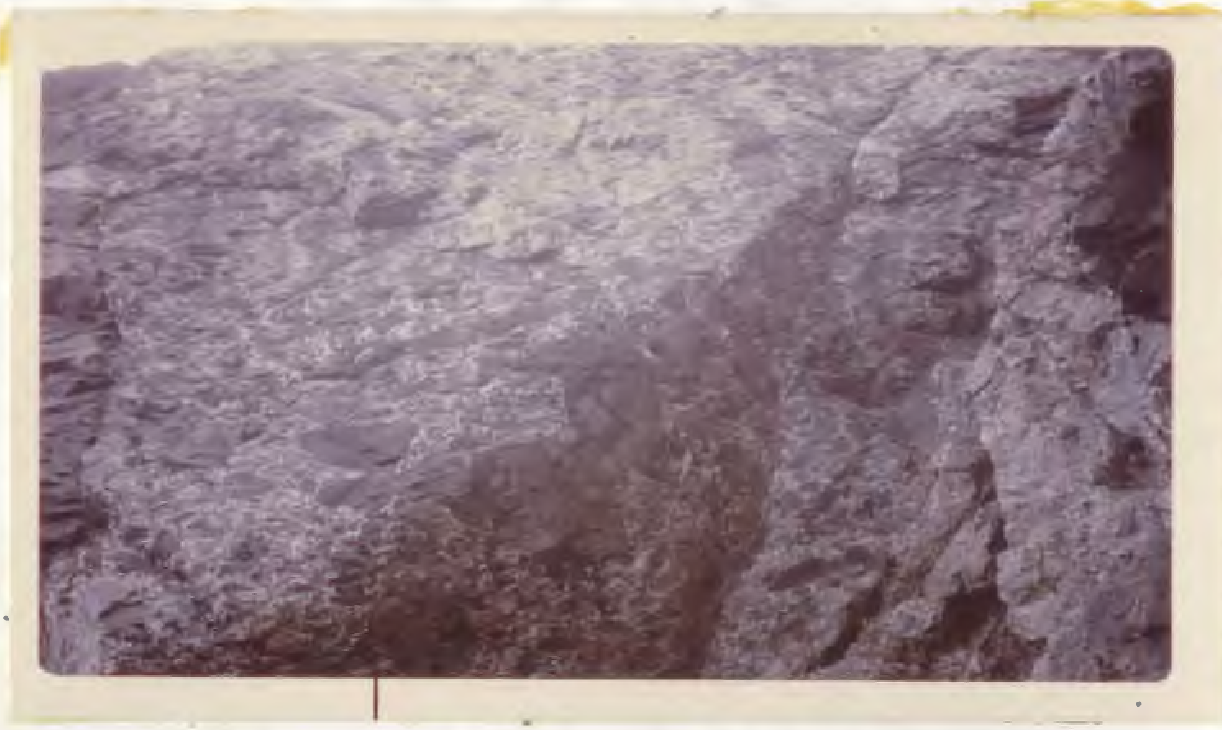


Plate 24. Explosive brecciation or diatreme developed on Western Head, northern Long Island.

Plate 25. Skeletal plagioclase microlites in a devitrified glass matrix, from the LOWER BASALT Member (x38), Stag Island. Plane polarized light.

Plate 26. Clinopyroxene microphenocrysts in the glassy basalt of the LOWER BASALT Member (x150), northern end of Stag Island. Plane polarized light.

Plate 27. Albite replacing plagioclase in the LOWER BASALT Member (x150), northern end of Stag Island. X-nicols.

Plate 28. Saussuritized and fresh plagioclase phenocrysts, microphenocrysts and microlites in a cryptocrystalline groundmass, from the PILLOW-ANDESITE Member, Cutwell Arm area, (x38), plane polarized light.

APPENDIX I

Analytical Methods

The major element oxides, excluding P_2O_5 were determined using a Perkin Elmer 303 Atomic Absorbtion Spectrometer. Sample preparation consists of dissolving 0.2000 grams of -200 mesh sample in 5 cc. of HF. This was further diluted with 50 cc. of saturated Boric Acid and made up to 200 cc. with distilled water. From this 'stock' solution further dilutions were made (5 in 50) for comparison with standard blends. These standards used were both artificial and United States Geological Survey rock standards.

In the cases of CaO and MgO, 10 cc. of La_2O_3 and 5 cc. of HCl were added per 50 cc. solution to act as a releasing agent to suppress the interference of aluminum and phosphorus with these determinations.

The oxides were calculated both graphically and mathematically by proportionality equations.

P_2O_5 was determined colorimentrically by the method described by Maxwell (1968, p. 394).

Tha analyses for all trace elements were carried out by X-ray fluorescence using a Phillips PW 1220 computerized spectrometer. Four grams of sample group to -200 mesh and pressed (15 tons for 1 minute) into Borax backed discs of powder, with 10% dilution with sugar as a binding agent. A tungsten X-ray tube and LiF analyser crystal were used in all cases. Excitation was 80 KV and 20 mA.

Table A-1 gives the accuracies and precisions of the methods used. The means ($\overline{X}$) used for the calculation of the precision of the Atomic Absorbtion analyses are those calculated by Mrs. G. Andrews, however, as can be noted the values obtained during the present study fall within the Range (R) given by Mrs. Andrews.

TABLE A-1

Accuracy of Atomic Absorbtion

BCR-1

wt.%	A	B
SiO_2	54.36	54.38
TiO_2	2.24	2.26
Al_2O_3	13.56	13.50
Fe_2O_3	13.40	13.32
CaO	6.94	6.70
MgO	3.46	3.56
Na_2O	3.26	3.29
K_2O	1.67	1.71
MnO	0.19	0.19

A = Abbey's proposed values.

B = values obtained in this study.

TABLE A-1 (cont.)

Precision of Atomic Absorbtion Analysis

BCR-1

wt.%	$\bar{X}$	R	S	N	C%
SiO_2	55.38	54.93 - 55.78	0.37	4	0.01
TiO_2	2.35	2.21 - 2.60	0.18	4	0.08
Al_2O_3	13.50	13.10 - 13.76	0.27	5	0.02
Fe_2O_3	13.00	12.64 - 13.41	0.28	5	0.02
CaO	6.63	6.59 - 6.74	0.07	4	0.01
MgO	3.57	3.50 - 3.65	0.06	5	0.02
Na_2O	3.23	3.16 - 3.31	0.05	5	0.02
K_2O	1.73	1.68 - 1.79	0.05	4	0.03
MnO	0.18	0.18 - 0.19	0.01	5	0.02

$\bar{X}$ = Mean R = Range (max.-min.); S = Standard deviation from mean;

N = No. of determinations

C = Coefficient of variation

Precision of X-ray Fluorescence

Element	No. of determinations	Mean	Standard Deviation
Zr	23	438	4
Sr	31	197	5
Rb	31	94	2
Zn	30	59	1
Cu	30	109	4
Ni	29	210	3
Co	32	176	1
Cr	31	362	2
V	32	63	1
Ba	31	1,783	13

APPENDIX II

TABLE A-II

Major and Trace Elements in Analysed Intrusive Rocks
from Halls Bay area, N.D.B.

Sample Numbers

	1	2	3	4	5	6	7	8
SiO_2	50.30	48.10	48.40	48.60	50.40	48.10	47.80	48.50
Al_2O_3	18.00	10.10	14.10	12.40	18.80	14.50	11.90	15.90
TiO_2	0.76	0.54	0.54	0.63	0.68	1.96	3.50	0.68
MnO	0.15	0.19	0.18	0.20	0.16	0.22	0.27	0.16
Fe_2O_3*	9.95	9.33	11.17	11.35	9.00	13.30	17.70	9.10
MgO	4.50	11.00	10.50	10.80	4.80	5.90	3.70	7.80
CaO	9.40	15.50	13.70	13.60	9.50	8.30	10.00	11.60
Na_2O	2.56	0.91	0.60	1.04	2.70	4.01	1.82	3.32
K_2O	0.75	0.45	0.31	0.35	0.63	0.15	.01	0.16
P_2O_5	0.10	0.05	n.d.	0.04	0.11	0.24	0.29	0.03
L.I.**	3.53	5.25	2.18	2.32	2.46	2.10	3.40	2.73
Total	100.00	101.42	101.68	101.33	99.24	98.72	100.48	99.98
Rb	18	14	10	2	12	2	n.d.	n.d.
Sr	365	300	484	240	423	243	280	242
Cr	75	540	338	410	100	80	62	375
Ni	16	80	80	75	25	20	5	95
Cu	15	10	40	80	n.d.	5	20	95
Zn	93	69	76	73	75	117	110	73

n.d. = not detected

* = Total Iron as Fe_2O_3

** = Loss on Ignition.

TABLE A-II (cont.)

	Sample Numbers							
	9	10	11	12	13	14	15	16
SiO_2	48.00	54.70	65.20	57.60	50.00	50.70	49.20	48.50
Al_2O_3	14.80	15.10	16.60	16.90	11.80	10.20	13.20	15.60
TiO_2	0.70	0.80	0.40	0.73	0.80	0.63	0.77	0.72
MnO	0.17	0.12	0.05	0.10	0.16	0.19	0.19	0.14
Fe_2O_3*	9.80	6.00	4.70	5.09	8.45	8.72	11.70	8.90
MgO	8.80	7.00	2.30	5.80	13.10	13.60	8.52	8.73
CaO	10.60	6.50	3.50	6.40	8.80	9.70	9.27	10.00
Na_2O_3	2.62	3.60	5.49	4.50	2.34	2.00	2.29	2.43
K_2O	0.12	2.08	1.44	1.54	1.08	0.97	0.13	0.32
P_2O_5	0.05	0.23	0.15	0.18	0.14	0.42	-	-
L.I.**	2.47	1.75	1.11	1.46	2.37	1.81	3.91	3.63
Total	98.13	97.88	100.94	100.30	99.04	98.94	99.18	98.97
Rb	n.d.	76	44	56	30	35	-	-
Sr	178	540	572	808	392	382	-	-
Cr	440	290	105	260	950	960	-	-
Ni	80	140	35	125	280	365	-	-
Cu	55	5	8	30	5	15	-	-
Zn	114	93	50	78	119	120	-	-

n.d. = Not detected

\- = Not determined

* = Total Iron as Fe_2O_3

** = Loss on Ignition

TABLE A-II (cont.)

Sample Numbers

	17	18	19	20	21
SiO	47.60	46.90	49.50	48.20	65.70
Al_2O_3	16.80	13.60	19.40	16.30	15.10
TiO_2	0.93	2.34	0.29	0.70	0.31
MnO	0.19	0.22	0.14	0.17	0.11
Fe_2O_3*	11.90	14.30	7.00	10.90	4.60
MgO	6.43	5.78	5.75	7.10	1.19
CaO	9.57	10.00	9.32	9.56	4.15
Na_2O	1.97	3.34	2.88	3.11	3.57
K_2O	0.31	0.28	1.69	0.40	1.41
P_2O_5	-	-	-	-	-
L.I.**	3.43	1.92	2.45	2.76	3.01
Total	99.13	98.68	98.42	98.74	99.15

- = Not determined

* = Total Iron as Fe_2O_3

** = Loss on Ignition

TABLE A-II (cont.)

	Sample Numbers	
	225	269
SiO_2	47.60	59.90
TiO_2	1.91	0.53
Al_2O_3	13.46	15.84
Fe_2O_3	1.76	1.51
FeO	10.23	5.52
MnO	0.19	0.11
NgO	6.00	2.56
CaO	9.61	1.98
Na_2O	3.72	2.80
K_2O	0.52	2.20
P_2O_5	0.29	0.36
L.I.**	2.37	4.80
Total	98.57	98.09
Q	-	24.32
Or	3.23	13.98
Ab	29.35	25.44
An	19.44	8.02
Ne	2.03	-
Aug	23.92	-
Hy	-	19.70
Ol	17.50	-
Mt	-	-
Ilm	3.81	1.08
Ap	0.71	0.90
Rb	11	58
Sr	119	36
Ba	56	604
Zr	115	129
Cu	71	-
Zn	94	101
Cr	86	14
Ni	45	3

** = Loss on Ignition

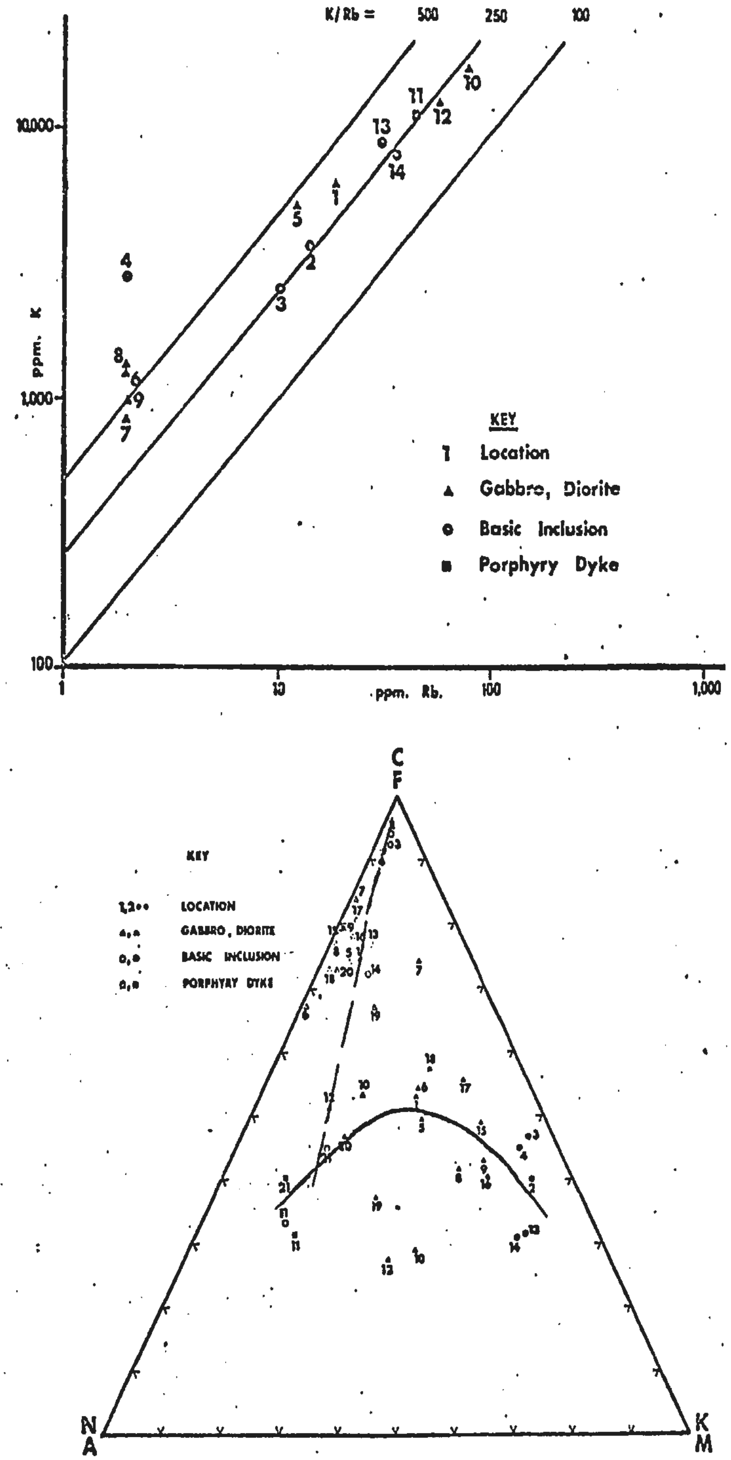


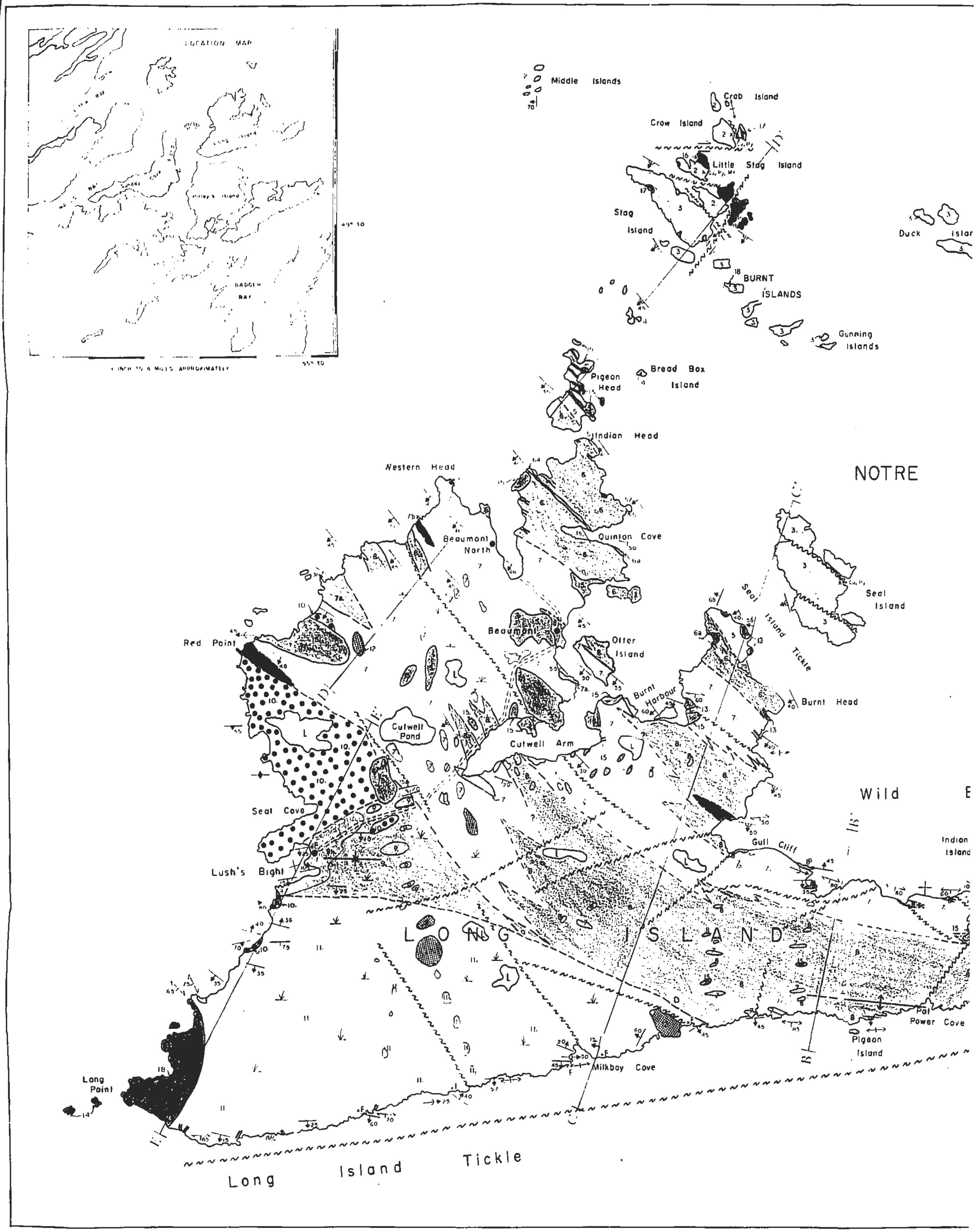
Figure A-II(after Kean, 1971) - K/Rb and FMA - CNK diagrams showing the 'non-oceanic' or non-tholeiitic nature of INTRUSIVE rocks in the Notre Dame Bay area, Newfoundland. Solid symbols represent the FMA plot; the open symbols, the CNK plot.

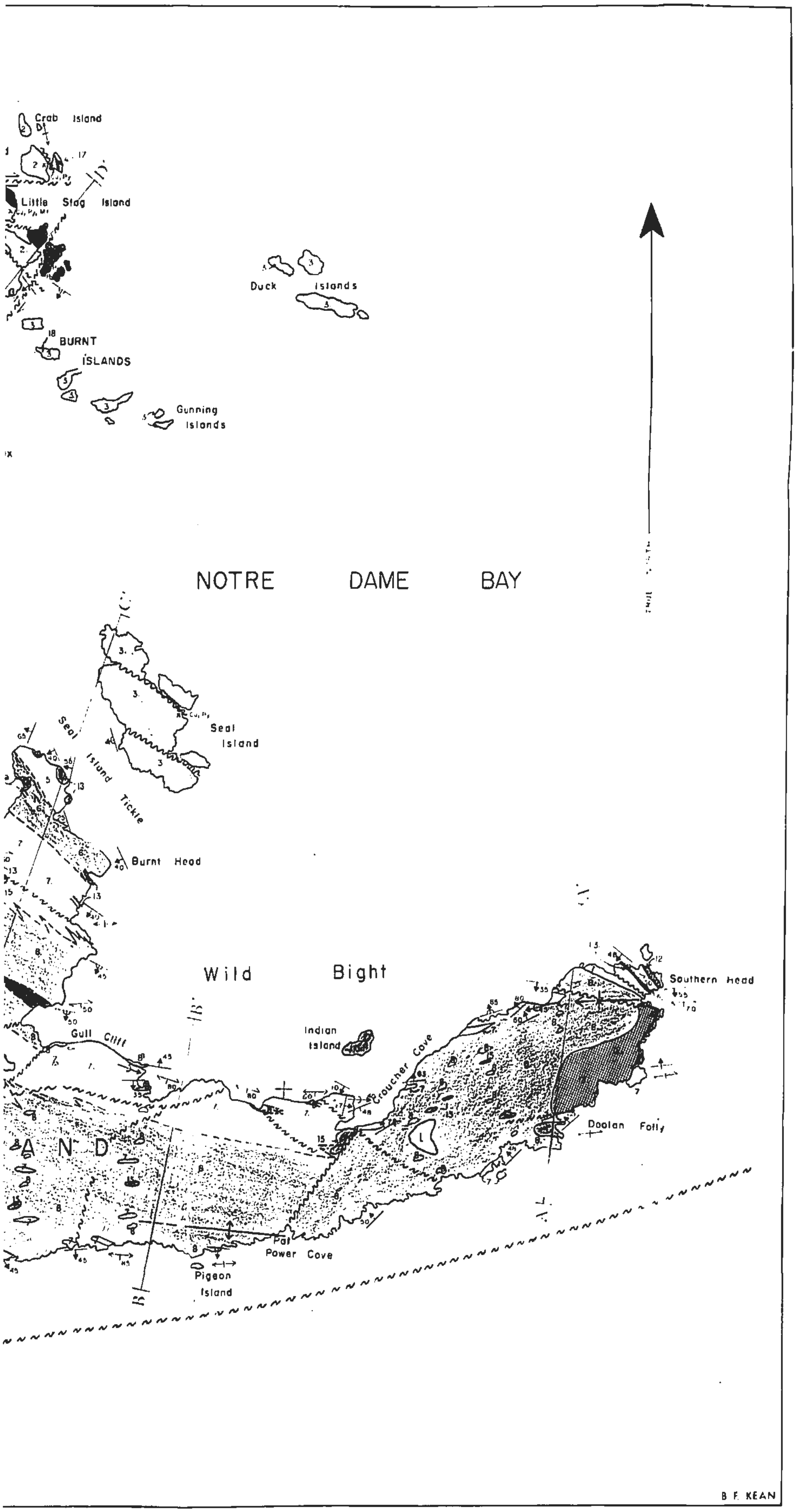
Sample Locations and Types of the Analysed Intrusive Rocks from Halls Bay area, Notre Dame Bay, Newfoundland

1. (K-5-70) Quartz Diorite, Sunday Cove Island.
2. (K-80-70) Basic Inclusions, Sunday Cove Island.
3. (K-9-70) Basic Inclusions, Sunday Cove Island.
4. (K-29-70) Basic Inclusion, Sunday Cove Island.
5. (K-34-70) Gabbro Dyke, Sunday Cove Island.
6. (KP-4-70) Gabbro Dyke, Pilleys Island.
7. (KP-5-70) Layered Gabbro boulder, Pilleys Island.
8. (KP-7-70) Gabbro Dyke, Pilleys Island.
9. (KL-8-70) Gabbro, Long Island Pluton.
10. (KL-10-70) Granodiorite, Long Island Pluton.
11. (KL-10A-70) Quartz-Feldspar Porphyry Dyke, Long Island
12. (KL-11-70) Granodiorite, Long Island Pluton.
13. (KL-11B-70) Basic Inclusion, Long Island Pluton.
14. (KL-11A-70) Basic Inclusion, Long Island Pluton.
15. (JRD - 6-70) Gabbro Dyke, King's Point Area.
16. (JRD-19-70) Gabbro Dyke, King's Point Area.
17. (JRD-97-70) Gabbro Dyke, King's Point Area.
18. (BM-158) Gabbro, Western Arm.
19. (BM-136) Gabbro, Western Arm.
20. (P-65-5) Gabbro, Map 12H 19E. 49°33'44"N. 56°04'25"W. Small stock north of a small lake (Vein Pond), 3/4 mile north of Davis Pond.
21. (BM-140) Porphyry Dyke, Western Arm

225. (K-225-71) Fine-grained Gabbro plug associated with porphyry diabase, Stag Island area, Long Island.

269. (K-269 (2)-71) Fine-grained late andesite dyke, Wild Bight, Long Island.


LOCATION MAP
BADGER BAY
1 INCH TO 4 MILES APPROXIMATELY
Middle Islands
Crab Island
Crow Island
Little Stag Island
Stag Island
BURNT ISLANDS
Gunning Islands
Duck
Pigeon Head
Bread Box Island
Indian Head
Western Head
NOTRE
Quinton Cove
Beaumont North
Seal Island
Seal Island Tickle
Red Point
Beaumont
Otter Island
Burnt Harbour
Burnt Head
Cutwell Pond
Cutwell Arm
Wild
Seal Cove
Gull Cliff
Indian Island
Lush's Bight
LONG ISLAND
Power Cove
Pigeon Island
Milkboy Cove
Long Point
Long Island Tickle



LEGEND

LATE ORDOVICIAN OR LATER

Lamprophyre Dykes

ORDOVICIAN

INTRUSIVE ROCKS

Porphyritic Diabase, Gabbro

Felsic Dykes

Quartz Feldspar Porphyry, Granodiorite

Granodiorite (Long Island Pluton)

Gabbro, Andesite, Diabase

Dacite

ORDOVICIAN

CUTWELL GROUP

LONG TICKLE formation
11 Interbedded and interfingered lava, agglomerate, tuff limestone

SEAL COVE COMPLEX
10 Dacitic intrusive (dykes, sills) and extrusive (flow, agglomerate, tuff) complex (Probably coeval with 7 to 11)

PARSON'S POINT formation
9 Interbedded limestone, limestone breccia, black shales, grits and pyroclastics

BURNT HEAD formation
8 PILLOW ANDESITE member
Pillows, isolated pillows, pillow breccia, massive flows

PYROCLASTIC member
7 Basic and intermediate tuff, chert, argillite
7b Agglomerate
7a Acid tuff

QUINTON COVE formation
6 Coarse agglomerate
6a Tuff

PIGEON HEAD formation
5 Black shales, basic and intermediate pyroclastics, arkose

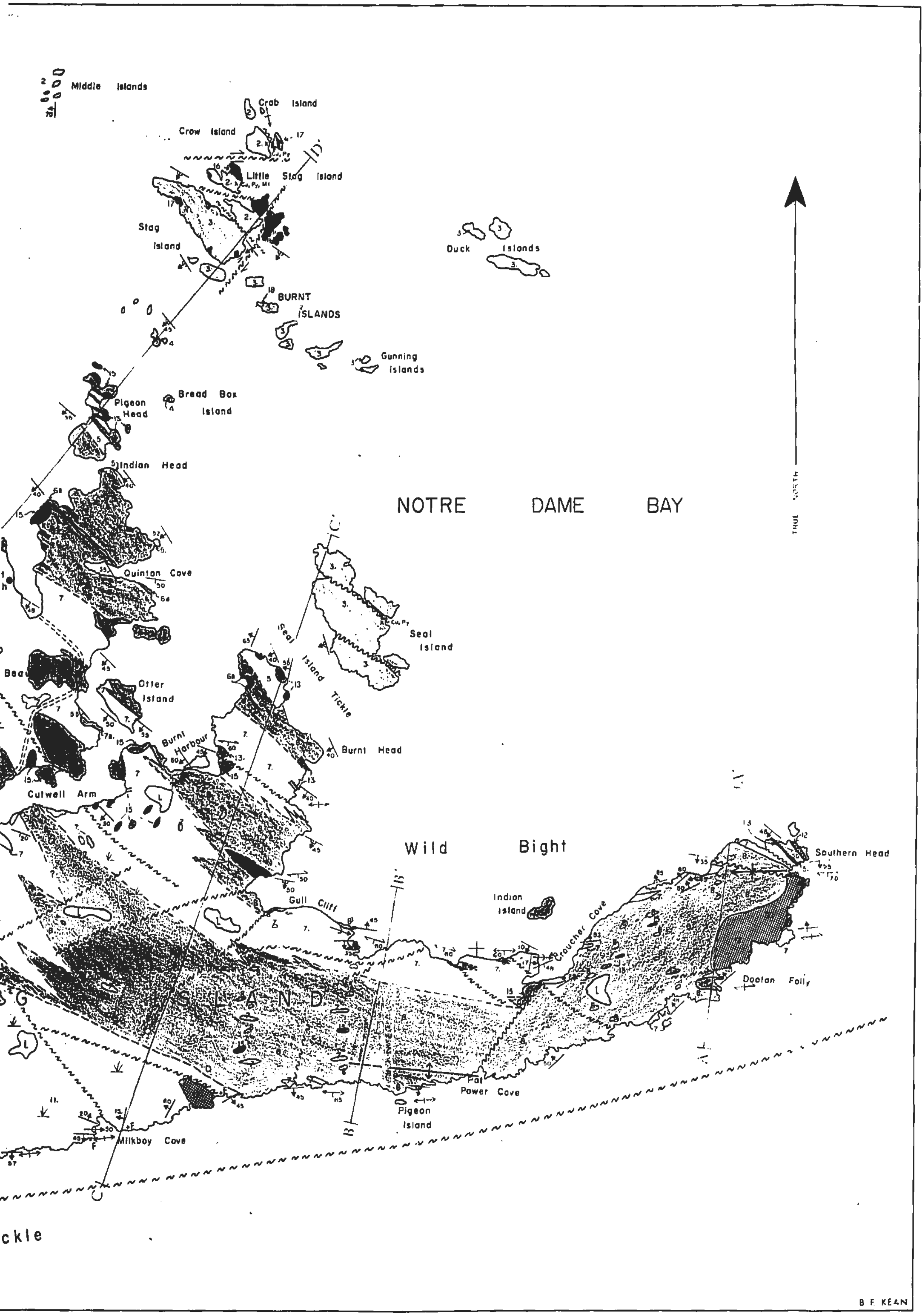
STAG ISLAND formation
4 UPPER BASALT member
Black pillow basalt

LOWER BASALT member
3 Grey-green glassy basalt pillows

BRECCIA member
2 Water-worked, explosive breccia deposit

INTRUSIVE member
1. Diabase dykes, gabbro and basaltic pillow lava

Bedding, tops k
Bedding, tops u
Flow banding
Schistosity (inc
Shearing (inclin
Minor fold (an
Major fold (an
Fault (defined,
Outcrop . . .
Geological cont
Mineral prospec
Road (gravel) .
Marsh . . . .
Lake, Pond . . .
Fossils . . . .



LEGEND

LATE ORDOVICIAN OR LATER

18	Lamprophyre Dykes

ORDOVICIAN

INTRUSIVE ROCKS

17	Porphyritic Diabase, Gab
16	Felsic Dykes
15	Quartz Feldspar Porphyr
14	Granodiorite (Long
13	Gabbro, Andesite, Dio
12	Dacite

ORDOVICIAN

CUTWELL GROUP

11	LONG TICKLE forma 11 Interbedded and interfin agglomerate, tuff limesto
10	SEAL COVE COMPLEX 10 Dacitic intrusive (dykes, sil extrusive (flow, agglomera (Probably coeval with 7 to 1
9	PARSON'S POINT format 9 Interbedded limestone, li black shales, grits and
8	BURNT HEAD formatio 8 PILLOW ANDESITE mem Pillows, isolated pillows massive flows
7	PYROCLASTIC member 7 Basic and intermediate argillite 7b Agglomerate 7a Acid tuff
6	QUINTON COVE form 6 Coarse agglomerate 6a Tuff
5	PIGEON HEAD format 5 Black shales, basic and pyroclastics, arkose
4	STAG ISLAND forma 4 UPPER BASALT member Black pillow basalt
3	LOWER BASALT member 3 Grey-green glassy ba
2	BRECCIA member 2 Water-worked, explosiv deposit
1	INTRUSIVE member 1. Diabase dykes, gabbro pillow lava

LEGEND

LATE ORDOVICIAN OR LATER

18	Lamprophyre Dykes

ORDOVICIAN (INTRUSIVE ROCKS)

17	Porphyritic Diabase, Gabbro
16	Felsic Dykes
15	Quartz Feldspar Porphyry, Granodiorite
14	Granodiorite (Long Island Pluton)
13	Gabbro, Andesite, Diabase
12	Dacite

ORDOVICIAN (CUTWELL GROUP)

11	LONG TICKLE formation 11 Interbedded and interfingered lava, agglomerate, tuff limestone
10	SEAL COVE COMPLEX 10 Dacitic intrusive (dykes, sills) and extrusive (flow, agglomerate, tuff) complex (Probably coeval with 7 to 11)
9	PARSON'S POINT formation 9 Interbedded limestone, limestone breccia, black shales, grits and pyroclastics
8	BURNT HEAD formation 8 PILLOW ANDESITE member Pillows, isolated pillows, pillow breccia, massive flows
7	PYROCLASTIC member 7 Basic and intermediate tuff, chert, argillite 7b Agglomerate 7a Acid tuff
6	QUINTON COVE formation 6 Coarse agglomerate 6a Tuff
5	PIGEON HEAD formation 5 Black shales, basic and intermediate pyroclastics, arkose
4	STAG ISLAND formation 4 UPPER BASALT member Black pillow basalt
3	LOWER BASALT member 3 Grey-green glassy basalt pillows
2	BRECCIA member 2 Water-worked, explosive breccia deposit
1	INTRUSIVE member 1 Diabase dykes, gabbro and basaltic pillow lava

KEY

- Bedding, tops known (horizontal, inclined, vertical, pillows)
- Bedding, tops unknown (inclined, vertical, pillows)
- Flow banding (inclined, vertical)
- Schistosity (inclined, vertical)
- Shearing (inclined, vertical)
- Minor fold (anticline, syncline)
- Major fold (anticline, syncline)
- Fault (defined, inferred)
- Outcrop
- Geological contact (known, inferred)
- Mineral prospect or occurrence
- Road (gravel)
- Marsh
- Lake, Pond
- Fossils

MINERAL SYMBOLS

Cu CHALCOPYRITE   Py PYRITE

SCALE

2000 FEET 0 2000 6000 FEET

GEOLOGY OF LONG ISLAND

MAP REF. 2E/12

1972

KEAN