THE TECTONIC SETTING OF THE COLCHESTER PLUTONS SOUTHWEST ARM, GREEN BAY, NEWFOUNDLAND

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by

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ABSTRACT

The area is underlain by Early Ordovician volcanic rocks and plutons of intermediate intrusive rocks and small bodies of serpentinised ultramafic rocks. These are unconformably overlain by red beds of the Silurian Springdale Group.

The Lush's Bight Group consists of basic variolitic pillow lavas with minor interbeds of sedimentary and pyroclastic rocks. Dikes and sills of diabase, quartz porphyry and lamprophyre cut the volcanic rocks. The Group has been divided into two broad lithological assemblages, the Jackson's Cove Unit and the Birchy Cove Unit, on the basis of colour, size, shape and orientation of pillows, presence or absence of varioles, degrees of deformation and alteration, petrological and chemical characters. The relative ages of these two units are uncertain.

Two epi-zonal plutons intrude the Lush's Bight volcanic rocks near Colchester Pond and Manful Point. The Colchester Pluton is a zoned pluton which from margin to core varies in composition from meladiorite through quartz diorite to potash deficient granophyric granodiorite. Granophyric texture of the central zone is interpreted as due to simultaneous crystallisation of quartz and felspar, after emplacement of the pluton. The compositional zoning is also interpreted as a post-emplacement event.

The Cooper's Cove Pluton, north of Manful Point, consists of a dioritic marginal zone and a quartz monzonite central zone. Contacts are sharp and the quartz monzonite intrudes the diorite. The pluton originated by successive intrusions.

The compositional resemblances of all the plutonic rocks in the area to the Lush's Bight basalts suggest a possible genetic relationship. The concept of an Island Arc and/or ocean floor environment seems to constitute the most likely milieu in which to produce these thick Ordovician pillow lava sequences and the various plutons and associated ultramafic pods.

Rocks of this area have undergone two main phases of deformation, D_1 and D_2. The first resulted in tight F_1 folds with axes striking nearly due east; the second deformation, D_2, produced large scale F_2 open flexures with axes striking from north northeast to northeast. A third minor deformation, D_3, produced only kink bands which are best seen in the sheared meta-basalts.

The sulphide mineralisation occurring in the area is interpreted as structurally controlled and epigenetic.

INTRODUCTION

The area near the southeast shore of Southwest Arm of Green Bay, Newfoundland has been of economic interest since 1878 when development work began on the Colchester copper deposit. This initial interest continued until the turn of the century and resulted in the discovery of several small prospects nearby. Interest in these prospects then waned, except for two excellent geological studies commissioned by the Newfoundland Government (Douglas et al., 1940; MacLean, 1947), until recent years brought renewed activity to the area. This was prompted both by the development of new methods of exploration and also by the successful development and exploitation of two old prospects in the vicinity -- Little Bay Mine and Whalesback Mine. In the early 1960's, M. J. Boylen Engineering Limited took over exploration rights of the old fee simple claims and carried out several seasons of mapping, prospecting and diamond drilling. In 1969, the Cerro de Pasco Company took over Boylen's interest in these claims and initiated further exploration work. Meanwhile, British Newfoundland Exploration Limited commenced geochemical and geophysical exploration of their concession, immediately southeast of the old fee simple claims.

Scientific interest in the rocks of this area began with MacLean's 1938-39 study (MacLean 1947). This showed that most of the mineral deposits of the region between Southwest Arm and Halls Bay were located in a widespread and apparently thick sequence of lava flows of undetermined structure. Interest continued when Neale and Nasn (1963) correlated the intrusive stocks of the Colchester Mine area with the Burlington Grano-diorite which occurs chiefly as a great batholith forming the core of the

Burlington Peninsula. Added significance was given to this correlation when Neale and Kennedy (1967) reported pebbles of granodiorite in the Ordovician (?) Baie Verte Group which had hitherto been considered to be cut by it. This raised the possibility that Lush's Bight rocks might unconformably overlie the Colchester intrusions instead of being intruded by them as originally stated by MacLean and Neale and Nash.

The present work was designed to: (1) determine the structural setting of the Colchester plutons, (2) test the proposed correlation of these plutons with those of the Burlington Peninsula, (3) determine the structural history and the scale of folding in the mineral-rich but structurally obscure Lush's Bight Group in conjunction with simultaneous detailed studies by Memorial University graduate students, Brian Marten and Gilbert McArthur.

The study area of 16 sq. miles is bounded on the southeast by the Silverdale-South Pond Fault and on the northwest by Southwest Arm of Green Bay -- it thus includes all of the original fee simple claims currently being explored by Cerro de Pasco and much of the adjacent concession under study by Brinex. Geologically it includes both the Colchester and Cooper's Cove Plutons, and much surrounding volcanic rocks of the Lush's Bight Group. Early in the seasons work it was established that the Colchester Pluton cut rocks of the Lush's Bight Group and in mid-season it was established that intrusive rocks resembling the Burlington Granodiorite, cut rocks typical of the Colchester Pluton. It was then possible to spend the remainder of the season examining structures and fabrics in the Lush's Bight Group and correlating them with post intrusion fabrics in the intrusive rocks. Although no stratigraphy could be deciphered in the Lush's Bight volcanic rocks, the scale of both the first phase folding and the second phase flexures was ascertained by top determinations and cleavage-bedding relationships in the pillow lavas and tuffs and by mapping out the strong first phase axial plane schistosity. Brief visits were made to all the old prospects although, unfortunately, no cooperative arrangement was established with the present holders of exploration rights permitting access to drill logs and examination of mineralised cores. However, previous hypotheses of northeast striking shear zones and faults acting as loci of these mineral deposits seems established beyond doubt. (MacLean, 1947; Douglas et al., 1940).

Accessibility

The area studied is bounded by North Lat. 49° 35' 15"; 49° 41' 30" and West Long. 55° 57' 45"; 56° 08' 45", on the eastern shore of the Southwest Arm, Green Bay. The prominent villages in the area are Jackson's Cove, Silverdale, Langdown Cove and Nicky's Nose with a total population of 250.

The area is 28 miles by road from Springdale, the nearest large town. The Trans-Canada Highway is 24 miles from Jackson's Cove. The nearest railway point is Badger, 64 miles. There is a weekly C.N. Coastal boat service to Harry's Harbour, about 3 miles from Jackson's Cove.

The road to Jackson's Cove from Springdale is the eastern margin of the area studied. West of this road, the area is accessible by old roads and trails, most of them are overgrown with shrubs and alders. A tractor-road extends from the main Jackson's Cove Road to Colchester Pond, 1½ miles, and extends 2 miles beyond this towards Swatridge Cove, thus connecting all the old copper workings in the area.

Physiography

The area consists of a hummocky to strongly lineated and dissected surface with elevations chiefly between 200 and 600 feet.

The topography is controlled by lithology and structure. The southwest corner of the area, chiefly underlain by Silurian Springdale Group sedimentary rocks which dip gently towards southwest, is generally a low featureless terrain with only a few shoreline scarps. The area between Manful Point and Silverdale, underlain by tightly folded Lush's Bight volcanic rocks, is rugged and thickly wooded. The central part of the area, underlain by the Colchester Plutons, is rounded and hummocky, a typical granitic terrain. Ridges trend northeast-roughly parallel to the regional strike.

Field Methods

The writer spent three months in the field and had the help of one field assistant, a skilled boatman.

The entire study was carried out from a camp located on Lem Knight's Farm in the northern part of the area. A camper trailer and a small cook tent concealed from the nearby road provided comfortable and efficient quarters and is recommended to other parties operating in such easily accessible areas. The Silverdale Road and the Colchester Mine trail acted as bases for inland traverses. Bicycles supplied by the M.U.N. Geology Department and a motor cycle owned by Otto Pynn were used for commuting to and from traverses. A 14-foot aluminium boat and 9.5 h.p. motor proved adequate for coastal work and for the odd foray across Green Bay to study correlative rocks.

The writer cannot overstress the value of regional reconnaissance to a study of this kind. He benefited by participating in the Memorial University Geology field trip across the entire island of Newfoundland in May, 1969. Also, during mid summer he accompanied E. R. W. Neale on a short field trip from the Baie Verte Road to Burlington village -- providing a complete cross section through the Burlington Granodiorite batholith. Without these opportunities it would have been impossible to draw the comparisons made in this thesis and the study would have suffered from ignorance of its regional context.

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REGIONAL GEOLOGICAL SETTING

The oldest rocks of the Burlington Peninsula (Figure 1) are complexly folded pre-Ordovician pelitic and psammitic schists, minor meta-conglomerate and metamorphosed basic sills and/or flows of the Fleur de Lys Supergroup which underlie the west part of the Peninsula. These occupy a belt 70 miles long that extends southwestward from Partridge Point on the north, to Birchy Lake about 20 miles south of the boundary of the accompanying sketch map, where it terminates against the Birchy Lake - Grand Lake fault zone. Basic schists and lineated amphibolites of volcanic origin conformably overlie the Fleur de Lys schists at Pacquet Harbour and extend westward and southward from this locality. These are referred to as Pacquet Harbour Group (Church 1969). Porphyritic granite, known as Cape Brule granite (Baird 1951) intruded these rocks prior to the earliest of the 3 major deformations to which they have been subjected (Coates and Kennedy 1969). Later, certainly following the second period of deformation, they were intruded by the Burlington Granodiorite batholith (Neale and Kennedy 1967).

Ordovician rocks include the Snooks Arm and Lush's Bight groups which occur on the western shores of the Notre Dame Bay and consist dominantly of basaltic and andesitic pillow lavas with important amounts of pyroclastic and sedimentary rocks. These were dated as Arenig on the basis of a single fossil find, the brachiopod Discotreta (MacLean 1947) in the Lush's Bight Group and on a single graptolite locality in the Snooks Arm rocks (Snelgrove 1928). A sequence of pillow lavas, cherts and pyroclastic rocks referred to as the Baie Verte Group (Watson 1947) extends

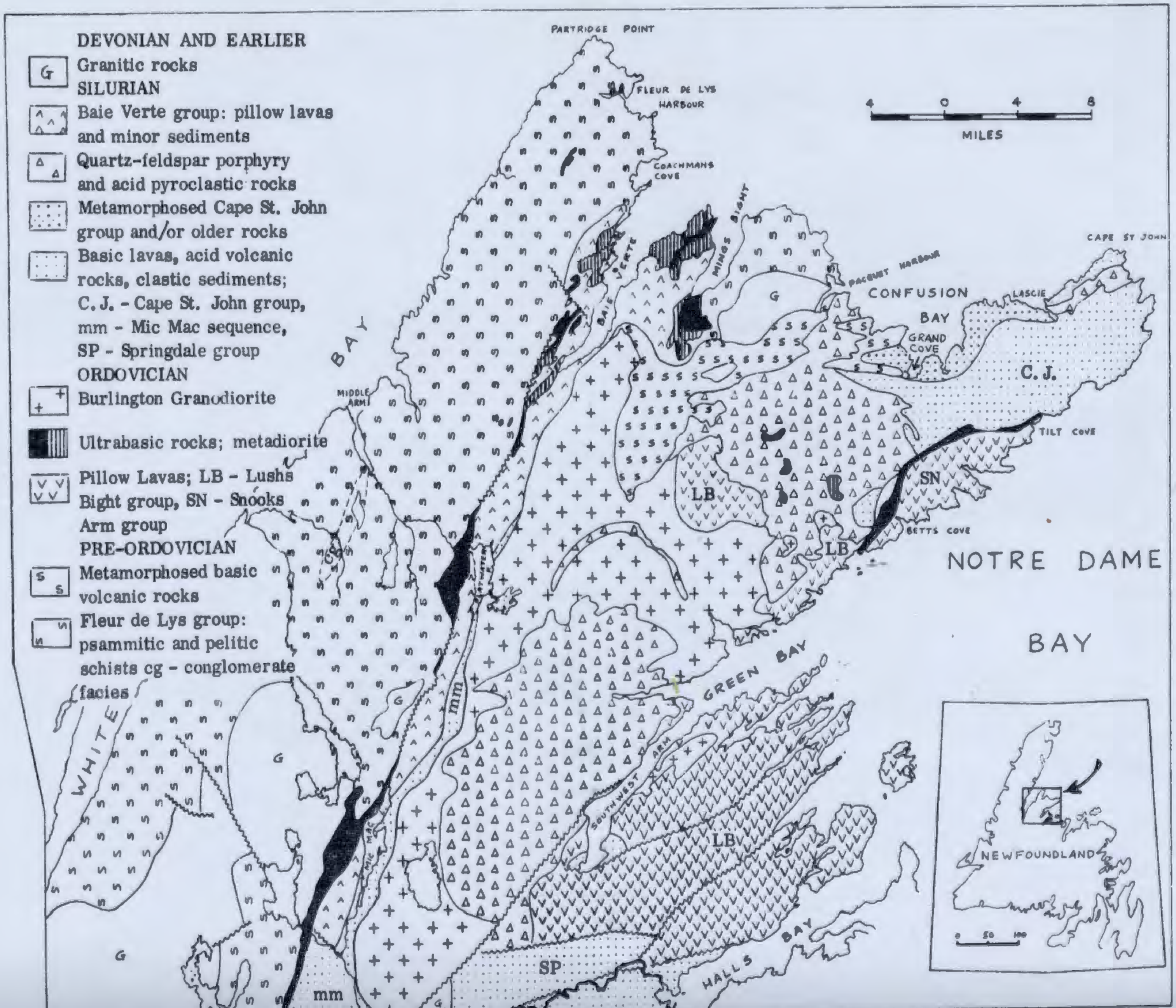

Figure 1. Generalized geological map of Burlington Peninsula.

After Neale and Kennedy (1967)

from the vicinity of Mic Mac Lake to Baie Verte village and beyond. It is commonly considered Ordovician because of lithological similarity to the Lush's Bight and Snooks Arm rocks and although this correlation has been disputed (Neale and Kennedy 1967) the consensus at the time of writing is that they are Ordovician (Neale, pers. comm.). A large batholith west of Green Bay, Notre Dame Bay, named Burlington Granodiorite (Baird 1951), extends between Mic Mac Lake and the town of Baie Verte. The granodiorite and related rocks occurring on the eastern shore of Southwest Arm, Green Bay (MacLean 1947) referred to in this report as the Cooper's Cove and Colchester Plutons were included with the Burlington Granodiorite by previous workers (Neale and Nash 1963).

Rocks mapped as Silurian include similar sequences of terrestrial sediments and basic and acid lavas in two separate outcrop areas: (1) In the Halls Bay area and near the head of Southwest Arm of Green Bay where they are known as the Springdale Group; (2) Between Mic Mac Lake and Flat Water Pond where they are referred to as the Mic Mac Lake sequence. Both sequences resemble the fossil dated Silurian Botwood Group (Williams 1967). A third sequence, which is lithologically similar but structurally more complex occurs in the vicinity of Cape St. John. Although previously considered Silurian (Williams 1967) it is now known, at least in part, to pre-date the Arenig Snooks Arm Group (Upadhyay, pers. comm.; Coates 1970). The Mic Mac Lake sequence lies unconformably on the Burlington Granodiorite (Neale and Nash 1963) and the basal conglomerate of this sequence contains pebbles of Burlington Granodiorite. A conglomerate in the Baie Verte Group reportedly contains similar pebbles (Church 1966; Neale and Kennedy 1967) but the present author found that at least some of the pebbles more closely resemble rocks of the Colchester Pluton.

The intrusive rocks of the area range in composition from peridotite to granite and rhyolite. Generally, the peridotite and associated ultramafic rocks have been considered Ordovician and/or older; the Burlington Granodiorite has also been considered Ordovician and/or older; generally the silicic porphyries and granites have been related to Silurian volcanism or Devonian climactic orogeny. However, it has recently been established (Coates, 1970) that some of the acid intrusions are very early in the intrusive sequence.

The present thesis area on the eastern shore of the Southwest Arm, Green Bay, is chiefly underlain by rocks of the Lush's Bight Group and plutons of intermediate intrusive rocks. The Lush's Bight in this area consists of basic variolitic pillow lavas with minor intercalations of sedimentary and pyroclastic rocks. The sedimentary rocks include greywacke, argillite and chert; the pyroclastic rocks are agglomerates, basic tuffs and metamorphosed ash beds. Dikes and sills of diabase, quartz porphyry and lamprophyre cut the volcanic rocks. The Lush's Bight Group volcanic rocks are intruded by an elliptical body called the Colchester Pluton in the central part of the area. It is a zoned pluton which varies in composition from potash deficient granophyric granodiorite in the central core zone to a meladiorite at the margins. Another small pluton, referred to as the Cooper's Cove Pluton, consists of a core of quartz monzonite surrounded by a marginal zone of diorite and meladiorite. Close spatial relationships, regional and theoretical considerations suggest that the Lush's Bight Group volcanic rocks, Colchester Pluton, Burlington Granodiorite, and Cooper's Cove Pluton may be genetically related. To a limited extent, this is supported by petrological and chemical data.

Ultramafic bodies occur as small pods in the vicinity of Manful Point.

Rocks of the Silurian(?) Springdale Group occur south of Manful Point where they overlie the steeply dipping Lush's Bight volcanic rocks. They include red conglomerate, sandstones, shales and minor beds of grey limestone. The conglomerates contain clasts of the Ordovician volcanic and intrusive rocks that underlie most of the map-area.

The rocks of this area have undergone two main phases of deformation, D_1 and D_2. The first resulted in tight F_1 folds with axes striking nearly due east; the second deformation, D_2, produced large scale F_2 open flexures with axes striking from north northeast to northeast (Figure 7). A third and very minor deformation D_3 produced only kink bands, best seen in sheared meta-basalts.

A major northeast striking fault extends southwest from Nicky's Nose through Line Pond - Brown Pond to South Pond. It truncates minor faults which strike east-west.

The first deformation D_1 and the east-west faults are possibly related to Taconian Orogeny (Ordovician). The second deformation D_2 may be related to Acadian Orogeny (Devonian). The northeast faults throughout the whole of Notre Dame Bay area have been interpreted as Acadian.

The sulphide mineralisation is interpreted to be structurally controlled - with an ultimate epigenetic origin.

LUSH'S BIGHT GROUP

The term Lush's Bight Group was first used by Espenshade (1937) to refer to the upper dominantly volcanic part of the Ordovician "Pilleys Series" in the adjacent area to the east. MacLean (1947) described and mapped three "sections" of the Lush's Bight Group. One of these, the Little Bay Head section, chiefly metamorphosed basic flow rocks, includes all of the Lush's Bight rocks described in this thesis. This section is overlain by the "Western Arm Section", described by Marten (1970). The Lush's Bight Group is dated as Arenig by a single brachiopod, Discotreta (MacLean 1947). Neale and Nash (1963) and Neale (ms.) mapped and described the western limits of the Lush's Bight Group in the King's Point Map Area.

The Lush's Bight Group underlies much of the thesis area. It consists mainly of a eugeosynclinal sequence of basic pillow lavas with minor amounts of interbedded marine volcaniclastic sedimentary rocks. All rocks of the group are cut by diabase and quartz porphyry dykes and sills. Alteration of the pillow lavas include chloritisation, epidotisation and silicification.

The pillow lavas in the area have been broadly divided into two broad lithological assemblages, the Jackson's Cove Unit and the Birchy Cove Unit, whose relative ages are uncertain. These divisions are based on the colour, size, shape and orientation of pillows, presence or absence of varioles, degrees of deformation and alteration, and mineralogical and chemical characters. Where mappable, pyroclastic and sedimentary rocks form a third unit which also has no stratigraphic significance.

Jackson's Cove Unit (Map Unit 1)

This is best exposed between Manful Point and Swatridge Cove along the eastern shore of the Southwest Arm; inland between South Pond and Saunder's Brook and between Jackson's Cove and Nicky's Nose, a total area of about 8.5 sq. miles. It consists chiefly of dark greenish grey pillowed basalt, which is altered to various degrees, together with minor amounts of pyroclastic and sedimentary rocks. The basalts of this unit are more altered and deformed than those to the east (Marten 1970), in the so-called Western Arm section (MacLean 1947) - possibly because they are lower in the Lush's Bight sequence. Rocks of the Jackson's Cove Unit are cut by dikes of diabase, lamprophyre, quartz porphyry and also quartz veins.

The Jackson's Cove Unit has the following 4 characteristics which are not found in the Birchy Cove Unit:

1. It commonly contains thin intercalated layers of tuff and red and green chert.

2. Its pillows are mainly ellipsoidal and have been flattened by later deformation in the planes of original flows. Pillows range in maximum dimension from one foot to three feet. (Plate VIIa).

3. The basalts show well developed schistosity on the outer rims of the pillows, due to chloritisation. These pillows show a strong, steeply dipping S_1 schistosity throughout the area and locally a weak S_2 schistosity with more gentle dips than S_1. S_2 is especially well developed around the Jackson's Cove Government wharf (Plate VIIb).

4. The lavas are intensely altered to chlorite and quartz chlorite

schists along shear zones and are hosts for the sulphide mineralisation seen in the area.

In thin section none of the original characters of the basalts are preserved due to the intense alteration which they have undergone. The only mafic minerals are tremolite-actinolite together with abundant epidote and chlorite. Plagioclase (An_{12}) with sphene, ilmenite, leucoxene, magnetite and pyrite are also present. The pyrite shows pressure shadows and chlorite trails occur around it which indicate that at least some of the pyrite is primary.

One altered amygdaloidal basalt from the Jackson's Cove Unit was analysed (Table I). This analysis, along with two cited by Neale (ms.) and three cited by MacLean (1947) are plotted on ternary and silica variation diagrams (Figures 2,3). The analyses indicate that pillow lavas of Jackson's Cove Unit resemble Nockolds (1954) average tholeiitic basalt.

Pyroclastic and Sedimentary Rocks (Map Unit 1a)

Thin intercalated layers of pyroclastic and sedimentary rocks are mapped within the Jackson's Cove Unit at Eastern Point and south of Western Point. They also occur in places along the eastern shore of the Southwest Arm but not in mappable thicknesses. The pyroclastic rocks consist of basic tuffs, volcanic breccia, agglomerates and metamorphosed ash beds. The sedimentary rocks are mainly volcanic wackes, argillite, iron formation and chert.

A common variety of basic tuff is a crystal tuff, which contains crystals of hornblende in a fine-grained matrix of hornblende, chlorite, epidote and calcite. This type occurs along the eastern shore of Southwest Arm, along the Jackson's Cove Road, and near West Brook at the contact with the Colchester Pluton.

Volcanic breccia was observed near Naked Man in a cliff surface and on the Jackson's Cove Road, 7,000 feet northeast of West Brook (Plate IIc). It consists of angular basic lava fragments ranging in size from 0.2 to 2.5 inches in a fine-grained volcanic matrix.

Agglomerate occurs on Eastern Point interbedded with cherts and other sedimentary rocks. The agglomerate shows well-developed S_1 schistosity which dips steeper than the feeble S_2 schistosity. It contains rounded, flattened fragments of porphyritic and amygdaloidal basic lavas ranging in size from 0.5 to 5 inches. There are occasional fragments up to 1.5 feet. The porphyritic basalt fragments are composed of plagioclase phenocrysts in a fine-grained groundmass of plagioclase and augite with abundant magnetite. The plagioclase is altered to epidote. The matrix in the agglomerate is composed of crystals of hornblende and plagioclase, with quartz, chlorite and carbonate.

The presence of volcanic breccia and agglomerate indicate that there was intermittent explosive activity during the generally quiescent volcanism of the Lush's Bight Group.

A 5-feet thick zone of brecciated lithic tuffs outcrop near the Jackson's Cove Government wharf (Plate VIIIb). The rounded fragments could be sheared fragments of pillows or flattened remnants of porphyritic and amygaloidal lavas with a strong S_1 and a weak S_2 cleavage. Autoclastic breccia also occurs here. It consists of angular fragments of volcanic rocks with chert forming the interstitial material (Plate Xb).

Red and green ferruginous chert commonly fills the interstices between the pillows of the Jackson's Cove and Birchy Cove Units, and also occurs as thin intercalated layers within the flows. The silica in the chert is very fine-grained and shows well-developed bedding where examined in thin section. Veins of quartz and carbonate cut the chert. Sampson (1923) studied the ferruginous chert formations of Notre Dame Bay area and suggested that the silica was contributed to the marine environment by magmatic emanations from submarine vents or fissures and that it was precipitated as colloidal silica. No evidence for or against this hypothesis was obtained in the present study.

The sedimentary rocks mainly consist of volcanic wackes, argillite and iron formations. Typical turbidite features - such as graded bedding and slump folds are common (Plate IIb). The early fabric of the pillow lavas appears as a strong penetrative cleavage in these sediments, the second fabric is a weak strain slip, developed locally. The volcanic wackes consist chiefly of porphyritic and amygdaloidal basalt fragments, plagioclase, divitrified glass, chert, chlorite, hornblende and epidote. The matrix is chloritic and epidotic which imparts the dark greenish colour to the rock.

The sedimentary and pyroclastic rocks are cut by diabase and lamprophyre dykes near Eastern Point.

Birchy Cove Unit (Map Unit 2)

This Unit is best exposed between Birchy Cove and Swatridge Cove. It includes light grey to greenish grey fine-grained flows which show excellent pillow forms (Plate VIIIa). In the coastal exposures the pillows are well preserved and very little external evidence of weathering and metamorphism are seen.

The pillow lavas of the Birchy Cove Unit are distinctly different from those of the Jackson's Cove Unit.

1. The pillows vary in size from 1 foot x 8 inches to 4 x 2 feet. They are the "close-packed" variety of pillows described by Carlisle (1963) and are relatively less deformed than those of the Jackson's Cove Unit (e.g. see Plate VIIa and VIIIa).

2. The pillow lavas of this Unit show "variolitic texture". A cross section through a typical pillow shows a concentric chilled margin about one inch thick, followed by 2 to 3 inches of "pimply zone" variolite, which grades to a core which is wholly composed of variolite (Plate IIa).

3. Radial jointing is prominent and weathering effects have been extensive along the numerous microscopic and macroscopic cracks.

4. The interstices between adjacent pillows are filled with small pillows (Plate VIIIb), ranging in maximum dimension from one to 12 inches. The small interstitial pillows are rounded and are essentially of the same mineralogical and chemical composition as the large pillows (Table 1). Hence they are also classified as "close-packed" variety. These grade into flow breccia and normal pillowed flows within a few hundred feet near Birchy Cove (Plate IXa).

5. The pillows show folded forms indicating that these were deformed while still plastic (Plate Xa). This feature is not seen in the Jackson's Cove Unit.

6. Alteration of these lavas is not apparent on fresh surfaces but thin sections show intense epidotisation of the plagioclase.

7. Red chert occupies the interstices between some pillows.

8. Minor folds occur in the flows which cut the pillow lavas (Plate IXb).

Thin sections of the pillowed basalts of the Birchy Cove Unit show typical variolitic textures (Tyrrell 1929; Harker 1909). The variolites vary considerably ranging from mere fan-like groupings of felspar microlites to sheaf-like aggregates to regular radiate spherulitic growth (Plate XIa,b). Variolites developed due to quick cooling of the lava and later divitrification (Daly 1903). Clinopyroxene occurs as micro-phenocrysts, in some thin sections. Other thin sections are composed of fine fibrous aggregates of chlorite, actinolite, epidote, zoisite, carbonate. At least some of the amphibole is pseudomorphic after pyroxene. Actinolite occurs as fine fibrous aggregates. The amygdules are filled with carbonate and chlorite.

One small pillow and three separate areas of a large pillow from the Birchy Cove Unit were analysed (Table 2). All these samples and one cited by Neale (ms.) are plotted on ternary and silica variation diagrams (Figures 2, 3). The analyses indicate that the pillow lavas of the Birchy Cove Unit resemble average tholeiitic andesite of Nockholds (1954) and average tholeiitic basalt of Hawaii (MacDonald 1964).

The following facts emerge from the foregoing:

1. The Jackson's Cove Unit basalts are lithologically, mineralogically and chemically distinctly different from those of the Birchy Cove Unit.

2. The bottom of each pillow conforms in shape with the top of the underlying pillow which indicates that each pillow was deposited subsequently

to those on which it rests. Because pillows are thus moulded on the ones below, they must have developed while still in a plastic condition, which is also evidenced by the folded forms (Plate Xa).

3. Chert occurs as irregular masses conforming to the pillow surfaces. Sampson (1923) suggested that the silica in the chert was a magmatic emanation from submarine vents or fissures and was deposited as colloidal silica coagulating around ferric hydroxide.

4. The pillow lavas are associated with pyroclastic and sedimentary rocks of marine origin.

5. Occurrence of varioles in the basalts indicate that the basalt cooled quickly and later divitrified.

Origin of Pillow Lavas

According to Tyrrell (1929, p. 37), the term "pillow" was first used in 1890 by G. A. Cole and J. W. Gregory to describe the ellipsoidal structures in variolitic rocks in the area of Mt. Genevre on the border of France and Italy.

Lewis (1914), Van Hise and Leith (1911), Johansen (1939), Shrock (1948), Wilson (1960), Snyder and Fraser (1963), MacDonald (1967), give excellent reviews of the origin of pillows from various occurrences all over the world.

Clements (1903) considers pillow lavas to be due to rolling over and over of blocks of aalava, while they still retain their plasticity. Daly (1903), Van Hise and Leith (1911), Bartrum (1930), Buddington (1926), Sampson (1923) and Solomon (1968) suggest that the pillow lavas are formed under submarine conditions, due to their usual association with deep-water sediments, pyroclastic material, marine fossils, and chert.

Snyder and Fraser (1963) suggested that pillow lavas were formed by intrusion of fluid magma into semi-consolidated and unconsolidated ocean-bottom muds. Henderson (1953) contends that they formed by extrusion and coagulation of lava in water. Wilson (1960) suggested that pillows formed as "globules in the same way as oil globulates when mingled with water" and were transported individually. Jones (1968) attributes pillow lavas to digital advance of pahoehoe in water.

The pillow lavas of the Lush's Bight Group are associated with marine sedimentary rocks, cherts, greywackes, and also pyroclastic rocks. Thus the pillows of the Lush's Bight Group formed by submarine extrusions. The volcanic episode developed moderately; most eruptions were quiescent outpourings although there were intermittent violent explosions as indicated by intercalated beds of tuff and volcanic breccia.

Relationship of Jackson's Cove and Birchy Cove Units

The age relationships between these two units are not known. Along its southern margin, the Birchy Cove Unit is separated from the Jackson's Cove Unit by the Saunder's Brook fault. Northward, it is faulted against pyroclastic rocks which form the lowest part of the Jackson's Cove Unit near Western Point. It can be said that there are two distinct volcanic assemblages that differ lithologically, structurally, petrologically anc chemically. They probably have stratigraphic significance in whole or in part, but more detailed study of their field relationships will be required before this can be clarified. Tentatively, the writer suggests that the higher degree of deformation of the Jackson's Cove Unit may indicate that these lavas were lower in the volcanic pile.

THE COLCHESTER PLUTON

The quartz diorite and related rocks occurring near Colchester Pond are referred to as the Colchester Pluton (Plate I). Neale and Nash (1963) mapped these as part of the Burlington Granodiorite. In the present thesis the Colchester Pluton is interpreted as a zoned pluton that differs somewhat from the type Burlington Granodiorite of the Burlington Peninsula. It is suggested that the Colchester Pluton, Cooper's Cove Pluton, and the Burlington Granodiorite may be genetically related to each other and also to the Lush's Bight volcanic rocks.

The Colchester Pluton occurs as an elliptical body with the longest diameter parallel to the regional strike and occupies an area of about 3.8 sq. miles. It is classified as an epi-zonal pluton (Buddington 1959) for the following reasons:

1. The pluton is spatially associated with low grade metamorphic Ordovician volcanic rocks. Several stocks and batholiths of similar composition in nearby areas are also known to be associated with lavas of similar composition. Thus, Marten (1970) related the gabbro body at Dollard's Arm, Western Arm, Green Bay to Lush's Bight volcanic rocks. Elsewhere, e.g. in the Western United States, epi-zonal intrusive bodies have been interpreted as genetically related to adjacent volcanic rocks (Callaghan 1933; Buddington and Callaghan 1936; Knopf 1957; Erikson, Jr. 1969; Mathews 1958).

2. The contact of the pluton and the adjacent country rock is sharp and cross-cutting relations show that the Colchester Pluton is

intrusive into the Lush's Bight Group.

3. Lack of a contact aureole suggests emplacement as a highly viscous magma at relatively low temperatures (600°C or below, Michot 1956).

4. The intense shearing and fracturing along the margins of the pluton is perhaps due to its emplacement and also to regional deformation. Cloos (1933), Mathews (1958), Waters and Krauskopf (1941) attribute similar marginal shear zones of plutons to stresses originating from their upward movement during emplacement.

5. Primary flow fabric is seen in the marginal zones of the pluton. The absence of primary flow layering towards the centre of the pluton may be due either to the decreasing influence of the contact or to its irregular shape.

The Colchester ZonedPluton has been divided into three broad compositional zones, marginal, transitional, and central, which from margin to core vary in composition from mela-diorite through quartz diorite to potash deficient granophyric granodiorite. The boundaries were drawn in the field in somewhat arbitrary fashion on the basis of increase in visible quartz and potash felspar and decrease in mafic mineral content from margin to core. Petrological and chemical analyses have substantiated the gradational variations from margin to core. The marginal zone is characterized by the presence of basic inclusions and the rocks show a high content of mafic minerals (up to 55%); progression toward the centre is marked by decrease in mafic minerals, increase in quartz and appearance of small amounts of potash felspar and granophyric texture.

A brief description of the three compositional zones is given below:

Marginal Zone

This zone, which occurs at the contact with the Lush's Bight volcanic rocks, varies in width from 250 feet to 2500 feet. It is intensely deformed, excellent intrusive contacts and cross-cutting relations are common. Tongues of the Colchester Pluton cut the basic tuffs at the periphery (Plate XIa). Lenticular mafic inclusions of country rock are abundant (Plate XIb).

The rocks in this zone show both primary flow layering and also well developed metamorphic fabric (Plate Va). Strong preferred orientation of hornblende is seen in nearly all outcrops and locally dark, elongated basic inclusions parallel the foliation. The primary flow layering is ascribed to movements of magma before complete consolidation. All rocks studied in thin section also show a deformational fabric which is perhaps due to the regional tectonic movements.

The rocks vary from dark greenish grey to green, from medium to coarse grained,(1.5 mm. to 2.5 mm.)and from mela-diorite to diorite and quartz diorite. Plagioclase, hornblende, clinopyroxene, and quartz are the chief constituents with tremolite, chlorite, epidote, opaque ores and carbonate as accessories. Plagioclase is euhedral, average composition An_{38}, and is clouded with epidote, zoïsite, due to saussuritisation. Quartz is anhedral and interstitial. There are two generations of hornblende. The first occurs as euhedral twinned phenocrysts, and a second uralitic variety forms rims around clinopyroxene.

Mela-diorite similar to that of the marginal zone of the Colchester Pluton occurs between Manful Point and Cooper's Cove where it is spatially associated with the Cooper's Cove Pluton. It is interpreted as a separate and distinct intrusion although it is included with the marginal zone of the Colchester Pluton for purposes of mapping.

Transitional Zone

This zone varies in width from 500 to 4,000 feet. Contacts are gradational and boundaries are drawn in the field where the rocks are finer grained and slightly richer in quartz than those of the marginal zone and exhibit fairly well-defined secondary foliation. In this zone, small basic inclusions are almost absent, but large roof pendants are common northeast of Colchester Pond. Shearing occurs at several localities.

The rocks vary from dark greenish to light greenish, are essentially medium-grained (1.0 to 2.0 mm.), and are mainly hornblende quartz diorite. The rocks in this zone show a transition between the marginal dark coloured and central zone leucocratic rocks, which are reflected in the mineralogy and also the chemical composition (Tables 3 and 4). The mafic minerals vary between 25 - 45%. The chief constituents are hornblende, clinopyroxene, plagioclase, quartz, actinolite, with epidote, carbonate, and magnetite. Two generations of hornblende are seen. The primary hornblende has strong pleochroism and birefringence and higher R.I. than the secondary uralitic hornblende which was formed by deutric alteration of pyroxene and occurs as a rim around pyroxene. The plagioclase is clouded with epidote minerals. The rocks have developed excellent schistosity. The schistosity is marked by the parallelism of chlorite and quartz grains (Plate XIVa). The pyroxene occurs as augen and the chlorite goes around these, indicating that the pyroxene grew prior to the development of schistosity. The schistosity is better developed in this zone than in the marginal zone, due to abundance of elongated and platy minerals such as hornblende and chlorite (see Table 3), and also due to the medium-grained texture. In general it is observed that the fine- and medium-grained plutonic rocks develop a more pronounced schistosity than coarse-grained varieties. Flattening and marginal breakdown of quartz grains is common, due to deformation. The plagioclase is euhedral to subhedral and its average composition is An_{32}.

Central Zone

The core of the Colchester Pluton was mapped as a separate unit in the field, on the first appearance of pink felspar. This coincides with a leucocratic aspect and an increase in quartz content. This zone is almost free of basic inclusions. The rocks vary from light greenish to light pinkish green, are medium grained and may be classified as transitional between quartz diorite and potash deficient granophyric granodiorite.

Granophyric textures characterize rocks of the central zone. There are all gradations from irregular micropegmatitic intergrowths in which the quartz felspar ratio is highly variable to more regular intergrowths of micrographic texture (Plate XVa). One of the forms is a cauliflower like rosette of micrographic quartz in a xenomorphic groundmass (Plate XIVa). Another type consists of central core of albite with radiating graphic growths of plagioclase and quartz (Plate XVa,b). On a small scale the radiating fringe type becomes a spherulitic or feathery type. Yet, another kind consists of coarse intergrowths of quartz and plagioclase (Plate XVIb). Thin section examination suggested that the granophyric texture is formed due to crystallisation from residual solutions of the magma. The existence of such residual solutions is testified to by the abundance of late quartz veins (Plate XIIb).

The chief constituents of the Central Zone rocks are quartz, plagioclase, potash felspar with epidote, zoisite, chlorite, carbonate, magnetite and sericite. Quartz occurs as subhedral to euhedral grains and shows undulatory extinction. The plagioclase An_{28} is euhedral to subhedral, shows oscillatory zoning, and is clouded with epidote in some specimens. The only mafic mineral seen in abundance is chlorite and it imparts the greenish colour to the rocks. Hornblende occurs sparingly. Small basic inclusions in these rocks contain quartz, plagioclase, chlorite and epidote as chief constituents and show well-developed schistosity under microscope. (Plate XVa). The chlorite and epidote are intergrown and there are inclusions of sphene in the chlorite. This indicates that the chlorite developed from pyroxene which is slightly titanium rich.

Deformation resulted in the preferred orientation of quartz crystals which exhibit cataclastic texture and undulatory extinction. Twin lamellae of plagioclase are bent which suggest that protoclastic deformation of plagioclase took place before crystallisation of interstitial quartz.

Origin of the Granophyric Texture

The granophyric texture is best developed around plagioclase. It varies from coarse to micrographic. The quartz and plagioclase are in optical continuity with each other. Relatively high amounts of quartz suggest that these rocks crystallised as a whole under a low water vapour pressure (Burnham 1967).

The origin of granophyric texture is a much discussed and still unsolved question. The various hypotheses put forward could be broadly grouped into two divisions.

I: Primary

Crystallisation from an acid magma (Leighton 1954; Hughes 1960; Dunham 1965).

II: Secondary

Deuteric alteration; hydrothermal alteration (Colony 1923; Drescher-Kaden 1948).

It has been already pointed out that the contact between the different zones of the Colchester Pluton are gradational. Thus the central zone of the Colchester Pluton is not a separate acidic intrusive and the formation of granophyric texture from an independent acidic magma is ruled out.

The textural characters already discussed indicate that the granophyre was formed due to simultaneous crystallisation of quartz and felspar, derived from the residual solutions, after the emplacement of the Colchester Pluton. After the pluton was emplaced, crystallisation started from the margin to the centre, and the core crystallised last. The alkali and silica apparently migrated towards the centre, where they crystallised simultaneously to give rise to the granophyre. Hydrothermal solutions could have also supplemented the concentration of alkalis and silica. The transfer of alkalis and silica could also have been effected through an aqueous-phase transfer (Burnham 1967).

Inclusions

Lenticular mafic xenoliths are abundant in the border zone of the Colchester Pluton but are generally absent from interior of the Pluton. Similar xenoliths have been called basic segregations, (Knopf and Thelan 1905), autoliths (Holland 1900; Pabst 1928) and inclusions (Hurlbut 1935; Bateman et al. 1963; Erikson 1969). The writer interprets them as inclusions and refers to them as such in the following pages.

They can be broadly divided into two types:

(1) Swarms of mafic inclusions which range up to 12 inches in diameter are oblate spheroids or discoids. At places these have sharp boundaries.

(2) Randomly distributed small clots of intergrown hornblende and intermediate plagioclase.

Minerals in these inclusions are similar to those in the enclosing quartz diorite and mela-diorite and in the volcanic rocks, but proportions differ in that they are richer in mafic minerals, chiefly hornblende. The common textures are allotriomorphic granular. The chief constituents are plagioclase, hornblende, quartz with lesser chlorite and magnetite.

The origin of similar inclusions has been explained in various ways by different workers:

1. Clots of early formed minerals in advanced stages of assimilation indicate an early stage in the absorption or fusion of neighbouring rocks by invading masses (Sederholm 1933). These may also indicate an earlier extensive migmatisation at a lower level in the crust (Krauskopf 1969).

2. Refractory material that was not melted when the magma was derived from country rock (Piwinskii 1967).

3. Fragments of wall rocks of appropriate composition, possibly also including the early mafic phase of the pluton (Wheeler 1955; Bateman et al. 1963; Erikson 1969). Bateman et al. (1963) explain some of the mafic inclusions in Sierra Nevada as semi-stable in magma of granodiorite composition and unstable in more felsic magma.

Field and petrographic evidence from the Colchester Pluton favours comparison with the xenoliths described as inclusions by Bateman and they are, hence, interpreted as unassimilated pieces of wall rock, which the granodiorite magma picked up at the time of emplacement.

Compositional Variation

Compositional variation has been studied primarily by modal analyses of thin sections. In addition, a chemical analysis has been made of a typical specimen of each rock type.

Modal Analysis

Modes were generally obtained by counting about 2000 points for each thin section with a Swift automatic counter.

The results are tabulated in Table 3.

1. It is seen from the analyses that the mineralogical composition varies from the margin to the centre. The average mafics decrease from the margin to the centre: from 23% in the marginal zone and 17% in the transitional zone to 5% in the central zone. In the central zone the only mafic mineral is chlorite.

2. Potash felspar appears in the central zone.

3. Granophyric texture appears in the central zone.

4. The average quartz content in the marginal zone is about 9.8% and increases to about 18.8% in the transitional zone and then to 26.7% in the central zone.

These relationships are apparent from the Figure 5, in which all the modal minerals except the accessories are plotted.

In the Figure 5 the modal averages of quartz, K-felspar and plagioclase for different rock types have been calculated to 100 percent and plotted on a triangular diagram, as Q (Quartz), P (Plagioclase), and K (K-felspar). It is seen that the rocks from the marginal zone fall in the diorite field, those of the transitional zone in the quartz diorite field and those of the central zone in quartz-rich quartz diorite and granodiorite fields. The Central Zone potash deficient granodiorite can also be classified as a trondhjemite.

Chemical Analyses

Three specimens were chemically analysed by atomic absorption methods in the Department of Geology, Memorial University of Newfoundland.

The results are tabulated in Table 4, which shows an expected variation in the different oxides from margin to central zone. K_2O, Na_2O and SiO_2 increase towards the centre, while the MgO and Al_2O_3 decrease towards the centre.

The ternary plots of K_2O - Na_2O - CaO and FeO (Fe_2O_3 + FeO) - Na_2O + K_2O - MgO (Figure 2) show an overall mafic to silicic trend. However, it is not possible to speculate on the composition of the original magma in view of the large amounts of material which has locally been assimilated.

It is noted that the rocks of the marginal zone have compositions close to those of the volcanic wall rocks which could suggest both a genetic relationship and assimilation of wall rock material. The general trend in the Colchester Pluton appears to have been enrichment of soda in the early phases and then enrichment of potash.

Causes of Compositional Zoning

Recent studies of several North American granitic batholiths demonstrate systematic zonal variation in composition. The rocks involved differ considerably, although the overall progression is much the same - from margin to interior all show a decrease in total mafic minerals matched by a proportional increase in felspar and quartz. Several hypotheses have been advocated for such compositional variation.

The White Creek Batholith, British Columbia, grades inward from biotite granodiorite to hornblende biotite granodiorite to quartz monzonite to leuco-monzonite. Reesor (1958) interprets the compositional zoning in this batholith as due to assimilation. The Bald Rock Batholith, California exhibits continuous gradation from a tonalitic border zone to a leucocratic trondhjemite core. Compton (1955) postulates assimilation of amphibolitic country rock by an initial trondhjemetic magma. The Bald Mountain Batholith, Oregon (Taubeneck 1957) grades from a broad tonalite margin to granodiorite interior, which is attributed to differentiation in situ, following intrusion. The Shaler Granodiorite Pluton, Aleutian Islands, grades from a pyroxene rich outer zone to a potassic rich central zone. Drewes et al. (1961) explains the zoning in the Shaler Pluton as due chiefly to late crystallisation of uncontaminated central portions of the magma and partly to hydrothermal solutions. The Tunk Lake Granite Pluton, Southeastern Maine, contains six concentric gradational zones ranging in composition from magnetite-aegerine augite chill zone at the margin to biotite quartz monzonite at the core. Karner (1968) explains the compositional variation in this pluton as due to the migration of silica-rich aqueous fluids from margin to centre after the pluton was emplaced. The Cartridge Pass Pluton in Sierra Nevada exhibits compositional zoning from equigranular granodiorite at the margin to porphyritic quartz monzonite. Bateman and others (1963) postulated crystal fractionation and thermo-diffusion for the Cartridge Pass Pluton. Vance (1961) proposed that early crystallisation of the outer portions of an intrusion would produce a crystalline envelope which could prevent upward escape of the volatile constituents, subsequently released in the crystallisation of the melt below. The released volatiles would tend to be collected in the upper portions of the magma, below the crystalline shell. Progressive crystallisation inward and upward will produce increasing amounts of the volatile phase which is forced downward. Thus the melt below would become more silicic and richer in alkalis with depth and this would modify the composition of the melt and contribute to late magmatic and deuteric changes.

From this and also from the next section which deals with petrogenesis, the following origin is conjectured for the compositional zoning in the Colchester Pluton. A granodiorite magma was produced by a combination of processes of differentiation of mantle derived material and/ or partial melting (anatexis) of the crustal material. After its emplacement, diorite and quartz diorite rocks were produced by assimilation of the wall rocks. As the magma was emplaced in low pressure zones, crystallisation proceeded from margin to core, and a crystalline shell formed on the outer margin, which sealed off the migration of the volatiles, rich in alkalis and silica. Assimilation of the wall rocks and their subsequent released volatile matter was followed by the transfer of elements to the centre so that the marginal zone, depleted in alkalies and silica, crystallised into mafic rich rocks. The alkalis and silica were also perhaps contributed by late residual solutions derived from the magma chamber. The central zone became enriched in alkalis and silica and water; and eventually simultaneous crystallisation of felspar and quartz produced granophyric texture (Dunham 1965; Wager 1961) in leucocratic rocks which are almost free of mafic minerals. Residual mafic constituents in the presence of abundant water would be expected to produce chlorite, the only mafic mineral of the central zone.

Thus the compositional zoning is interpreted as a post-emplacement event.

Mode of Emplacement

The common association of batholiths with eugeosynclinal assemblages in space and time seems best interpreted as evidence of a genetic relationship between batholiths and geosynclinal volcanic rocks.

A cognate relationship between Ordovician volcanism and plutonism in the Central Mobile Belt of Newfoundland has been suggested by several workers (Neale ms.; Williams 1969; Marten 1970). Parallels elsewhere include the granodiorite batholiths of the Cascades and Aleutian provinces which share the compositional patterns of the volcanic rocks they intrude and of the volcanic rocks which overlie them (Drewes 1961; Tabor et al. 1969). Hamilton and others (1967) explains the association of volcanic rocks and granitic batholiths by a combination of Dickson's (1958) concept of zone melting and that of partial melting, within the upper mantle and lower crust. Due to differences in pressure, in a magma chamber, most volatile components migrate towards the top of the chamber. These volatile components melt the roof rocks and incorporate them. Progressive crystallisation of the magma from the bottom upward gives rise to leucocratic rocks at different levels.

Emplacement of the Colchester Pluton may resemble the mechanism proposed (Drewes and others, 1961) for the plutonic rocks of Unalaska Island, Aleutian Islands. These are the products of the crystallisation of a granodiorite magma that invaded rocks of the Unalaska formation by assimilation, stoping and forceful intrusion and possibly melting. The Colchester Pluton has a similar geological setting, i.e. association with submarine volcanic and deep sea sedimentary rocks. Fusion (anatexis) of the upper mantle may have produced basalts of the Lush's Bight Group. Partial melting of crustal material during upward movement of upper mantle material produced granodiorite magma, which was slightly lower in quartz and potash felspar (Buddington 1959; Burnham 1967; Drewes and others 1961) than the present surface rocks, which by assimilation of the wall rocks produced mela-diorite, diorite and quartz diorite of border facies. It was emplaced by a combination of processes of stoping and forceful intrusion. Roof pendants northeast of Colchester Pond substantiate the theory of stoping and the contact of the pluton with the wall rocks indicate forceful intrusion. The compositional variation in the pluton indicates assimilation and probably partial melting of the wall rocks. The periphery of the pluton is sheared, which may be due to the upward movement of the pluton during emplacement. Migration of alkalis and silica from the marginal zone to the centre and also late residual solutions and simultaneous crystallisation of quartz and felspar gave rise to the granophyric texture. The presence of late residual solutions is substantiated by the large quartz veins cutting the pluton.

COOPER'S COVE PLUTON

A small pluton consisting of a quartz monzonite (adamellite) core surrounded by a marginal zone of diorite and meladiorite occurs near Cooper's Cove on the eastern shore of the Southwest Arm. It is named Cooper's Cove Pluton by the author. Neale and Nash (1963) originally mapped it as part of the Burlington Granodiorite.

The diorite and meladiorite of the marginal zone strongly resemble some of the rocks of the marginal zone of the Colchester Pluton. They are cut by numerous aplite and diabase dikes. These marginal rocks also serve as host for the several small pods of ultramafic rocks which occur within the map area. In one locality, at Cooper's Cove, an ultramafic pod is located along the contact between diorite and lavas of the Lush's Bight Group. Elsewhere the contact between Lush's Bight rocks and the marginal zone of the Cooper's Cove Pluton is chiefly ill-defined, due to lack of outcrop. Inclusions of altered Lush's Bight rocks occur within the dioritic marginal zone close to the assumed contact zone.

The marginal zone rocks of the pluton are medium to coarse-grained and are chiefly meladiorite and diorite in composition. They exhibit feeble foliation. Examined microscopically they are seen to consist of plagioclase (An_{48}), hornblende, actinolite and quartz. Some of the amphibole is altered to chlorite. The plagioclase is relatively unaltered and exhibits excellent albite twinning and shows bent cleavage planes indicating that the rocks have undergone deformation.

The quartz monzonite core of the pluton is later than and cuts the dioritic marginal rocks. Well displayed intrusive contacts occur 9,000 feet north of Manful Point, along the eastern shore of Southwest Arm, and also 2,750 feet west of McNeily Pond. Inclusions of diorite and meladiorite are common within the quartz monzonite in several places along its contact with the dioritic marginal rocks.

The quartz monzonite is light greenish grey on fresh surfaces and pinkish grey on weathered surfaces; medium to coarse grained and porphyritic (Plate Vc). It has well-developed secondary foliation. In thin section it is seen to consist of plagioclase, potassium felspar, quartz, biotite, hornblende and chlorite, with sphene, apatite and opaque ores as accessories. The plagioclase occurs as thick tabular crystals, which are mostly zoned. Both normal zoning and oscillatory zoning are common. The average composition is An_{35}. Some grains that are extremely clean and fresh in one part are riddled with saussuritic alteration products in other parts. Slight sericitisation of the plagioclase is also common. The potassium felspar which occurs as small to large anhedra and also as euhedra, is chiefly microcline and microcline microperthite. The quartz is anhedral and usually has strain shadows and is flattened in the foliation planes. Granulation, recrystallisation and marginal breakdown of the quartz (Plate XVIIa) and its seriate nature suggest that deformation was more intense in this pluton than in the Colchester Plutons. Biotite, which is more abundant than hornblende, ranges from small ragged flakes to thick tabular grains.

Modal Composition

Modal analyses for the quartz monzonite of the Cooper's Cove Pluton are plotted on a Q-P-K ternary diagram (Figure 6) and as histograms of different modal minerals (Figure 5). It is seen that these rocks fall in the quartz monzonite (adamellite) field according to Johansen (1939).

Chemical Analyses

One sample each of quartz monzonite and diorite were analysed and the analyses are listed in Table 5 and plotted in Figures 2 and 3. The quartz monzonite has the highest K_2O content of all samples analysed.

Structural Setting

It appears that the Cooper's Cove Pluton has undergone a major deformation D_1 which produced a strong foliation S_1. The effect of second deformation is not clear except that intense shearing and fracturing followed D_1.

Mode of Emplacement

The strong contrast in composition and the sharp intrusive contacts between the core zone quartz monzonite and the marginal zone diorite and meladiorite suggest multiple intrusions. There is no evidence of the gradational relationships that characterize the Colchester Pluton. Inclusions of dioritic rocks within the quartz monzonite testify to solidification of the marginal diorite before emplacement of the quartz monzonite. That the quartz monzonite was emplaced mechanically, after cooling of the diorite, is further evidenced by cataclastic effects at its margins and in the bordering diorite and by swarms of felsic dikes emplaced within these zones of cataclasis and/or dislocation. The quartz monzonite was emplaced before the first penetrative deformation, D_1, because the S_1 foliation is well developed in this rock and is apparent at least locally, in the marginal diorite and meladiorite.

It is suggested that, following emplacement of the diorite and meladiorite, chemical evolution must have occurred below the present level of exposure before intrusion of the quartz monzonite. The two intrusive events were probably not widely separated in time.

BURLINGTON GRANODIORITE

Baird (1951) referred to the quartz diorite and granodiorite rocks occurring in Burlington Peninsula as Burlington Granodiorite. Neale and Nash (1963) and Neale (ms.) mapped these rocks where they extended into the King's Point and Baie Verte map areas.

An attempt was made to study variations in the type Burlington Granodiorite of the Burlington Peninsula to permit comparison with the plutons correlated with it in the present map area. Collections were made along the Burlington road on a traverse with Dr. E. R. W. Neale. In addition, data collected by Neale (ms.) is also cited herein.

The rocks have developed feeble to strong foliation (Plate VIa). Thin section examination shows that they consist of plagioclase, potash felspar, quartz, biotite, hornblende, with magnetite, sphene, apatite, and zircon. Plagioclase occurs as subhedral to euhedral crystals ranging from 0.70 mm. to 5.25 mm. which show oscillatory and normal zoning and alteration to epidote and sericite. Potash felspar is microcline and microcline microperthite. Quartz is interstitial and shows strain shadows. In general, typical Burlington granodiorite shows less deformational features than rocks of the Cooper's Cove Pluton, such as marginal breakdown of quartz crystals and strong preferred orientation of various minerals (Plate XVIIIa).

Modal Composition

Modal composition of the Burlington Granodiorite is plotted in Figures 5 and 6. Most of the rocks fall in the granodiorite field of the

Q-P-K ternary diagram. The plagioclase, quartz and potash felspar have almost uniform distribution.

Chemical Composition

One sample of Burlington Granodiorite collected from near Burlington village was analysed and the rest of the analyses cited in Table 4 are from Neale (ms.).

All analyses are plotted on variation diagrams (Figure 3) and as K_2O - Na_2O - CaO and FeO - Na_2O + K_2O - MgO ternary diagrams (Figure 2). All the analyses fall in an intermediate range between the transitional zone of the Colchester Pluton on one hand and the central zone of the Cooper's Cove Pluton on the other.

PETROGENESIS

The Ordovician intrusions, pillow lavas and sediments of the Colchester area and, in fact, of the entire Western Notre Dame Bay region, represent a common rock association. Similar close spatial and temporal associations of ultrabasic rocks, epidiorites, pillow lavas, greywackes, cherts and argillites are well known in ancient fold belts throughout the world. Logically enough, they had led to theories of genetic links between the igneous rocks involved and eventual intrusion or extrusion into a deep water sedimentary environment.

Compositional similarities of the Colchester suite of intrusive and extrusive rocks to igneous suites in the Western United States and Canada (Figure 7) have been mentioned in the foregoing pages. Although petrological and chemical data in the present study are too scanty to be significant in themselves, combined with geological evidence they could suggest a possible genetic relationship between Ordovician intrusive and extrusive rocks of the Colchester area. This is consonant with the position of the Colchester area in recently proposed models for the evolution of the Central Mobile Belt of Newfoundland (Williams 1964) in which the present study is located.

Wilson (1966) has suggested that proto-Atlantic Ocean closed in early Paleozoic times and that the Central Mobile Belt included remnants of deep sea floor in the zone of juncture of the continents that were rafted together at this time. The concept has been enlarged upon by Dewey (1969). As recent exploration of the deep sea floors, especially in the vicinity of mid-ocean ridges, has proved the presence of pillow lavas, serpentinites, gabbros and even such products of igneous differentiation as diorites (Aumento 1969) - the concept seems to fit the eugeosynclinal Appalachian region as a whole and the Central Mobile Belt of Newfoundland in particular. In a recent, more detailed model proposed by Bird and Dewey (1970) the present map area is shown as the site of an Ordovician island arc lying west of a Benioff Zone. Although these authors interpret the Lush's Bight Group as Eocambrian and as representing part of the ocean floor, there seems no good reason to doubt its Ordovician age and, actually, the island arc environment is, if anything, more suitable than the concept of derivation from a layer of the ocean floor. Thus Drewes and others (1961) noted the association of a small zoned Miocene granodiorite pluton with basic volcanic rocks in the Aleutian Islands, a present island arc environment lying west of North America on the continental side of a Benioff Zone. The Colchester environment in early Ordovician times must have been similar in many ways to the Aleutians in Tertiary time.

It seems possible (if speculatory) that Ordovician igneous activity in this area was both the direct product of mantle-derived basaltic magma, and also of the hybridization of such magma by fusion of crustal material to produce an intermediate magma. The sharp contacts of the core zone quartz monzonite with the marginal meladiorite of the Cooper's Cove Pluton suggest that further differentiation of the intermediate magma took place - in this case below the present level of exposure.

SPRINGDALE GROUP

The term "Springdale Formation" was first used by Espenshade (1937) to refer to red beds exposed around Springdale village and also on Pilley's Island. Subsequently, MacLean (1947) mapped volcanic units intercalated with the red beds and referred to the sequence as the "Springdale Group".

The red conglomerates, sandstones, shales and minor beds of grey limestone occurring southwest of Manful Point, in the present thesis area, are also referred to the Springdale Group (MacLean 1947; Neale and Nash 1963).

The basal unit of these rocks is a red polymictic conglomerate which outcrops almost 100 feet south of the last exposure of the Lush's Bight Group, along the eastern shore of the Southwest Arm, south of Manful Point. The conglomerate contains clasts of diorite, tonalite, granodiorite, granite, granophyre, quartz porphyry, acid and basic volcanic rocks, agglomerates, serpentinite, volcanic glass, ignimbrite, and chert in a matrix of epidote and plagioclase. The clasts are rounded to sub-rounded and generally range in diameter from 0.5 to 6 inches, exceptionally they are up to 1.5 feet diameter. The conglomerate becomes finer grained towards the southwest. The clasts in these conglomerates are similar to the rocks of the Colchester and Cooper's Cove Plutons, the Burlington Granodiorite and the Lush's Bight Group exposed immediately to the north and west of these Springdale outcrops. Thus, the clasts are interpreted to have been derived from these rocks.

The sandstones and shales are pale reddish brown, dark reddish brown and greyish red in colour. There are thin intercalated layers of grey limestone. Ripple marks, mud cracks and cross-lamination are common in the sandy and shaly beds, which indicate a shallow water and fluviatile environment of deposition.

Twenhofel and Shrock (1937) and Williams (1967) suggested that the source areas for the Springdale Group were tectonic lands formed in the late Ordovician (Taconic) orogenic episode. Helwig and Sarpi (1969) also suggested a similar source area for the Ordovician-Silurian conglomerates in the New World Island area to the east. In the present area, the rocks of the Springdale Group are interpreted to have been derived from a tectonically elevated source area, composed of the Colchester and Cooper's Cove Plutons and the Lush's Bight volcanic rocks.

The rocks of the Springdale Group were originally assigned to the Silurian by Espenshade (1937) and MacLean (1947). Later they were called Devonian by Twenhofel (1947) and Kalliokoski (1953, 1955). Neale and Nash (1963) and Williams (1962) reassigned them to the Silurian due to their similarity to the fossil-dated Botwood Group.

MISCELLANEOUS MINOR INTRUSIONS

A number of minor intrusions were observed, chiefly as dikes and sills which cut some or all of the Lush's Bight volcanic rocks, the Burlington Granodiorite, the Colchester and the Cooper's Cove Plutons. The intrusions consist of ultramafic rock, diabase, quartz porphyry and lamprophyre. In addition, aplite and granophyre dikes and veins cut the Burlington Granodiorite, Colchester and Cooper's Cove Plutons. Quartz veins cut all the rock units of the area.

(a) Ultramafic Intrusions

Four small pods of ultramafic rocks occur along the eastern shore of the Southwest Arm. The locations are: (i) Near Cooper's Cove at the contact of the Cooper's Cove and Colchester Plutons; (ii) 5,250 feet north of Manful Point; (iii) 7,250 feet N 60°E of Manful Point on the eastern shore of a small lake and (iv) 6,500 feet N 70°E of Manful Point on the edge of a large marshy area.

Another discovery of an ultramafic pod was made east of this map area during 1969 summer by mining company personnel, near Tims Pond, one mile east of Brown Pond (H.R. Peters, pers. comm.).

The ultramafic bodies near Southwest Arm are peridotites which are pale yellowish brown to moderate yellowish brown on weathered surfaces. Fresh surfaces are mottled dusky blue, medium bluish grey and pale yellowish brown. The Tims Pond occurrence is a greenish serpentinite (Plate IIIb).

The peridotites consist of clinopyroxene, olivine, carbonate, serpentine, tremolite, chlorite, chromite, and magnetite. Serpentine occurs as pseudomorphs after olivine. A veinlet of cross-fibre asbestos was noted in one of the thin sections of peridotite.

The Tims Pond serpentinite consists essentially of serpentine with carbonate cut by thin veinlets of cross-fibre chrysotile asbestos (Plate IIb). The serpentine shows mesh structure.

The occurrence of a number of small ultramafic pods in this area is very interesting in the light of occurrences of ultramafic rocks in the Betts Cove - Tilt Cove and Baie Verte - Mic Mac Lake regions (Neale 1957; Neale and Kennedy 1967). Neale (1957) reported intrusions of serpentinized ultramafic rocks into the Ordovician Snooks Arm Group and also into the Silurian (?) Cape St. John Group. Some conglomerate members of the Cape St. John Group contain rounded pebbles and cobbles of serpentinized ultramafic rocks. Neale (1957) and Upadhyay (pers. comm.) interpret the intrusion of the serpentinite into the Cape St. John Group as due to remobilisation under orogenic conditions.

Various hypotheses have been proposed for the formation of alpine serpentinites (Wyllie 1967); crystal settling of basaltic magma either in stratiform complexes at depth or in submarine lava flows; crystallisation from ultrabasic magmas; intrusions of solid primitive mantle material or of residual mantle material remaining after the removal of a basaltic fraction; fragments of the oceanic crust incorporated into an orogenic belt by mantle convection currents. As the early history of many serpentinite bodies is obscured by deformation and metamorphism, uncertainties and controversies about their ultimate origin are to be expected.

The main characteristics of the ultramafic rocks in the Colchester area are similar to features outlined by Thayer (1967): They are closely related spatially and structurally to a eugeosynclinal sequence consisting chiefly of volcanic rocks and intermediate intrusions. The lack of contact aureoles and the close association with fault zones suggests that they may have been emplaced as cold diapiric masses.

It is suggested that the ultramafic bodies in the Colchester area formed from residual mantle material after removal of the basalt fraction. The basalt fraction gave rise to Lush's Bight volcanic rocks and the Colchester and Cooper's Cove Plutons. Later, pods of the serpentinized ultrabasic rocks were tectonically squeezed into the volcanic and dioritic host rocks.

(b) Diabase

There are a number of diabase dikes cutting the Lush's Bight Group volcanic rocks and the Colchester and Cooper's Cove Plutons. Structurally, these are broadly divided into two groups:

(i) Those that have feeble to moderate S_1 schistosity which is visible to the naked eye. They also show alteration of their primary minerals. They are interpreted as pre-D_1 intrusions.

(ii) Those which are unaltered and have little or no trace of a secondary fabric are interpreted to be post-D_1 deformation.

Excellent cross-cutting relations were seen near Eastern Point (Plate XIXa), Jackson's Cove, Birchy Cove, Firecatch Cove, Swatridge Cove, Manful Point and Big Pond. The contacts are sharp with chilled margins of about one to two inches.

The pre-D_1 diabase is greenish in colour due to alteration of clinopyroxene to uralitic hornblende and chlorite. Well developed schistosity is due to the parallelism of chlorite and hornblende. Ilmenite is altered to leucoxene, which forms rims around it. Quartz occurs as interstitial grains between the felspars and hornblende. The felspars are altered to epidote. Opaque iron oxides occur as scattered grains and dust.

The post D_1 diabase is fresh and is typically dark grey in colour and fine to medium grained. Sub-ophitic texture (Plate XIXb) is apparent megascopically and in thin section is seen to consist of calcic plagioclase (An_{70}) laths surrounded by clinopyroxene and olivine, with accessory magnetite, ilmenite, pyrite, serpentine and chlorite. The pyroxene is titanaugite with purplish brown hues. Euhedral to subhedral crystals of olivine are altered to serpentine.

Late stage basic intrusions are apparently due to repetition of igneous intrusive history in the area. The early, pre-D_1 dikes are probably related to the Ordovician volcanism that produced the Lush's Bight pillow lavas. The post-D_1 intrusions appear to be related to post-Ordovician (Silurian ?) volcanic activity. Basic volcanic activity is known in the Silurian Springdale Group (Neale and Nash 1963) and it is possible that the late basic dikes are related to this episode of igneous activity.

(c) Quartz Porphyry

There are two varieties of quartz porphyry. The first is light greenish in colour and occurs as dikes along the periphery of the Colchester Pluton at its contact with the Lush's Bight Group and in dikes which are abundant on the western side of the pluton. It also occurs in scattered, outcrops along the Colchester - Old English Mine road cuts. It shows a well-developed schistosity, which is generally parallel to the S_1 regional schistosity and suggests that intrusion preceded D_1 deformation. A thin section of a typical specimen shows porphyritic texture with phenocrysts of quartz and some plagioclase in a fine-grained aphanitic groundmass of the same composition. Chlorite and carbonate occur as accessories. The schistosity is imparted by the alignment of chlorite flakes.

The second type of quartz porphyry is milky white. It occurs in dikes chiefly along the eastern shore of the Southwest Arm, which vary in thickness from one to three feet. It is particularly well exposed near Swatridge Cove and Eastern Point. These dikes cut the volcanic rocks of the Jackson's Cove Unit of the Lush's Bight Group and also cut the diabase dikes described above. This variety of porphyry shows excellent flow layering. At places the dike rocks are sheared and closely jointed. Due to differential weathering the quartz porphyry dikes commonly stand out as linear positive relief features (Plate XIIa).

(d) Lamprophyre

Lamprophyre dikes, 0.50 to 2 feet thick, cut the basic tuffs near Eastern Point. Tongues of these cut the volcanic rocks. There is a narrow chilled margin (0.5 inches) at contacts with the basic tuffs (Plate IIIc). The dikes are sheared and well jointed.

The lamprophyres are latest in the intrusive history. They are dark greenish grey to black; the centres of the dikes are commonly coarse and porphyritic with pyroxene and twinned hornblende phenocrysts, whereas the margins are fine-grained, and show well-developed trachytic texture (Plate XXIb). These lamprophyres consist essentially of hornblende, clinopyroxene, plagioclase, carbonates and chlorite and could be classified as spessartites.

(e) Granophyre

Small dikes and sills of light pinkish coloured granophyre cut the Burlington Granodiorite along Burlington road and also north of Middle Arm village, on the western shores of the Southwest Arm. These are composed of quartz, potash felspar and plagioclase with chlorite and magnetite as accessories. Granophyric intergrowths of potassium felspar and quartz are seen (Plate XXb). These occur as fine comb-like intergrowths of potash felspar and quartz and at places occur as rims around plagioclase which are partially replaced. This comb-like intergrowth indicates that the quartz and potash felspar crystallised together in the late stage. They are probably the product of residual solutions. Thus the granophyre is interpreted as a late stage acidic intrusive.

STRUCTURE

The area is characterized by changes in trend of the steeply dipping schistosity from northeast around Colchester Pond, to north northwest in the Manful Point region and to easterly in the Jackson's Cove region. The volcanic and intrusive rocks are intensely deformed throughout this area in comparison with those of the Western Arm section in the adjacent region to the west (MacLean 1947; Marten 1970).

It appears that the area has undergone two important deformations, D_1 and D_2 and a third minor deformation D_3. The first phase of deformation D_1 resulted in tight F_1 folding about northeast striking axes which is related to a strong S_1 schistosity. The second deformation produced north northeast to northeast trending broad open F_2 flexural folds.

Folds

The F_1 folds are mapped between Joe's Cove and Jackson's Cove on the basis of facing directions obtained from pillow lavas (Figure 8). The F_2 folds are broad flexures, which include an anticline around Colchester Pond and synclines at Manful Point and Jackson's Cove. Figure 8 shows both sets of fold axes together with trend lines of S_1 schistosity. The area has been divided into three blocks, and the poles to S_1 schistosity in these areas have been plotted. Block 1 has been subdivided into two parts, 1a and 1b, in order to show the relationship of the northwest striking foliation in the Cooper's Cove Pluton to that of the rest of the area. It is obvious that the swing in the trend of S_1 schistosity is due to the second phase folding. The stereograms have not been contoured because sampling was not carried out on a grid pattern and it is felt that scatter diagrams give a good regional picture. The stereograms in all five cases clearly show that the first schistosity S_1 has been folded by the second deformation D_2, producing F_2 folds with north northeast to northeast axial surfaces. It appears that the main Colchester Pluton acted as a relatively stable block during the deformation and the rocks of the less competent Lush's Bight Group were folded around it producing a broad anticlinal fold. Minor F_2 flexures have taken place in the Colchester area as indicated by the variations of the S_1 schistosity trend within it.

The relationship of the F_2 flexures to a second cleavage, present in the rocks near Jackson's Cove and also around the Colchester area is not clear. This S_2 cleavage strikes within 20° of the S_1 strike and has a gentler dip.

The minor deformation D_3 caused kink bands in the sheared volcanic rocks that are seen south of Mine Pond, along the Colchester Mine Road and along Jackson's Cove Road, near West Brook.

Faults

There are two sets of faults in the area. One set trends almost east-west and the other trends northeast.

The important east-west trending faults are the Saunder's Brook and Jackson's Cove faults. The Saunder's Brook fault separates the Jackson's Cove Unit of the Lush's Bight Group and the Colchester Pluton from the Birchy Cove Unit of the Lush's Bight Group. Intense shearing and fault gouge occurs along Saunder's Brook. The Jackson's Cove road fault separates the Birchy Cove Unit from the Jackson's Cove Unit. Intense shearing in the basalts is seen along the Jackson's Cove road.

A major northeast fault which extends from Nicky's Nose through Brown Pond to South Pond truncates both the Saunder's Brook and Jackson's Cove road faults. This major fault separates the Colchester intrusive rocks and the Lush's Bight volcanic rocks on the west from northwesterly striking volcanic rocks (also assigned to the Lush's Bight) on the east. Intense shearing associated with it is seen in the volcanic rocks along the Silverdale road. It has further been substantiated by drilling around Brown Pond where extensive shear and gouge zones were encountered in the cores (H.R. Peters, pers. comm.). The Southwest Arm fault separates the Lush's Bight Group and Colchester Plutons on the eastern shore from silicic volcanic rocks and porphyry on the western shore of the Arm. It was interpreted as due to Acadian movements (Neale and Nash 1963). Similar northeast striking faults characterize the whole of western Notre Dame Bay area (MacLean 1947).

The S_1 schistosity produced by the first deformation (D_1) is seen well-developed in all the rock types of the Lush's Bight Group. The Colchester and the Cooper's Cove Plutons also contain a well-developed S_1 schistosity, which suggests that it was produced after the emplacement of these plutons. The S_1 schistosity has been flexed by a second deformation (D_2).

It is tentatively concluded that the D_1 deformation resulted from Ordovician Taconic orogeny and was followed by faulting along east-west lines. D_2 deformation which caused broad flexuring of the earlier structures was probably due to Acadian orogeny. It was followed by faulting along northeast lines. Williams and others (1970) interpret similar broad flexures throughout the Central Mobile Belt of Newfoundland to be late Acadian features.

REGIONAL SIGNIFICANCE OF COLCHESTER GEOLOGY

The present thesis area is located in the Central Mobile Belt of Newfoundland, interpreted by Williams (1964) as a narrow deep sea trough in Eo-Cambrian to Ordovician times, bordered by marginal shelf clastics, e.g., Fleur de Lys Group and Gander Lake Group. It contains most of the rocks that characterise the Ordovician of that belt, viz., pillow lavas, volcaniclastic sediments, cherts, pods of serpentinised ultramafic rocks and dioritic plutons. Despite its small size, the area thus poses some of the problems associated with Ordovician rocks of the Central Mobile Belt and possibly offers some of the answers. The main problems deal with the correlation of unfossiliferous or sparsely fossiliferous volcanic sequences and the relative ages of their associated intrusions and with the ultimate origin of such typical "eugeosynclinal assemblages".

Correlation Problems

The Lush's Bight Group dates as Early Ordovician by MacLean (1947), resembles the Snooks Arm Group (Snelgrove 1928) to the north and the Baie Verte Group (Watson 1947) to the west. All three sequences show structural lithological similarities which suggest a common and roughly synchronous origin.

However, Neale and Kennedy (1967) recently proposed that the Baie Verte Group could be as young as Silurian on the basis that it contains pebbles of Burlington Granodiorite and it overlies a Silurian(?) silicic volcanic sequence (Mic Mac Group) which itself rests unconformably on the Burlington Granodiorite.

The present study has shown that the Lush's Bight volcanic rocks are intruded by pre-tectonic plutons which are genetically related to the Burlington granodiorite. At Western Arm, in the adjacent area to the east, Marten (1970) has shown that a rather similar pluton intrudes the Lush's Bight Group but in this locality Lush's Bight Group volcaniclastic rocks contain clasts of quartz diorite and diorite (Neale and Kennedy; Marten 1970). It has been suggested in previous sections of this thesis that the early plutons of this area are genetically related to Ordovician volcanism, therefore clasts of diorite, quartz diorite and granodiorite in the Lush's Bight and/or the Baie Verte rocks do not necessarily imply a major unconformity or other major time break.

Also without necessarily reflecting on the age of the unfossiliferous Mic Mac Group, it might be pointed out that the Lush's Bight Group is closely associated with a silicic volcanic sequence, the Catcher's Pond Group which is now known to be of Lower Ordovician age (Neale and Fahraeus, pers. comm.), and that the Snooks Arm Group may be younger than at least part of the silicic volcanic sequence known as the Cape St. John Group (Upadhyay, pers. comm.).

It has also been suggested on the basis of long range comparisons and generalisations (Bird and Dewey, Fig. 5, 1970), that the Lush's Bight Group is Late Precambrian and was later involved in a "precocious" Taconian orogeny in earliest Ordovician time (Rodgers 1967). The writer finds little substance to this age assignment for there is no evidence from the present study or that offered to suggest that sequences of several ages are included in the Lush's Bight Group as presently mapped (Williams 1967b).

The early Ordovician age is based on: (1) a single brachiopod *Discotreta* indicative of Arenig age described by MacLean (1947) from Clam Pond; (2) similar volcanic rocks on Limestone Island and at Lush's Bight village yield Ordovician fossil assemblages from intercalated slate or limestone interlayers (Williams 1962).

Bearing on Closing Atlantic Ocean and the Origin of Eugeosynclinal Rocks

Probably the most acceptable models for the origin and deformation of eugeosynclinal sequences are those which involve the newly developed hypotheses of spreading ocean floors and plate tectonics. This approach pictures Appalachian mountain building as the product of a closing Atlantic Ocean in Early Paleozoic time (Wilson 1966). According to this theory, the Central Mobile Belt (Williams 1964) represents the zone between an original North American continent and a Proto African continent that was rafted towards it (Dewey 1969). Following the model proposed by Bird and Dewey (1970) the Colchester area lies immediately west of the former locus of a west dipping Benioff zone. This tectonic setting would suggest a volcanic Island Arc environment. Colchester geology suggests such a setting - the thick sequence of Lush's Bight pillow lavas and the associated pyroclastic rocks, cherts, argillites, and greywackes are all typical products of such an environment. The pods of serpentinised ultramafic rocks which occur within the area, at least partly localized along shear zones, undoubtedly represent part of the sea floor tectonically squeezed into the overlying lavas. The granodiorite to dioritic plutons, roughly contemporaneous with the volcanic rocks, are genetically related to them and possibly the result of fusion of basaltic material in proximity to the Benioff Zone. In discussing the origin of the peculiar zoning in one of the Colchester Plutons the writer has cited a similar zoned pluton in the Aleutian arc. Possibly an even broader analogy is valid - in Early Ordovician time the Colchester region and nearby areas on the Springdale and Burlington Peninsulas must have greatly resembled the Aleutians of Mid-Cenozoic to recent times.

In conclusion, geology of the Colchester area in so far as applicable, seems to corroborate the theory of a closing Atlantic Ocean in Early Paleozoic time.

ECONOMIC GEOLOGY

History of Exploration

In the present area, copper was mined from Colchester, McNeily, Old English and Swatridge mines (Figure 9). The Colchester property was developed in 1878 and was worked in a small way until 1901. The McNeily Mine was discovered in 1892 (MacLean 1947) but the period of operation is not known. The combined production from the two mines was approximately 800 tons of hand sorted high grade copper ore. On the Old English property, shafts were sunk about 1878 and the property was mined for approximately five years (MacLean 1947). On the Swatridge property two shafts were sunk during the winter of 1876 and the work was suspended in the spring of 1877 after a few tons of ore had been raised (Murray and Howley 1881).

M. J. Boylen Engineering Company holds exploration rights for the McNeily, Colchester, Old English and Swatridge properties and, at present, Cerro de Pasco Mining Corporation is carrying out exploration work under agreement with Boylen. British Newfoundland Exploration Limited holds the rest of the area under concession (Figure 9).

G. S. W. Bruce (Brown 1963) in his private report of 1951 for Falconbridge Nickel Mines Limited calculated approximately 3,000 tons of ore averaging 1.80% copper on the various dumps of the Colchester and McNeily properties.

Brown (1963) prepared a geological outcrop map of the McNeily, Colchester and Old English properties on scale 1 inch - 200 feet for the

M. J. Boylen Engineering Company during 1962-63. He also carried out geochemical soil sampling, a magnetometer survey and channel sampling. Diamond drilling totalling 7,327 feet in 15 holes was also undertaken to explore the Colchester zone and to check the results of the magnetic and geochemical surveys. The magnetic survey indicated seven anomalies. The geochemical survey delineated a number of copper "highs" in the areas of positive magnetic anomalies.

Merchant (1966) carried out geological mapping in the Swatridge area for M. J. Boylen Engineering Company.

Cerro de Pasco Company has recently taken a sub-lease from Boylen Engineering Company. They commenced mapping during the summer of 1969 and are contemplating further extensive diamond drilling on the magnetic anomalies recommended by Brown (1963) and also on a self potential anomaly (A.B. Baldwin, pers. comm.).

General Setting

Sulphide mineralisation in the area is concentrated in chlorite and quartz chlorite schists and also in quartz veins, along a shear zone which marks the western periphery of the Colchester Pluton; and also along minor shear zones which range from a few hundred to a few thousand feet. These shear zones appear to have been channels along which hydrothermal solutions travelled and altered the Lush's Bight Group basalts to chlorite and quartz chlorite schists. The chlorite and quartz chlorite proved to be good host rocks for the sulphide mineralisation. The quartz veins show intense granulation and breaking down along their margins and these granulated zones are replaced by the sulphides (Plate XXIIIb). Thus, all evidence suggests that the mineralisation is post-shearing.

All the shear zones along which sulphide mineralisation is seen are parallel to the major northeast faulting. The northeast faulting in the Little Bay area (MacLean 1947) is dated as Acadian and thus the mineralisation is also interpreted as Acadian.

The sulphide deposits of the Colchester area resemble each other and are essentially a pyrite-chalcopyrite type. The mineralogy is very simple, chief constituents being: magnetite, pyrite, chalcopyrite, locally galena and tetrahedrite, with quartz, epidote and chlorite as gangue.

Description of the Mineral Showings

Swatridge Property

An old shaft is located near Swatridge Cove on the eastern shore of the Southwest Arm. A shear zone striking east-west and dipping 80° north is the locus of a two-feet thick quartz vein. The quartz vein is mineralised with chalcopyrite, pyrite and galena. The country rock is quartz talc chlorite schist. A porphyritic diabase dike cuts the chlorite schists.

Colchester and McNeily Mines

The Colchester Mine property is about 8,000 feet almost due south of Naked Man, and the McNeily shafts are about 2,000 feet southwest of the Colchester Mine.

(a) McNeily Pond Pits

MacLean (1947) reported two main shafts and two pits and at the present time these occur as four abandoned pits along the road.

The shear zones in dark grey chlorite schists strike N 25° E to N 35° E and dip 70° - 75° southeast. Talc has developed along the zones of shearing. The mineralisation consists of chalcopyrite, pyrite and magnetite.

(b) Colchester Mine

Three pits were examined around Mine Pond and Colchester Pond.

1. East of Mine Pond, in a large inclined adit, a shear zone about 4 feet wide consists of chlorite schists which strike N.E. and dip 70°N.W. The mineralisation is chalcopyrite and pyrite.

2. In a second pit, on the east bank of one of the arms of the Colchester Pond, sheared chlorite schists strike N 40° E and dip 80° N.W. The mineralised zone is about 10 feet wide. In the cliff section, a short distance above this pit, mineralisation consists of chalcopyrite and pyrite which occur as veins and stringers in the dark grey chlorite schists. It appears that this zone is a continuation of the one east of Mine Pond.

3. An abandoned pit occurs about 700 feet southeast of the second pit. Here highly sheared chloritic amygdaloidal altered basalts, strike N 25°E and dip 78°N.W. The ore minerals are chiefly chalcopyrite and pyrite. Fifty feet west of the pit, coarse quartz porphyry intrudes the volcanic rocks.

Old English Mine

A number of old workings are located along the Colchester - Old English trail.

1. In the first pit 5,000 feet north of Mine Pond occurrence, quartz chlorite schists strike N 35°E and dip 75°S.E. Well-developed cleavage strikes N 10°E and dips 70°S.E. The chlorite schists are mineralised with fine veins and stringers of pyrite, chalcopyrite. The mineralised zone is about 10 feet wide.

2. A shear zone 750 feet northeast of the first pit, strikes north - south and dips 50°E. A quartz vein about 6 inches wide occurs within this shear zone. The quartz chlorite schist and the quartz veins are mineralised.

3. 2,250 feet northeast from this pit, another long open pit was examined in which the shear zone strikes N 30°E and dips vertically. The sheared quartz chlorite schists strike N 30°E and dips 65°N.W. Quartz porphyry intrusions strike N 55°E and dip 80°N.W. The mineralised zone is about 2 feet wide. Chalcopyrite and pyrite occur as thin stringers one inch thick which dip 80°N.W.

Other Minor Occurrences

There are a few other minor occurrences of sulphide mineralisation in the area, located along small shear zones. They include:

1. A shear zone 2,000 feet southwest of Naked Man, on the coast, in chloritic schists intercalated with tuff bands which strike N 20°E and dip 55°S.E. Chalcopyrite and pyrite are present within the shear zone.

2. A shear zone about 8 feet wide in chlorite schists occurs on the coast, about 4,500 feet northeast of Manful Point, along the eastern shore of the Southwest Arm. The chlorite schists strike N 20°W and dip 75°N.E. Limonite stains are seen on the surface. Chalcopyrite and pyrite are contained in the schists.

3. Near Ferndale, on the western bank of a small pond, a minor shear zone about 3 feet wide is mineralised with chalcopyrite. Limonite and malachite stains coat the weathered surfaces.

4. A minor occurrence of sulphide mineralisation was discovered by mining company personnel during the summer of 1969,1000 feet east of Colchester Pond (H. R. Peters, pers. comm.). Chalcopyrite and pyrite mineralisation occurs chiefly in the quartz veins and also in the chlorite schists, within the marginal zone of the Colchester Pluton. The chlorite schists occur as large caught-up and unassimilated patches of altered volcanic rocks and may be even roof-pendants.

Silverdale Mine

At Silverdale, sheared basalts strike N-S and dip 72°W. 1,000 feet west of this locality, the sheared basalts strike E-W and dip 75°S. This minor shear zone indicated by sheared basalts and change in their trend is parallel and very near to the major northeast striking Nicky's Nose - South Pond fault. Galena and chalcopyrite are associated with the sheared chlorite schists and quartz veins in the Silverdale shaft.

Mineralogy

Microscopic study of polished sections of ore collected from the surface and from various pits, dumps and shear zones show magnetite, pyrite, chalcopyrite, galena, tetrahedrite, covellite, and limonite. The present lease holders, Cerro de Pasco Mining Company Limited did not permit access to core samples and thus the study was mainly confined to surface grab samples and conclusions on the origin of the ore must await further study. However, certain generalisations can be made on the basis of other observations.

The various minerals and their textural relationships are described below.

Magnetite

Magnetite appears to be the earliest mineral. It replaced the country rocks, chlorite and quartz chlorite schists and quartz veins. Magnetite pseudomorphs after the chlorite are common (Plate XXIa). The magnetite has a platy occurrence, is slightly anisotropic and little blebs of ilmenite are seen which are perhaps due to ex-solution. Magnetite is the predominant metallic mineral in the McNeily showings which probably accounts for the magnetic anomalies which were discovered in a 1963 survey (Brown 1963).

Pyrite

Pyrite is the next most abundant mineral. It is predominant in the Old English Mine showings where early pyrite is seen in the chlorite schists outside the ore zones. It shows pressure shadows of chlorite and the S_1 schistosity which bends around the pyrite indicates that it pre-dates S_1 deformation.

The later pyrite occurs as small cubes, pyritohedra and anhedral grains which replace magnetite. It is often fractured and is veined by chalcopyrite. Limonite forms rims around the pyrite (Plate XXIb).

Chalcopyrite

Chalcopyrite occurs as blebs in the pyrite and also in veins. It corrodes the gangue (Plate XXIIa) and also replaces pyrite and magnetite along fractures. The chalcopyrite is twinned. It contains inclusions of magnetite and is altered to limonite and covellite along fractures (Plate XXIIb).

Galena

Galena occurs in the Silverdale shaft where it is associated with chalcopyrite and quartz gangue. Bent cleavages testify to plastic deformation (Plate XXIIIa). It replaces chalcopyrite along fractures.

Tetrahedrite

This mineral occurs as bleb-like inclusions with smooth rounded boundaries in galena.

Paragenesis

The sequence of formation of various minerals in the Colchester area from earliest to latest is: chlorite, quartz, magnetite, pyrite, chalcopyrite, tetrahedrite, covellite and limonite.

Ore Genesis

Sulphide mineralisation occurs in the altered basalts and in chloritised shear zones and fault zones in the Colchester area. Near Horse Shoe Pond (west of Big Pond), mineralisation occurs within the Colchester Pluton, near its western periphery. In regard to this last occurrence, it is worth noting that Ney (1966) in British Columbia suggested that the place to look for copper is on the peripheries of the intrusions rather than within the intrusions.

An epigenetic origin of the sulphide mineralisation is indicated by some of the observed features:

1. The ore is localised in the chlorite schists and quartz veins, along shear zones and minor faults mainly on the western periphery of the Colchester Pluton. Thus the ore is structurally controlled.

2. The replacement textures indicate that the sulphides were formed later than the host rocks.

The ultimate source of the copper sulphides in the host rocks could be due either to magmatic hydrothermal activity or to Lush's Bight volcanism.

A magmatic hydrothermal source is suggested by the spatial association of the sulphide deposits with the Colchester Pluton and also by presence of quartz veins and granophyric texture in the Colchester Pluton.

A volcanic source of the sulphides is indicated by their association with the Lush's Bight volcanic rocks. Williams (1963) pointed out the close association of the copper minerals with the volcanic rocks in the Notre Dame Bay area and suggested that this could indicate their genetic relationship to the volcanism.

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TABLE 1: Chemical Analyses of Lush's Bight Group

	Jackson's Cove Unit					Normal Tholeiitic Basalt
	S-35+	NA-3153*	NA-3152*	MacL-1**	MacL-2**	Nockolds(1954)
SiO_2	58.3	50.3	47.1	46.92	48.82	50.83
Al_2O_3	8.1	15.5	16.4	16.32	15.67	14.07
Fe_2O_3		2.4	3.0	2.85	1.79	2.88
FeO		6.25	7.67	8.26	7.57	9.06
$FeO + Fe_2O_3$	7.59					
CaO	8.69	11.0	9.1	12.40	10.46	10.42
MgO	9.92	6.5	8.6	6.62	7.41	6.34
Na_2O	1.15	3.1	2.6	2.32	3.38	2.23
K_2O	0.27	0.04	0.54	1.92	0.20	0.82
H_2O+	4.80	2.5	3.3	0.08	2.65	0.91
H_2O-					0.03	
TiO_2		0.80	1.5	1.72	0.85	2.03
P_2O_5		0.03	0.16	0.18	0.05	0.23
MnO	0.12	0.15	0.17	0.18	0.18	0.18
CO_2		0.43	0.48	0.03	1.10	
S					0.07	

*Neale (ms)

**MacLean (1947)

+ Analyst: Mrs. G. Andrews.

TABLE 2: Chemical Analyses of Birchy Cove Unit Variolitic Basalts

	S-333*	NA-3155**	S-332+ Top*	S-332+ Middle*	S-332+ Bottom*	Average Tholeiitic Andesite Nockolds(1954)
SiO_2	48.7	51.6	51.7	49.6	49.0	51.43
Al_2O_3	13.8	17.6	13.3	13.0	13.4	13.05
Fe_2O_3		2.2				3.36
FeO		5.16				9.74
Fe_2O_3 + FeO	10.30		9.60	8.24	9.85	
CaO	12.08	9.7	11.66	13.10	12.64	8.78
MgO	10.54	7.8	9.44	8.76	10.59	5.28
Na_2O	0.21	3.1	1.18	1.67	1.18	3.18
K_2O	0.35	0.18	0.19	0.14	0.30	1.04
H_2O+ / H_2O-	3.59	3.2	2.47	2.94	3.31	0.87
TiO_2	0.38	0.33	0.27	0.28	0.32	2.60
P_2O_5		0.02				0.48
MnO		0.15	0.15	0.17	0.17	0.19
CO_2		0.24				
S						

*Analyst: Mrs. G. Andrews (Grab samples)
**Neale (ms)
+Pillow sampled in three sections.

TABLE: 3: Modal Analyses of rocks from Colchester Pluton (Volume Percent)

	Marginal Zone						Transitional Zone			Central Zone				
	A_3	S-15	S-30	S-64	S-28	S-46	S-76	S-34	S-58	S-124	S-143	S-125	MN-48	S-100
1. Plagioclase	65.3	33.7	48.7	52.5	47.1	17.4	42.3	44.5	32.3	33.6	43.2	40.8	41.5	18.03
2. Quartz	1.5	8.5	18.1	1.3	10.7	18.9	21.7	14.2	20.5	26.4	18.5	43.1	32.0	13.4
3. Pyroxene	7.8	9.7	--	1.4	--	39.6	--	--	21.2	--	--	--	--	--
4. Amphibole	16.6	38.5	25.1	39.0	34.8	19.6	23.4	23.0	8.0	--	--	--	--	--
5. Potash felspar	--	--	--	--	--	--	--	--	--	6.8	4.9	1.1	3.2	1.3
6. Granophyre	--	--	--	--	--	--	--	--	--	32.5	26.5	3.2	17.0	56.1
7. Chlorite	7.0	9.9	9.0	5.7	7.1	6.2	11.8	11.1	18.0	--	--	6.5	6.2	4.2
8. Accessories	--	--	--	0.1	--	0.4	--	0.2	--	0.7	--	5.5	0.26	5.3

TABLE 4: Chemical analyses of Colchester, Cooper's Cove Plutons and Burlington Granodiorite

	Colchester Pluton			Cooper's Cove Pluton		Burlington Granodiorite			
	Marginal Zone S-30+	Transitional Zone S-76+	Central Zone S-124+	Meladiorite Marginal Zone S-205+	Quartz Monzonite Core S-190+	S-J+	BV-97*	BV173	W301-9**
SiO_2	57.7	61.6	78.2	55.6	75.0	65.2	64.7	64.3	68.27
Al_2O_3	14.6	12.3	11.9	13.0	13.4	14.8	16.2	16.6	15.73
Fe_2O_3							1.1	1.5	1.27
FeO							2.43	2.83	1.92
Fe_2O_3+FeO	6.86	5.33	2.61	5.43	2.40	4.09			
CaO	8.95	6.14	2.84	12.21	2.88	3.81	3.4	4.0	2.44
MgO	6.30	7.48	0.45	10.72	0.98	3.39	2.3	3.1	1.91
Na_2O	2.17	2.88	3.35	1.39	2.99	4.23	4.0	4.1	5.24
K_2O	0.28	0.74	1.00	0.39	4.11	2.40	2.1	2.0	1.76
H_2O+	2.08								
H_2O+ / H_2O-		1.77	0.94	1.59	0.79	0.91	1.34	0.93	0.81
H_2O-									
TiO_2			0.1			0.34	0.54	0.7	0.47
P_2O_5							0.16	0.2	0.18
MnO	0.10	0.07	0.05	0.10	0.06	0.07	0.05	0.1	0.06
CO_2							0.42	0.01	0.04
S									

*Neale (ms); **Watson (1947); +Analyst: Mrs. G. Andrews. (Grab samples)

TABLE 5: Modal analyses of Cooper's Cove Pluton and Burlington Granodiorite (Volume Percent)

	Cooper's Cove Pluton									Burlington Granodiorite										
	S-193	S-231	S-190	S-185	N-3035	N-3077	S-H-69	S-E-69	S-B-69	S-J-69	S-L-69	BV-* 173	NA-* 2535	NA-* 2606	NA-* 2552	NA-* 2125	NA-* 3076	BV-* 99	NA-* 2609	W-** 3019
Plagioclase	37.0	51.1	32.8	39.3	61.4	51.5	54.4	43.3	59.3	44.0	60.5	58.5	66.4	36.8	40.0	38.2	51.7	54.5	66.3	58.1
Quartz	19.9	17.9	27.2	26.6	17.4	22.2	25.2	27.5	15.8	19.6	7.0	15.1	16.9	39.4	25.8	40.5	18.1	19.6	28.0	28.8
Potash Felspar	19.1	7.2	21.4	20.8	6.9	11.3	11.6	18.4	9.8	16.0	3.6	9.7	3.9	16.2	25.0	16.5	14.1	9.2	2.6	3.1
Biotite	--	3.8	9.5	5.1	0.7	2.0	--	3.8	0.9	10.6	10.8	7.5	1.7	--	0.3	--	2.3	4.4	--	11.0
Hornblende	14.2	9.7	0.2	1.2	5.6	1.4	1.5	5.9	7.8	9.2	15.5	6.6	3.4	--	3.3	3.8	8.0	5.2	---	--
Chlorite	9.4	9.2	--	4.1	6.5	10.4	6.2	0.9	4.6	5.8	--	0.9	5.7	6.4	5.3	--	4.0	3.9	2.2	--
Accessories	0.8	1.0	1.1	3.7	1.4	1.2	1.5	0.2	0.9	--	2.6	1.4	2.0	1.2	0.3	1.0	1.8	2.8	0.9	5.0

*Neale (ms); **Watson (1947, p. 16).

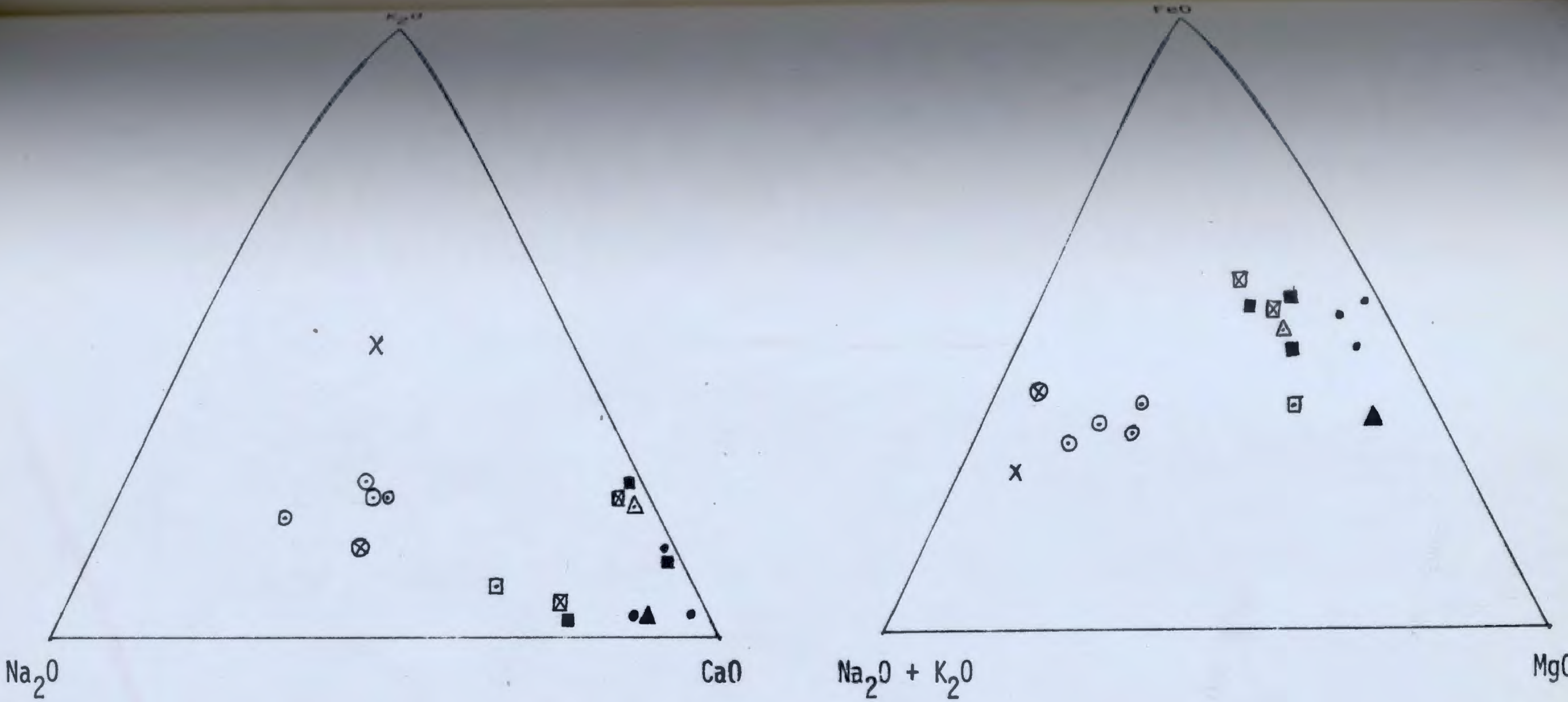


Figure 2: Chemical variation of rocks from the Colchester area and Burlington Peninsula.

X Quartz Monzonite, Cooper's Cove Pluton

⊙ Burlington Granodiorite

Colchester Pluton

⊗ Central Zone

⊡ Transitional Zone

△ Marginal Zone

• Lush's Bight Group Basalt (Analyst: Mrs. G. Andrews)

⊠ Lush's Bight Group Basalt (MacLean 1947)

■ Lush's Bight Group Basalt (Neale ms.)

▲ Average Whalesback Basalt (Papezik 1967)

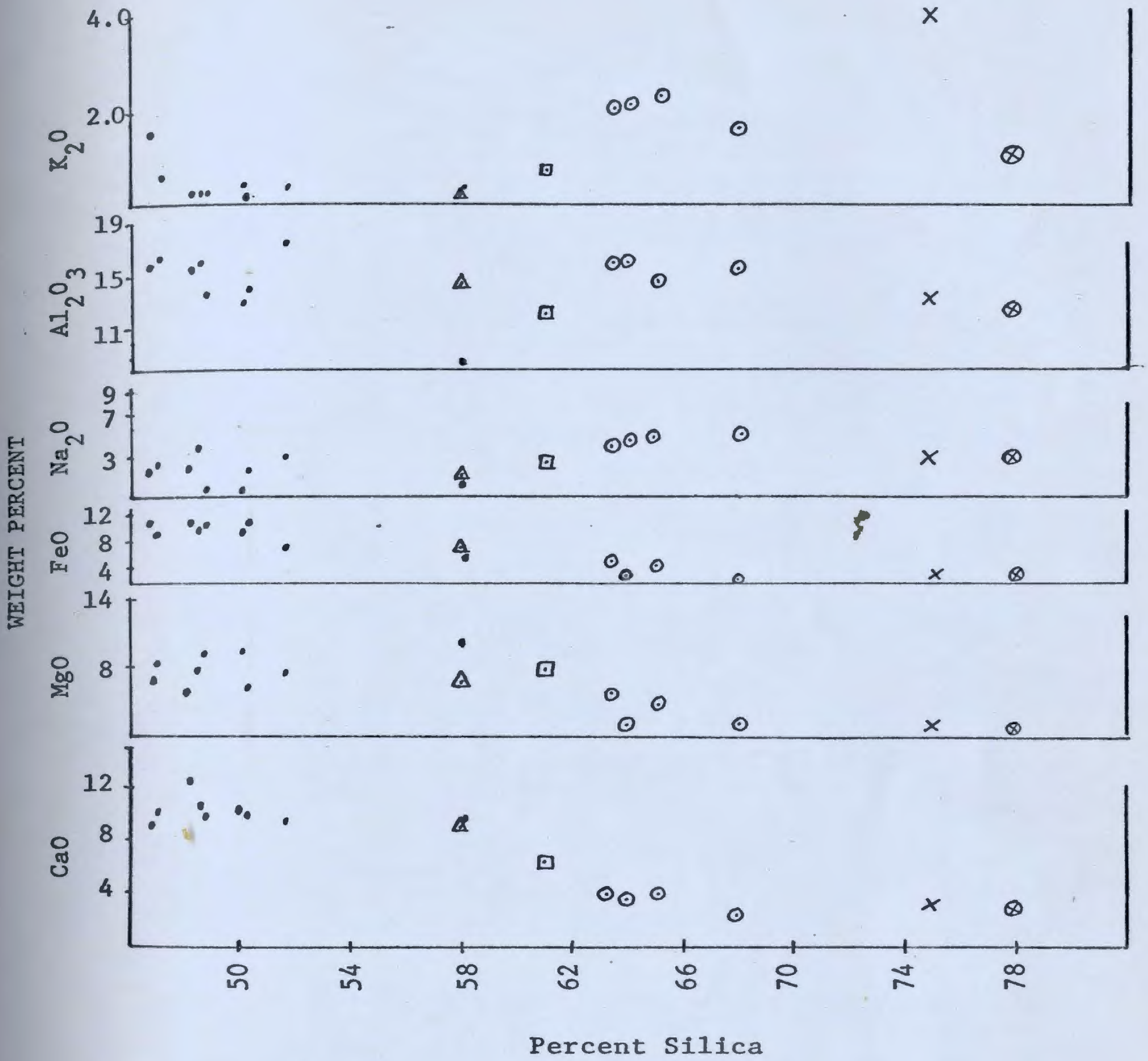


Figure 3: Silica v. other oxides in the rocks of the Colchester area and Burlington Peninsula. Total iron calculated as FeO (weight percent).

Colchester Pluton

⊗ Central Zone

⊡ Transitional Zone

△ Marginal Zone

× Quartz Monzonite, Cooper's Cove Pluton

⊙ Burlington Granodiorite

• Lush's Bight Group

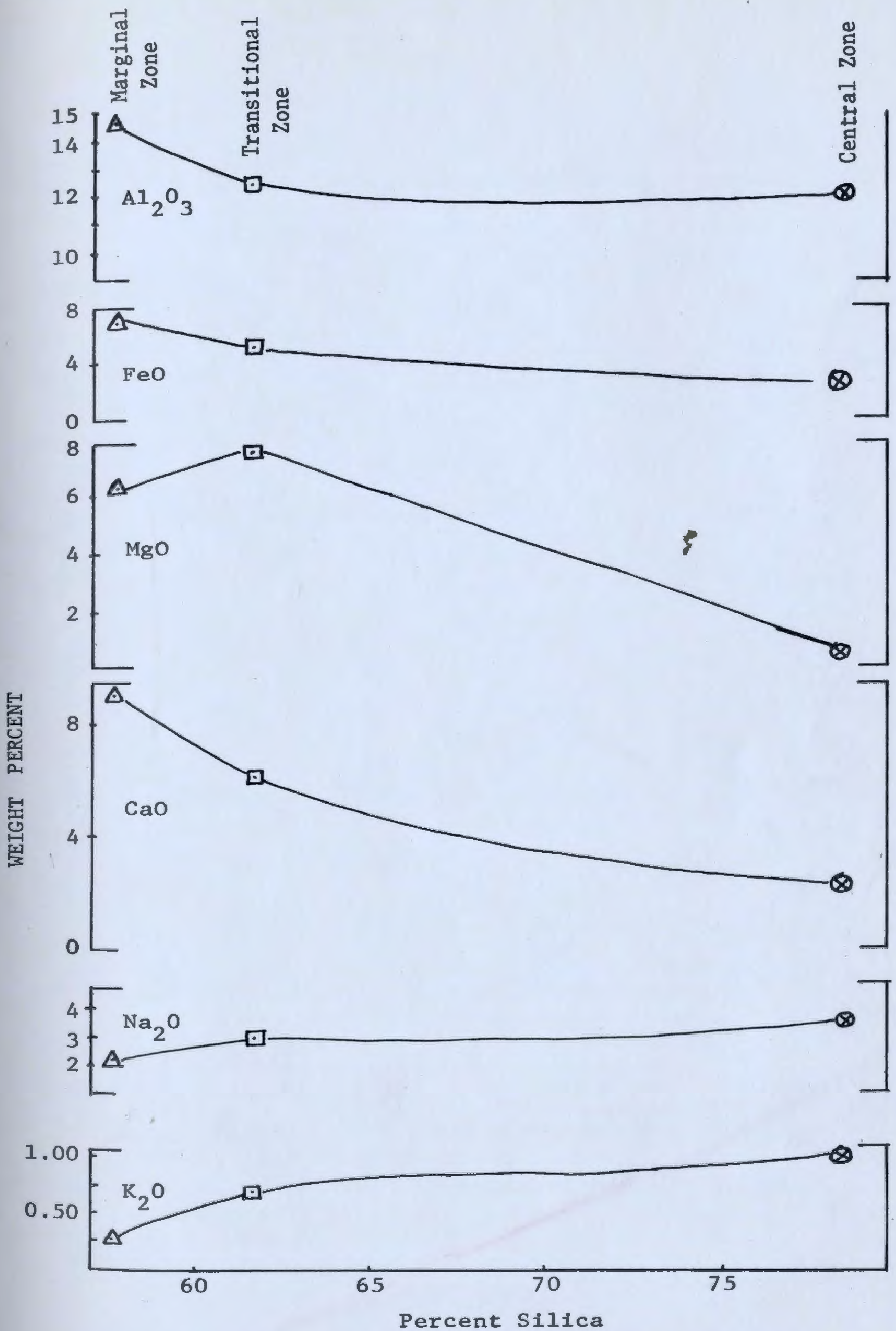


Figure 4: Variation diagram of the various oxides in the different zones of the Colchester Pluton.

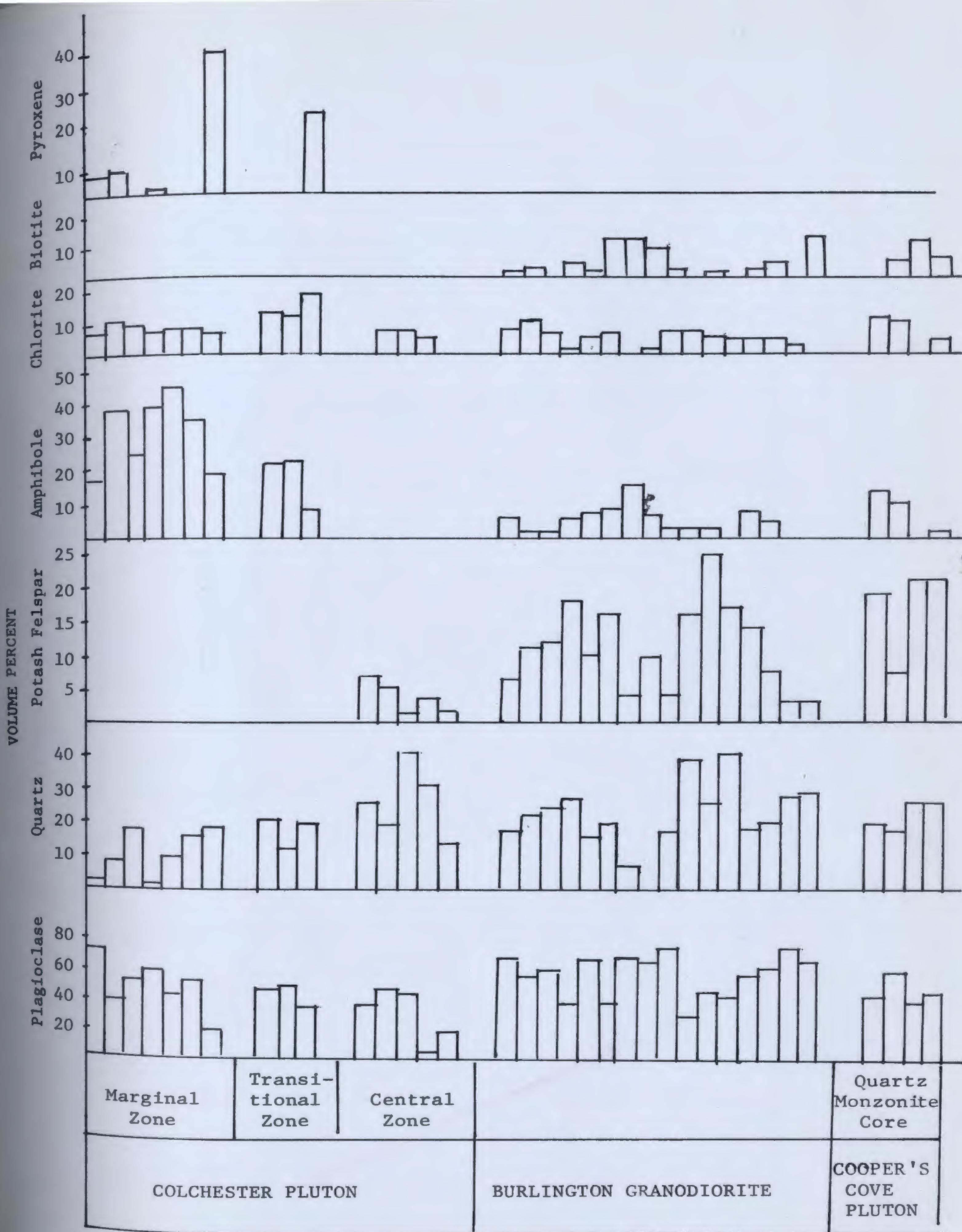


Figure 5: Modal compositional variation of the Colchester, Cooper's Cove Plutons and Burlington Granodiorite.

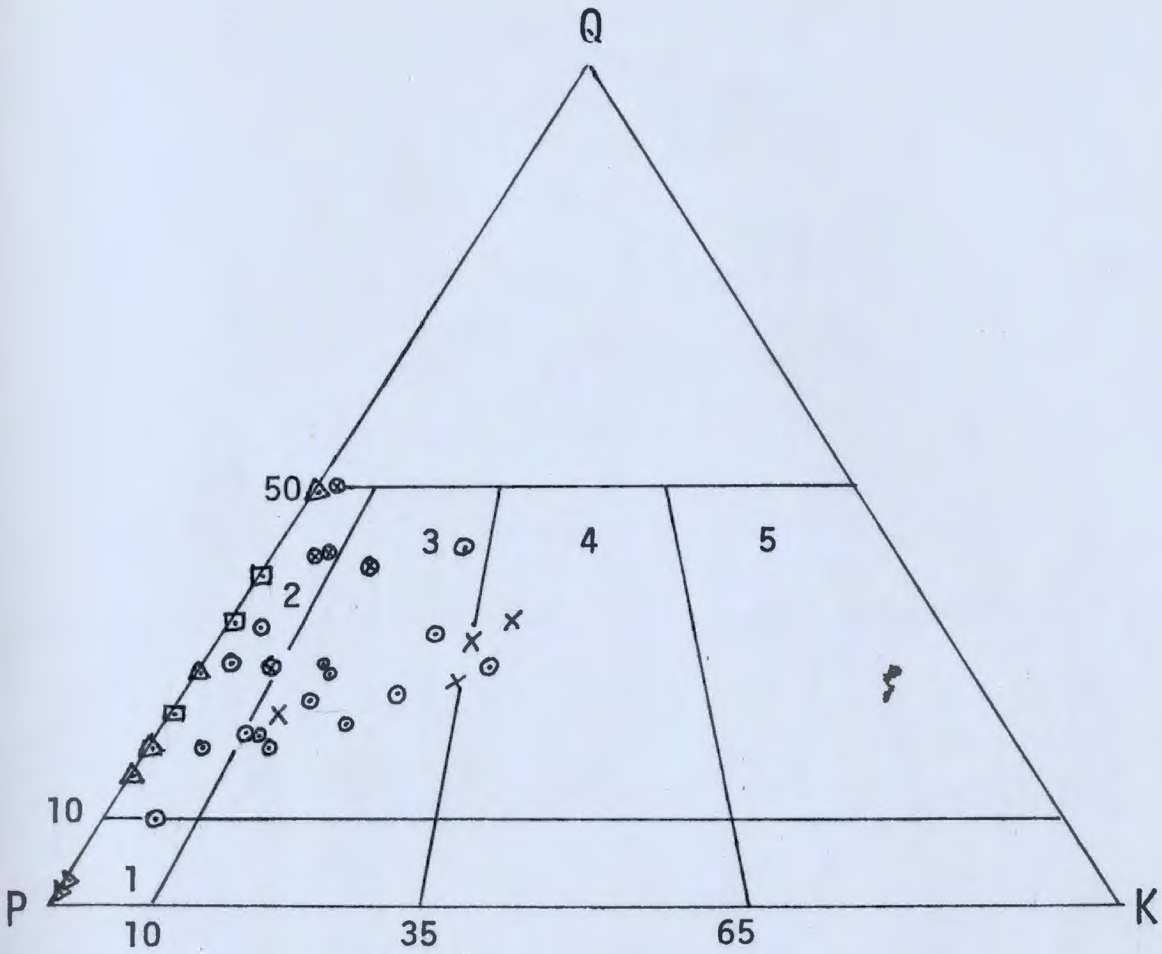


Figure 6: Modal composition of the Colchester plutons and associated rocks.

Explanation:

X Cooper's Cove pluton, core zone

⊙ Burlington granodiorite

Colchester pluton

⊗ Central Zone

⊡ Transitional Zone

△ Marginal Zone

1. Diorite and gabbro
2. Tonalite and quartz gabbro
3. Granodiorite
4. Quartz Monzonite (Adamellite)
5. Granite

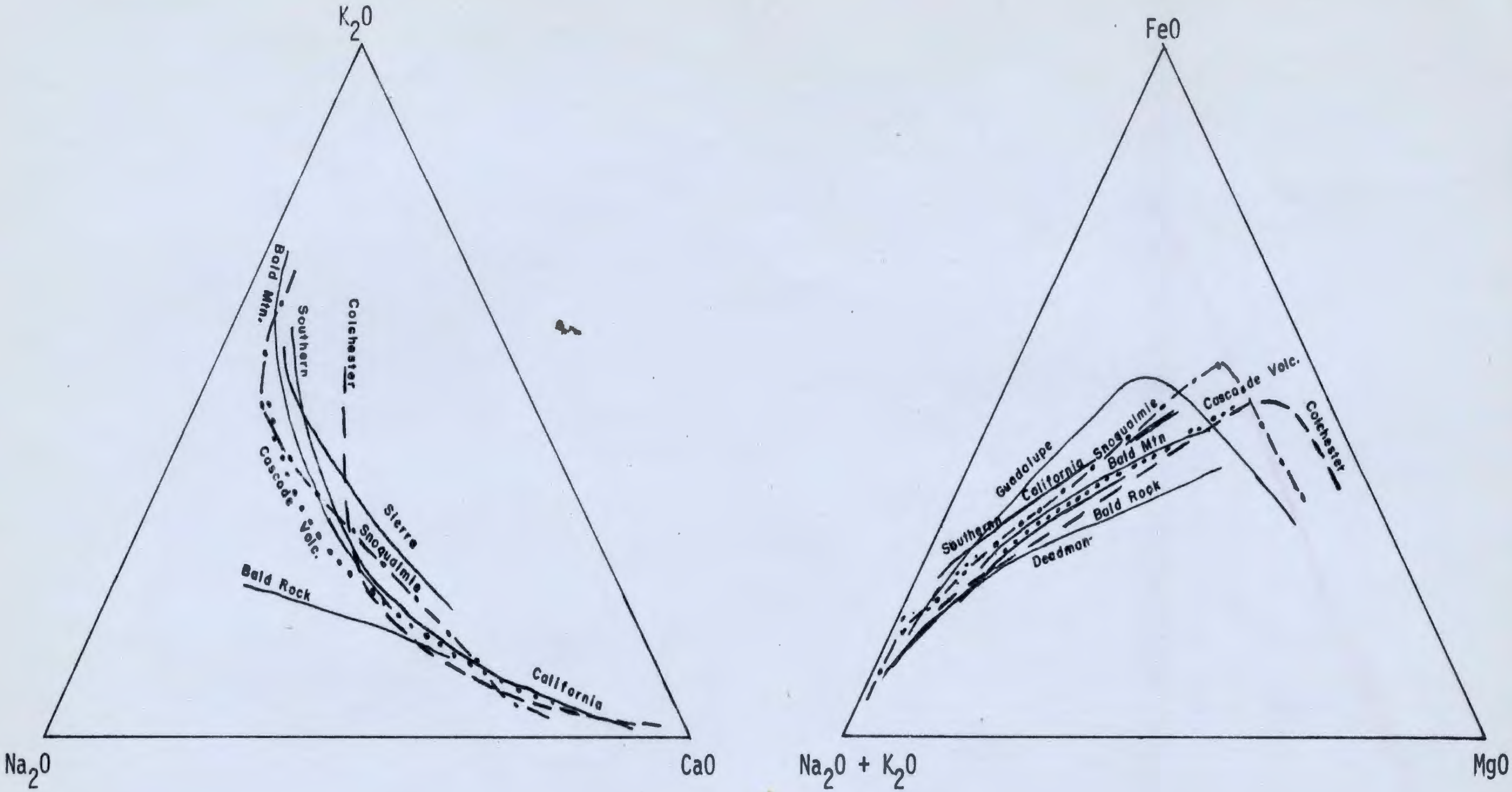


Figure 7: Comparison of the Chemical trend of the rocks of the Colchester area with those of other calc-alkaline suites. The Guadalupe complex (Best 1963), the Southern California batholith (Larsen 1948), the Bald Mountain batholith (Taubeneck 1957), Cascade volcanic lavas (Carmichel 1964), the Bald Rock batholith (Larsen and Poldervaart 1961), Snoqualmie batholith (Erikson 1969), and the Deadman Peak pluton (Holdaway 1963). Total iron of all suites recalculated as FeO (weight percent).

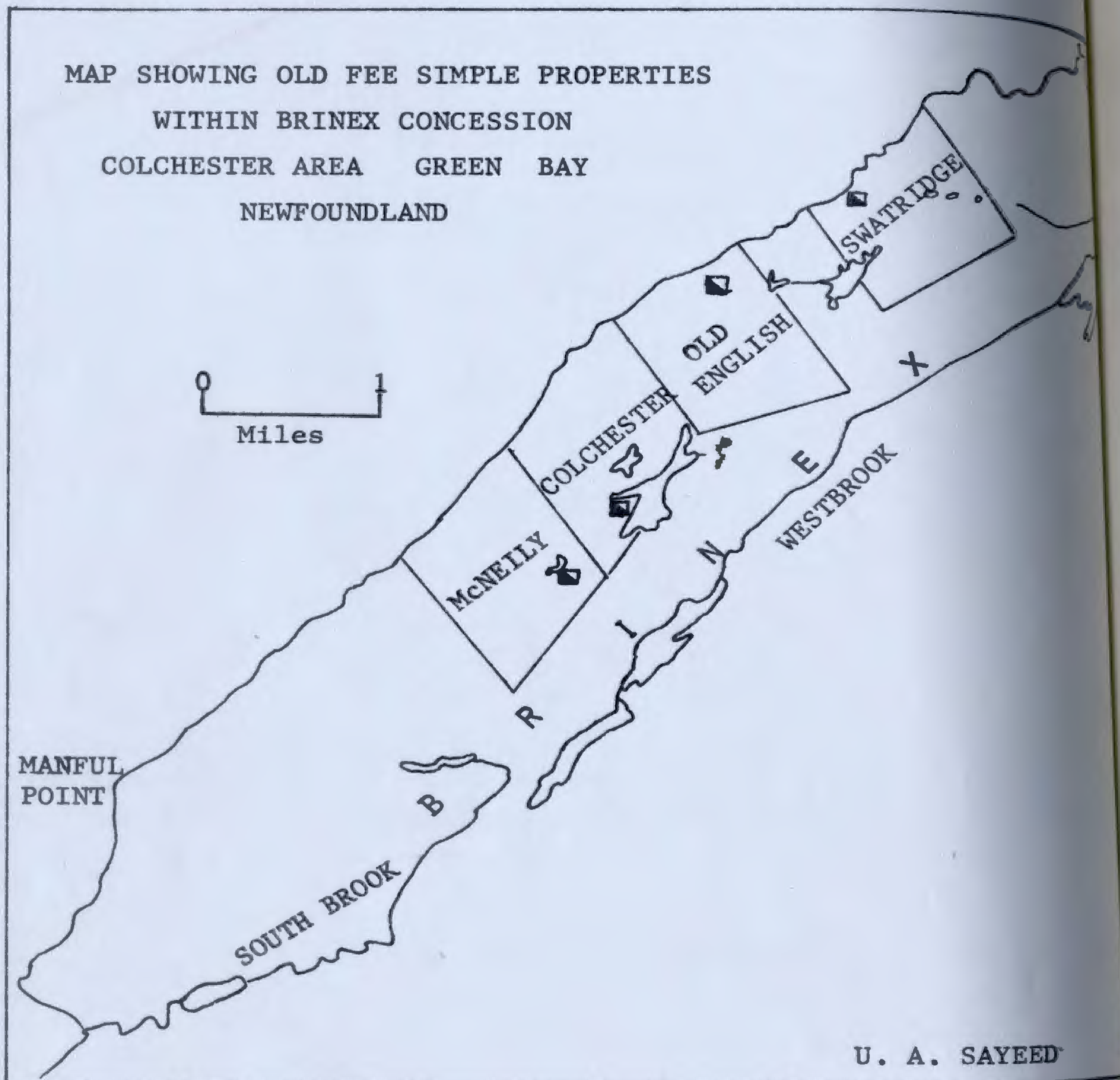


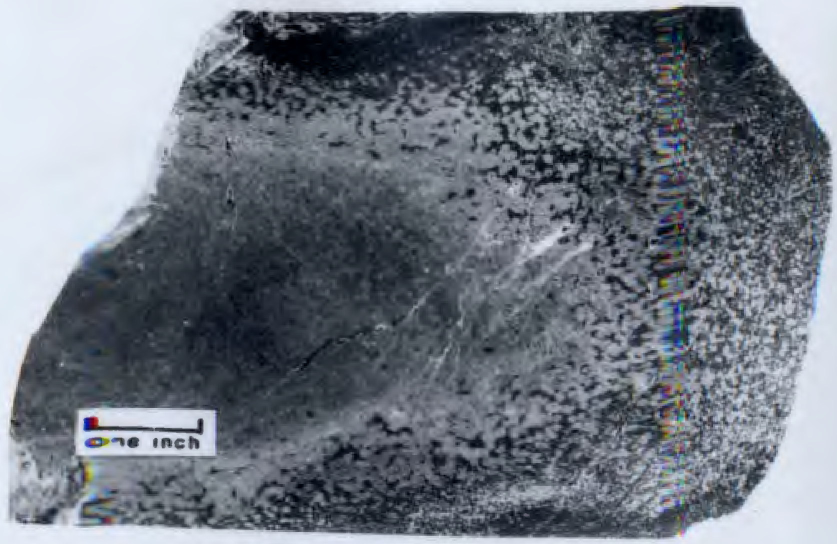
Figure 9: Map showing Old Fee Simple properties within BRINEX concession, Colchester Area, Green Bay, Newfoundland.

APPENDIX: LOCATION OF SAMPLES REFERRED TO IN THE TABLES.

S.No.	Sample No.	Location	Rock Unit
1.	S-35	Near Saunder's Brook, Colchester area.	
2.	S-333	Birchy Cove, Colchester area.	
3.	S-332	Birchy Cove, Colchester area.	
4.	NA-3155	Birchy Cove, Colchester area.	
5.	NA-3153	6,500 feet, S 50°E from Jackson's Cove Road Bridge, South Brook, Colchester area.	Lush's Bight Gr
6.	MacL-1	North shore of Hennessey Island, Three Arms, Green Bay.	
7.	MacL-2	Morris Cove, 2,500 feet southwest of North Bull, Little Bay Head, Green Bay.	
8.	S-30	1,000 feet south of Saunder's Brook, Colchester area.	
9.	S-76	Northwest of West Brook, Colchester area.	
10.	S-124	1500 feet south of Big Pond, Colchester area.	
11.	A_3	Near West Brook,Colchester area.	
12.	S-15	1500 feet west of Ferndale, Colchester area.	Colchester Plu
13.	S-64	Near West Brook, Colchester area	
14.	S-28	2300 feet west of Ferndale, Colchester area.	

S.No.	Sample No.	Location	Rock Unit
15.	S-46	2,500 feet west of Ferndale, Colchester area.	
16.	S-34	Near Saunder's Brook, Colchester area	
17.	S-58	Near West Brook, Colchester area.	
18.	S-143	Near Big Pond, Colchester area.	
19.	S-125	Near Big Pond Colchester area.	Colchester Pl
20.	MN-48	4,000 feet southwest of Big Pond, Colchester area.	
21.	S-100	1300 feet east of Big Pond, Colchester area.	
22.	S-205	3000 feet north of Manful Point, Colchester area	Pluton near Man Point
23.	S-190	5,500 feet south of Cooper's Cove, Colchester area.	
24.	S-193	3,250 feet south of Cooper's Cove, Colchester area	Cooper's Co Pluton
25.	S-231	Near Cooper's Cove, Colchester area	
26.	S-185	6,750 feet south of Cooper's Cove, Colchester area.	
27.	N-3035	Near Middle Arm village, Green Bay.	
28.	N-3077	Near Middle Arm, Green Bay.	Burlington Granodiori

S.No.	Sample No.	Location	Rock Unit
29	NA-2535	North of Kidney Pond, Baie Verte Road	
30	NA-2606	East of Mic Mac Lake	
31	NA-2552	Near Kidney Pond, Baie Verte Road	
32	NA-3076	Middle Arm Village	Burlington Granodiorite
33	NA-2125	Near Mic Mac Lake	
34	NA-2609	East of Gull Pond, Baie Verte Road	
35.	BV-99	Burlington Road at Cross Country Brook bridge, Burlington Peninsula.	
36.	BV-173	Churchyard at Burlington village.	
37.	W301-9	Steady Waters, Baie Verte Map area.	
38.	S-B-69	Camp 165 Road, along Baie Verte Road	Burlington Granodiorite (from Burlington Peninsula)
39.	S-E-69	16 miles west of Burlington village, along Burlington Road	
40.	S-J-69	Near Burlington village.	
41.	S-H-69	12 miles west of Burlington along Burlington village Road.	
42.	S-L-69	North of Middle Arm village, along Burlington-Middle Arm Road.	



a

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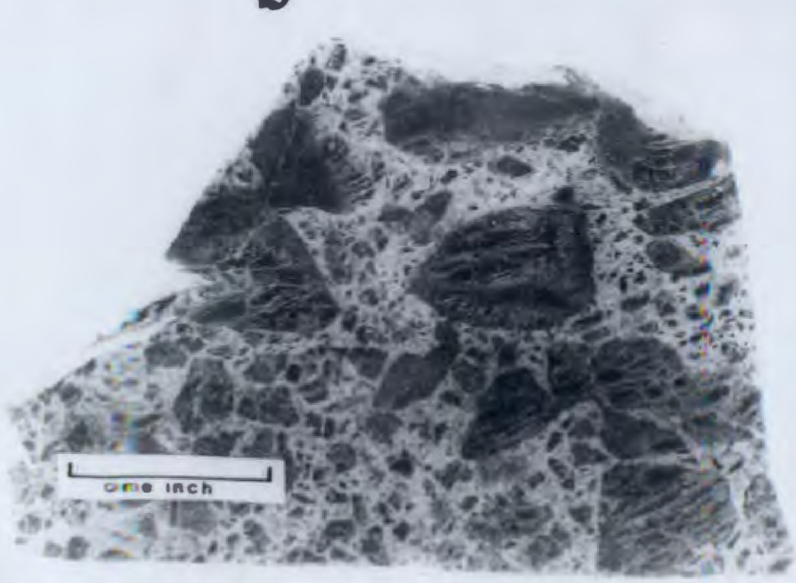

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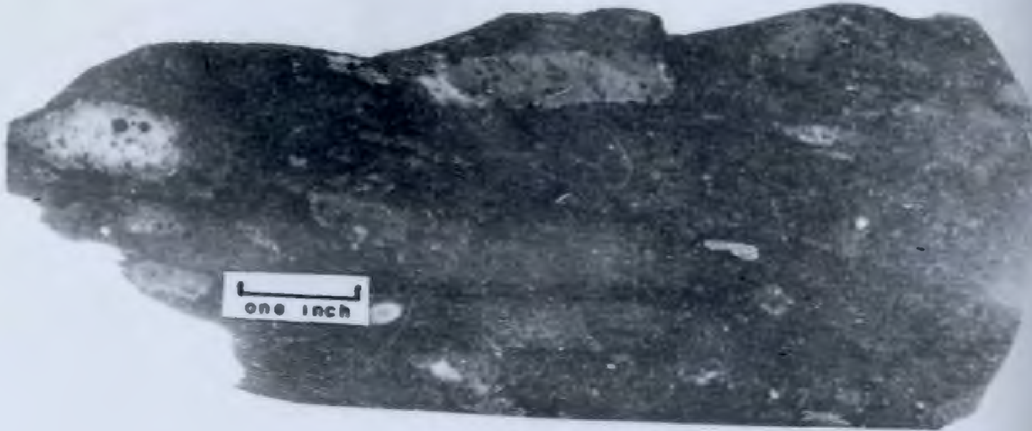

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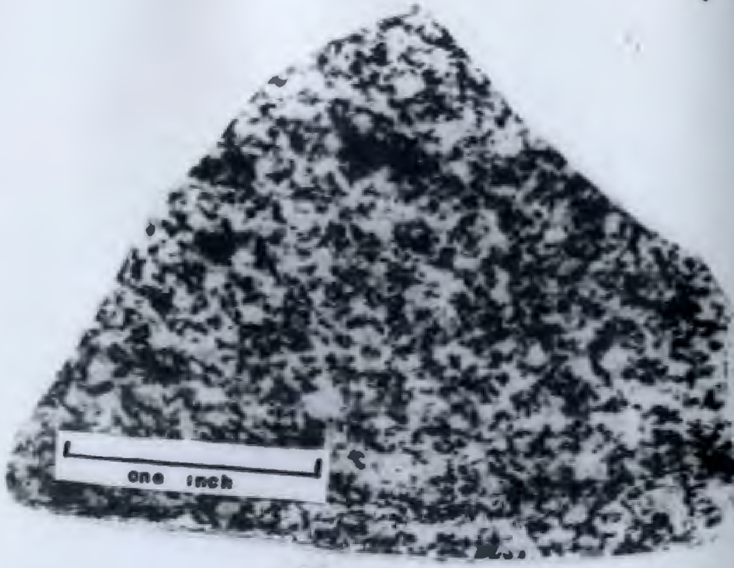
PLATE



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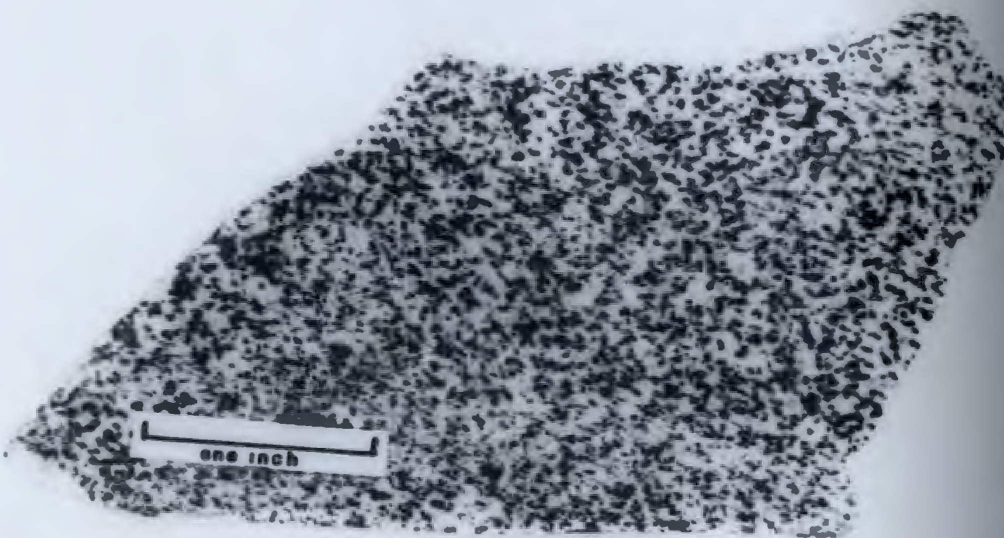

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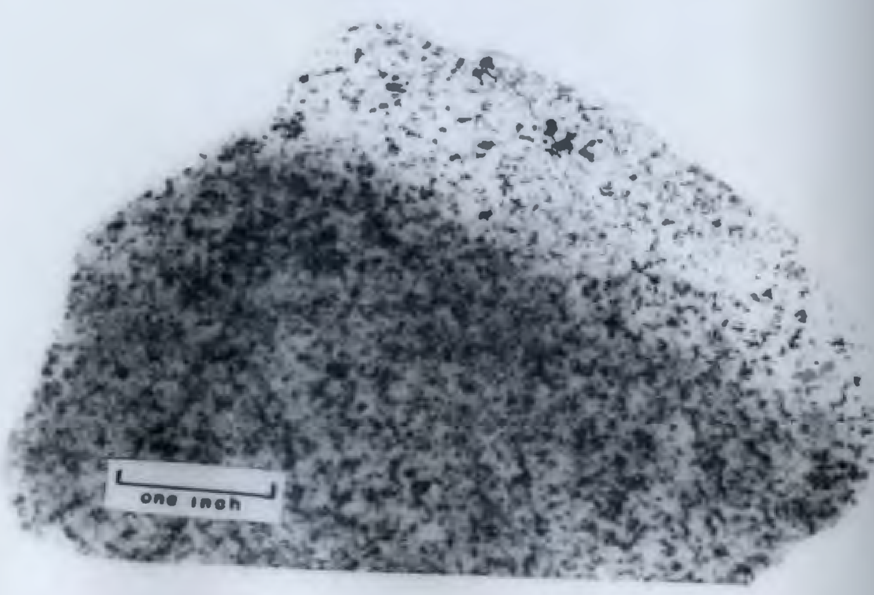

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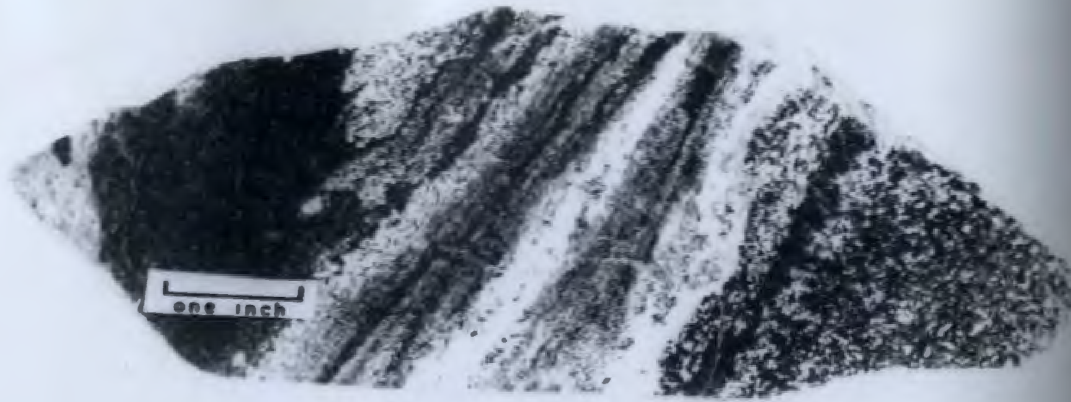

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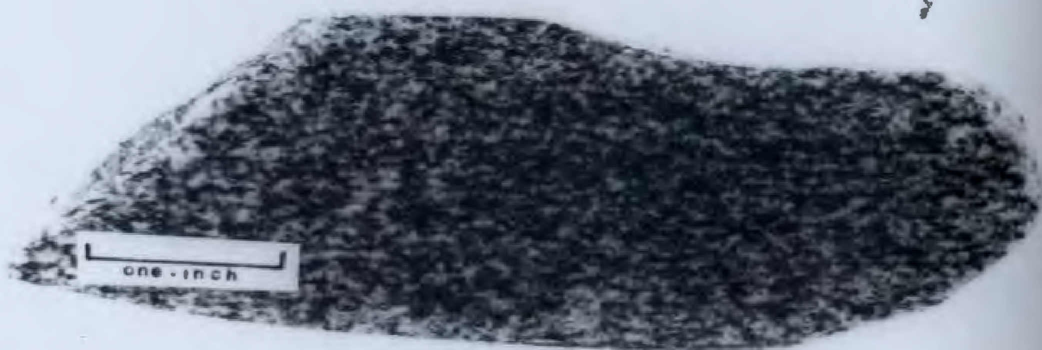

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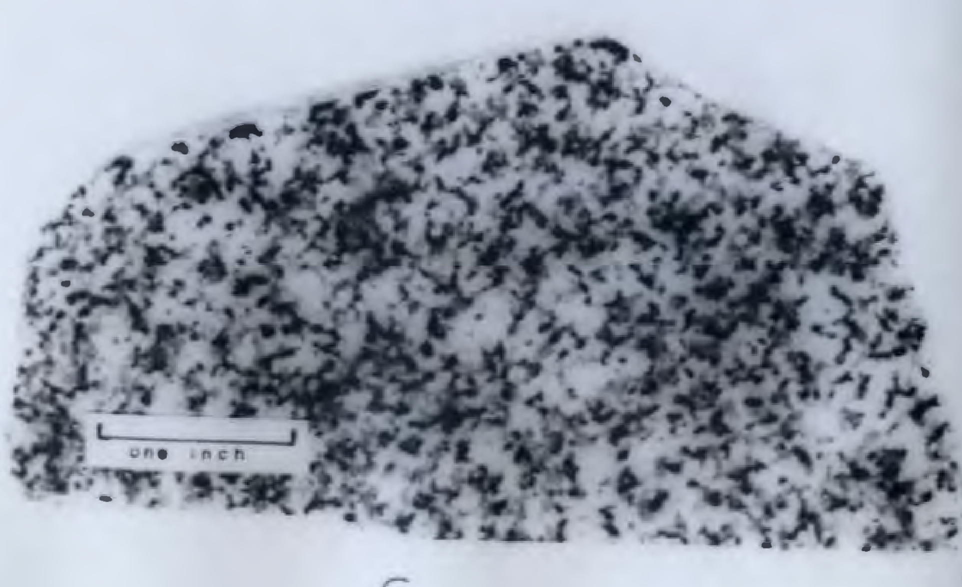

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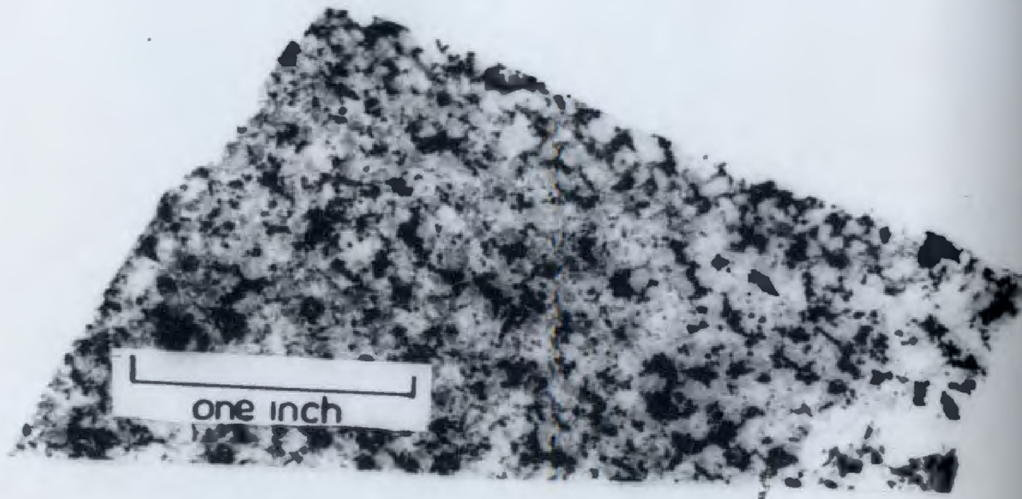

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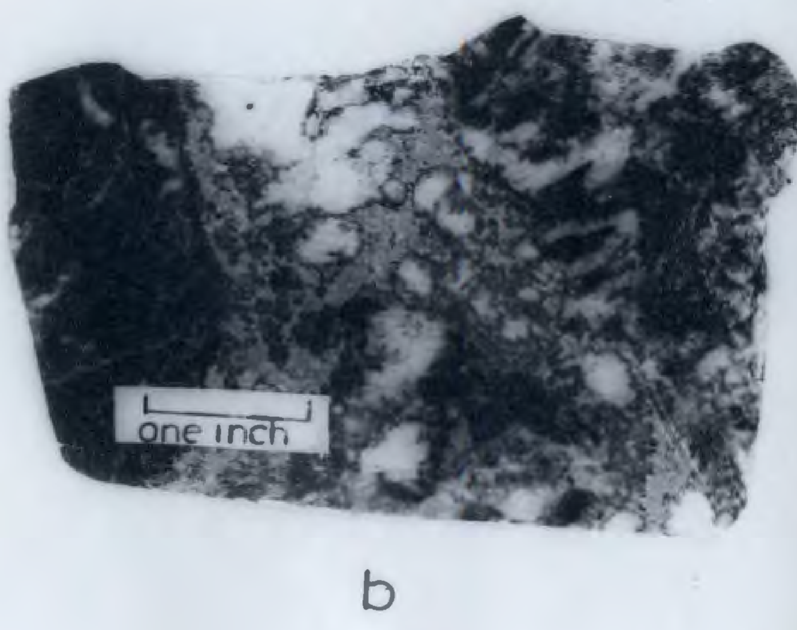

b

PLATE

a

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PLATE

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PLATE IX

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b

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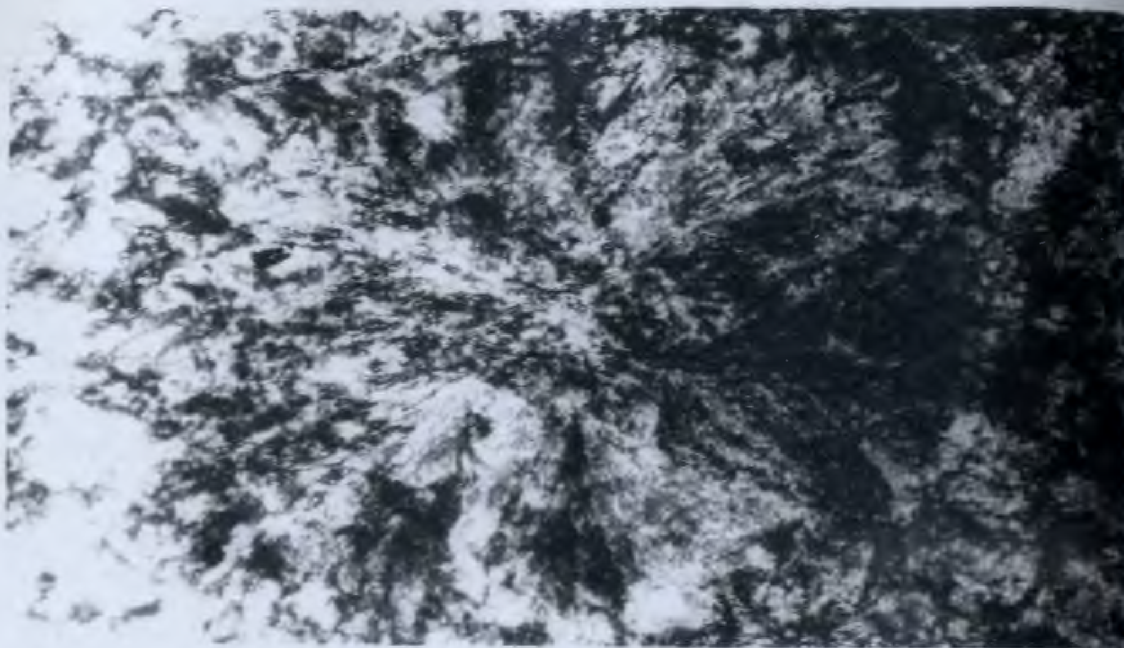
b

PLATE



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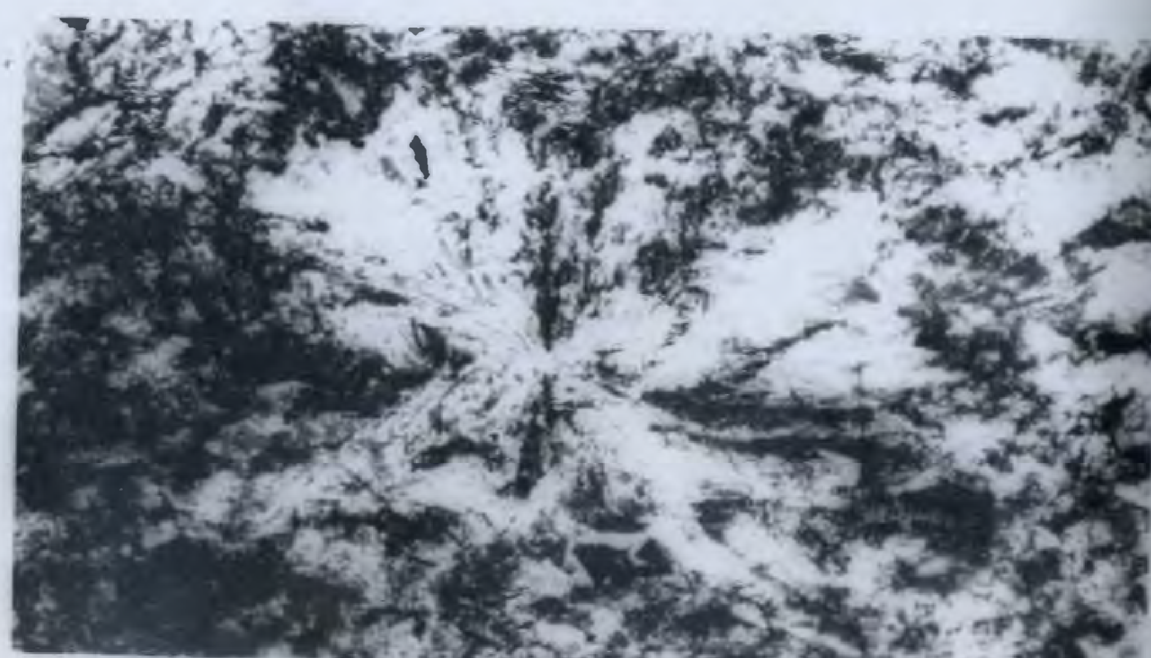

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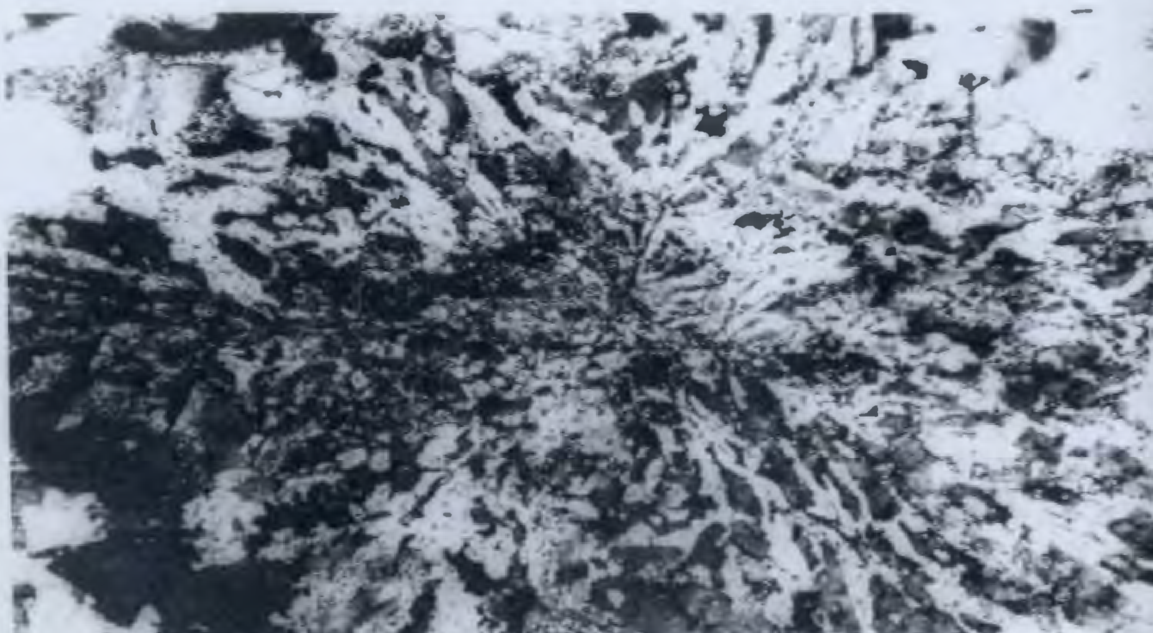
PLAT

a



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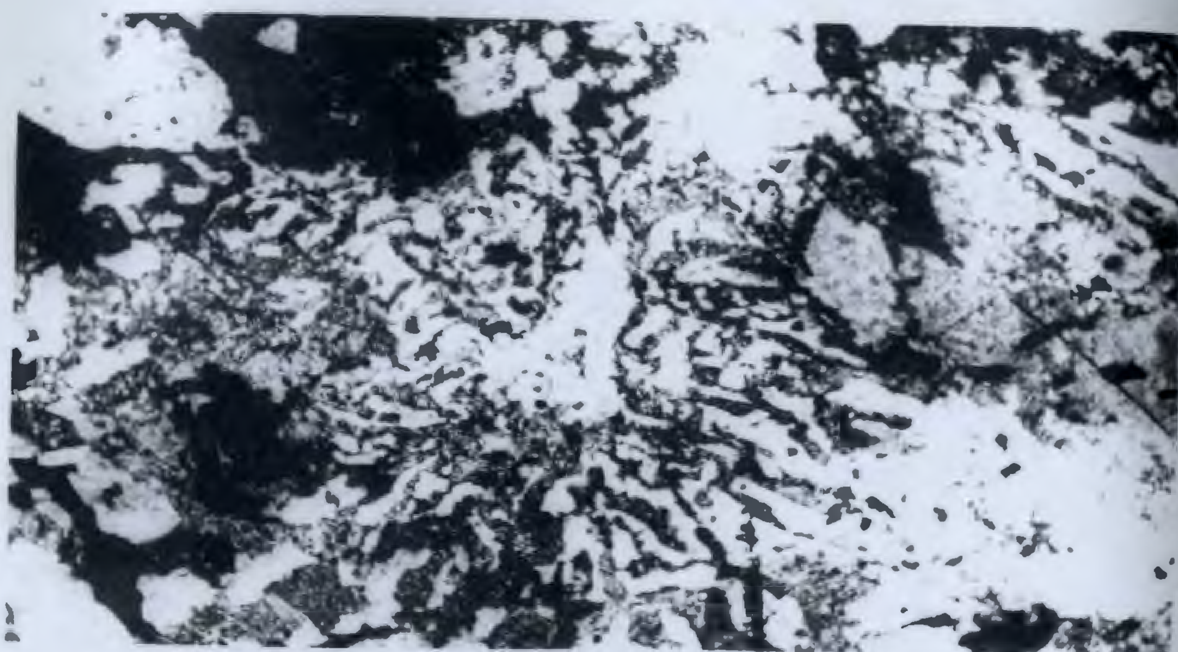

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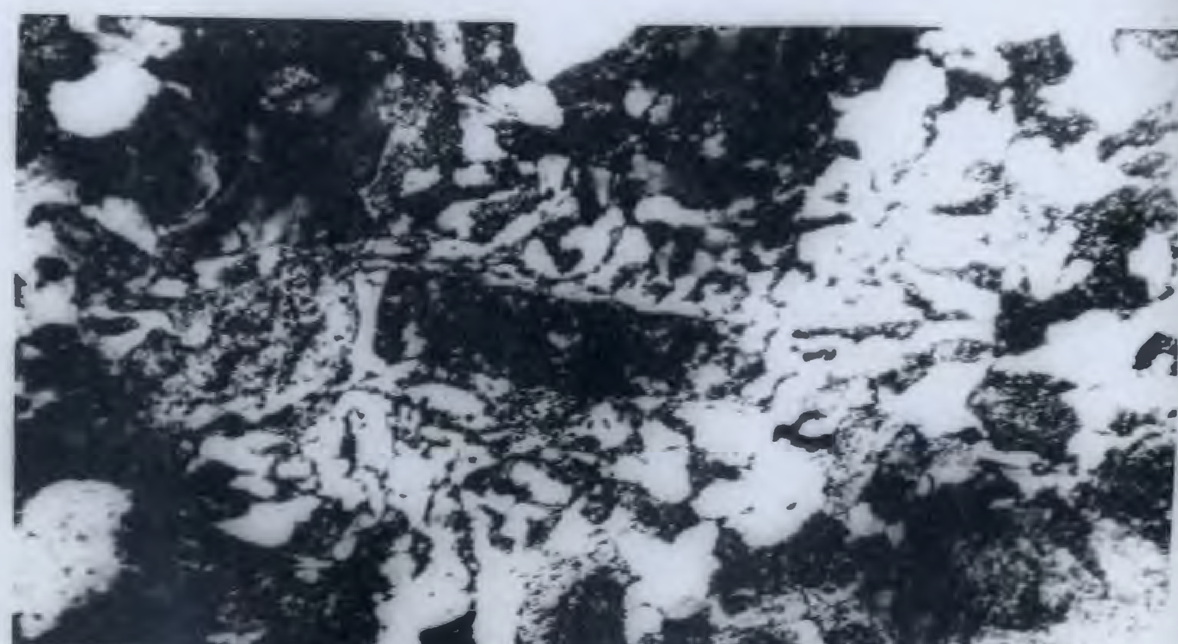

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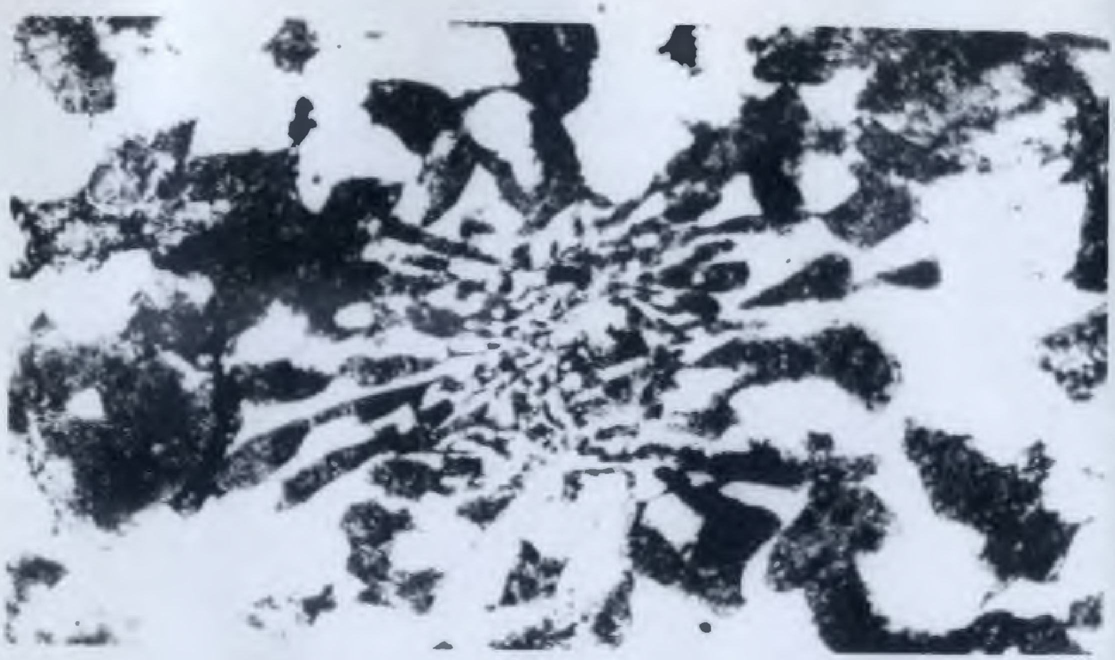

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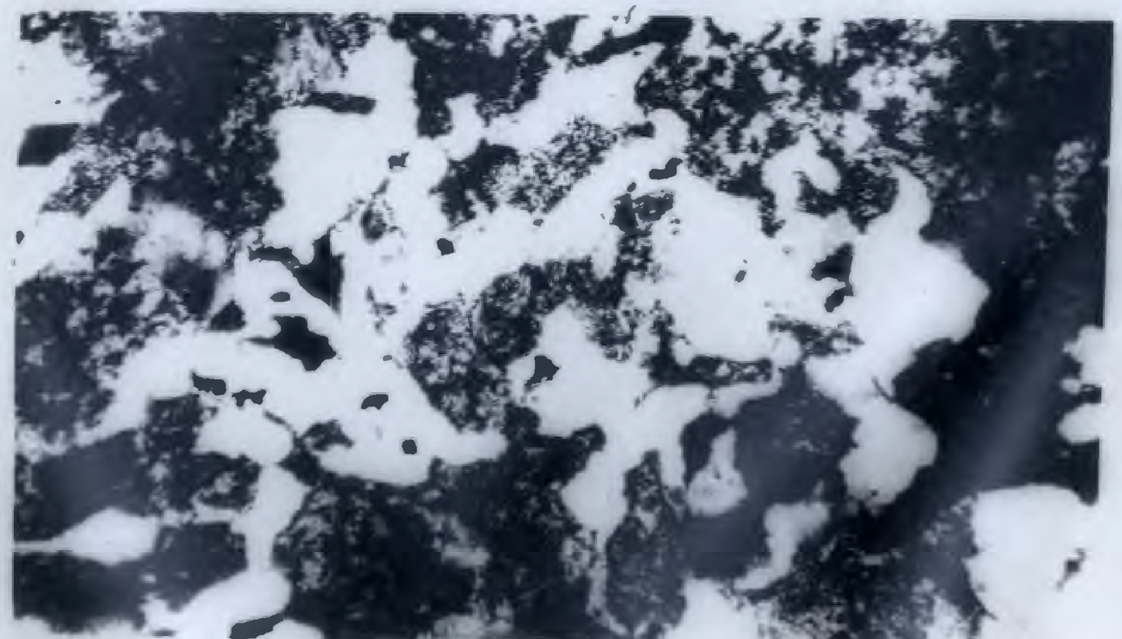

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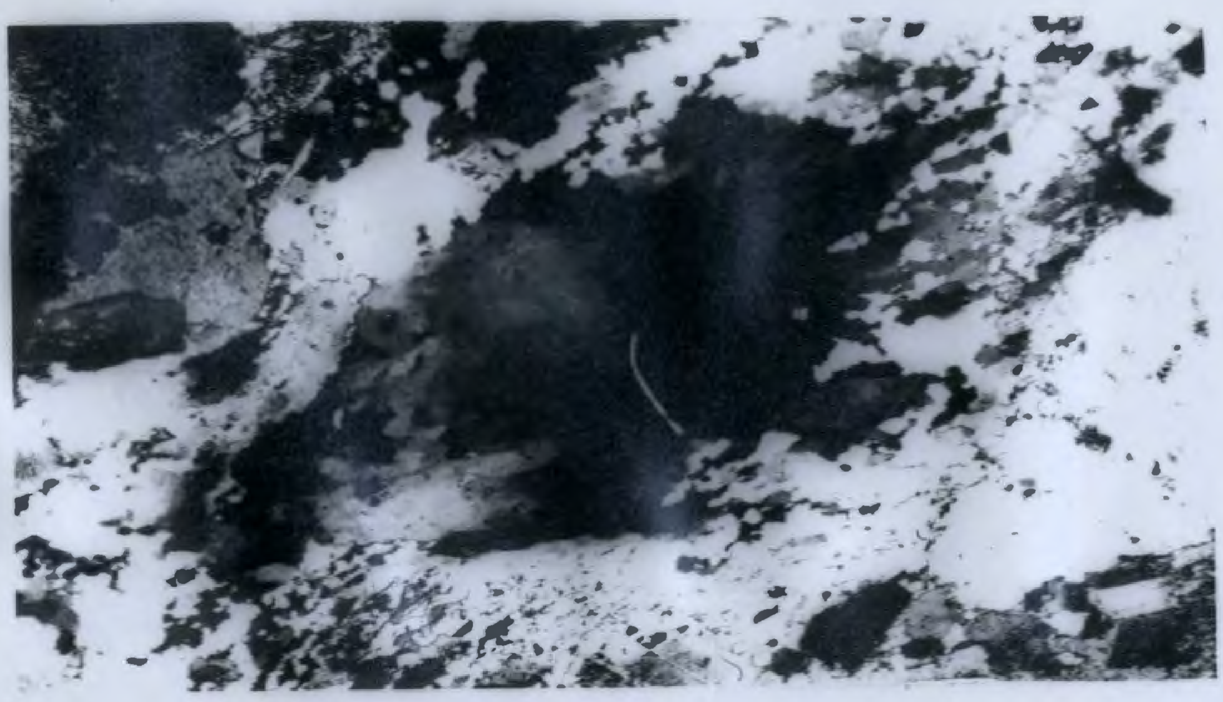

a

PLATE

a

b

PLATE

a

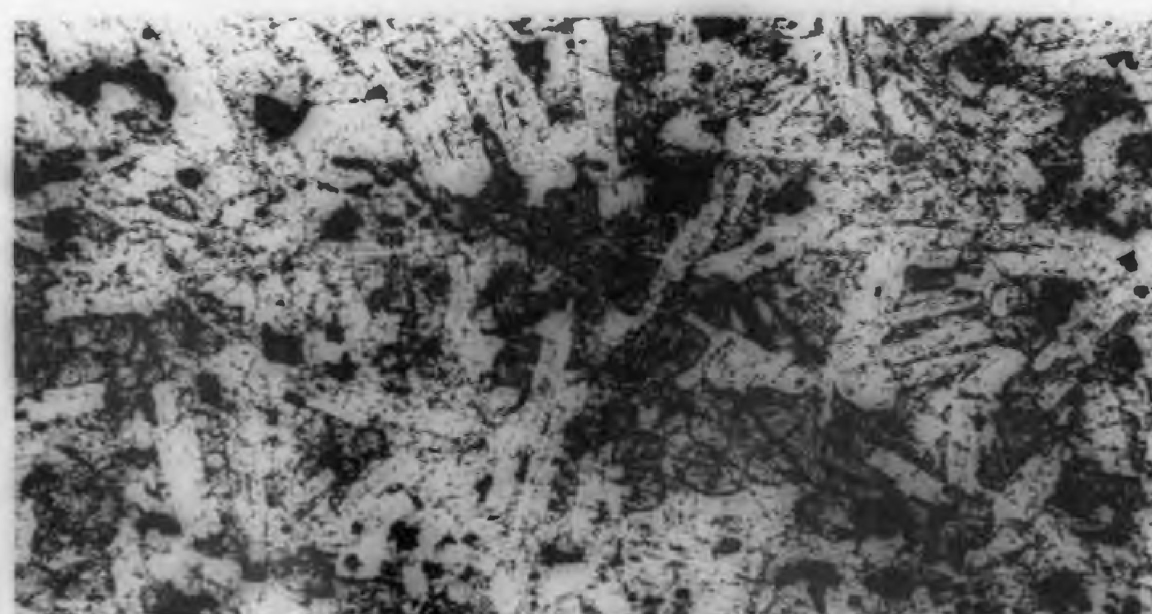

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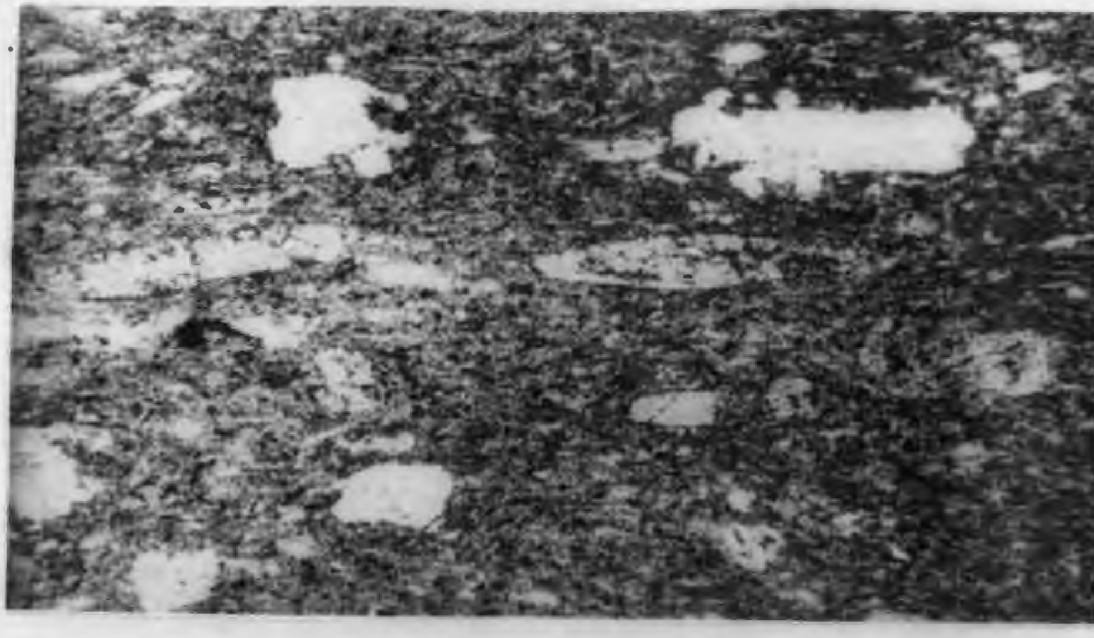
PLATE XX



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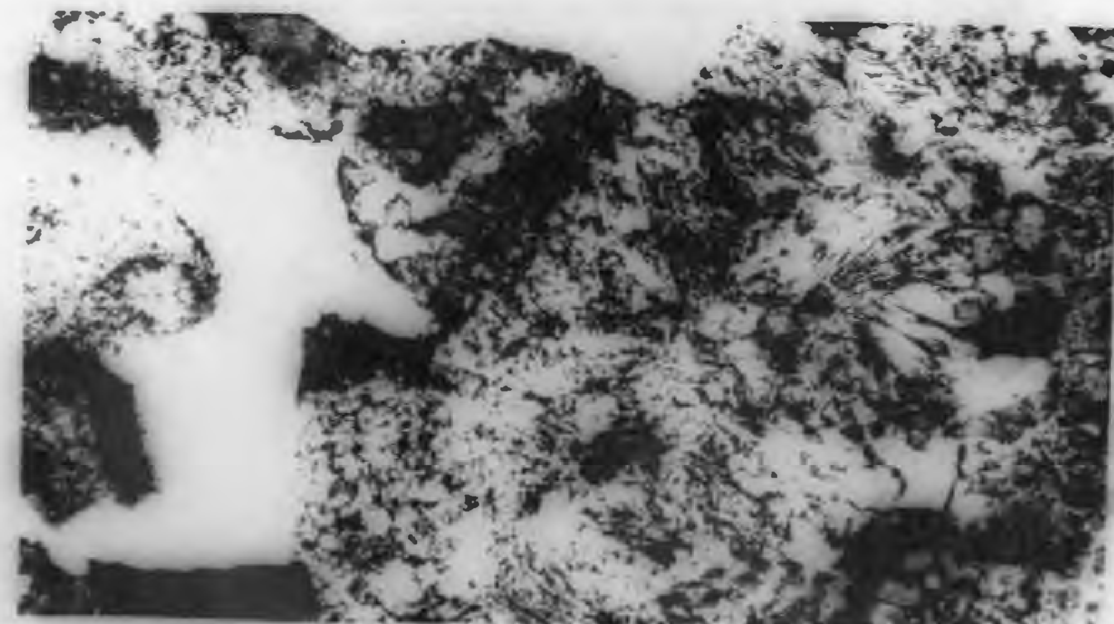

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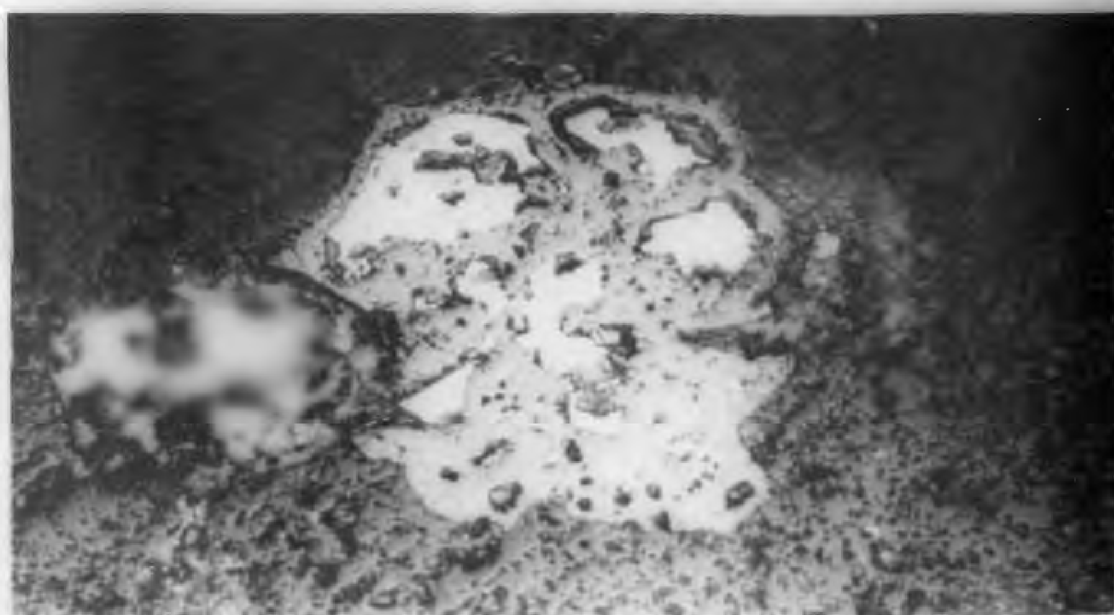
PLATE X

a



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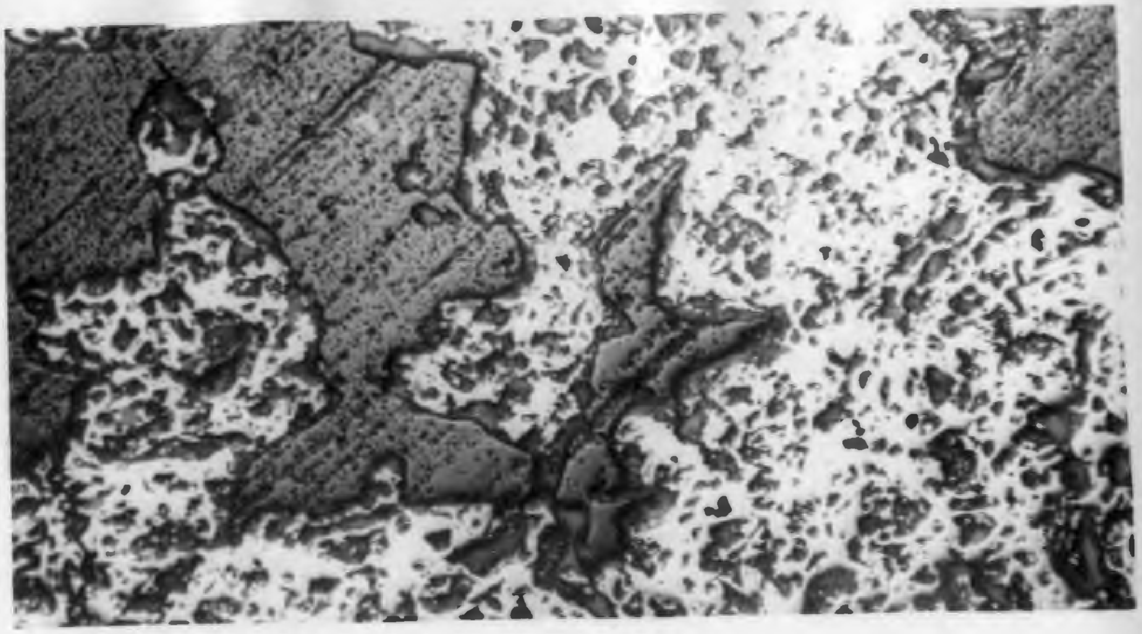

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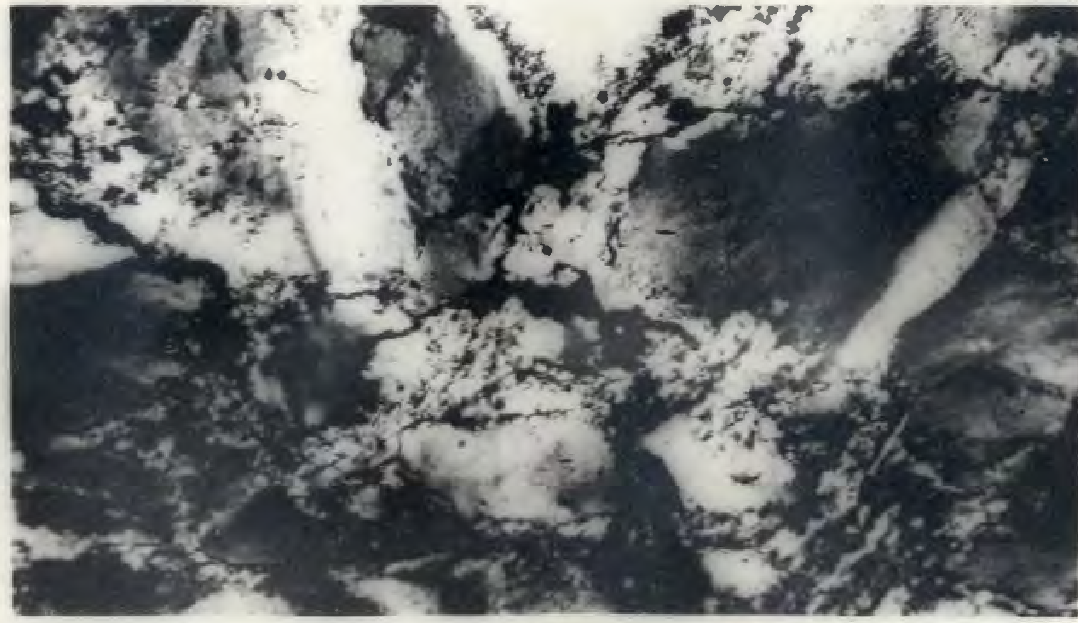

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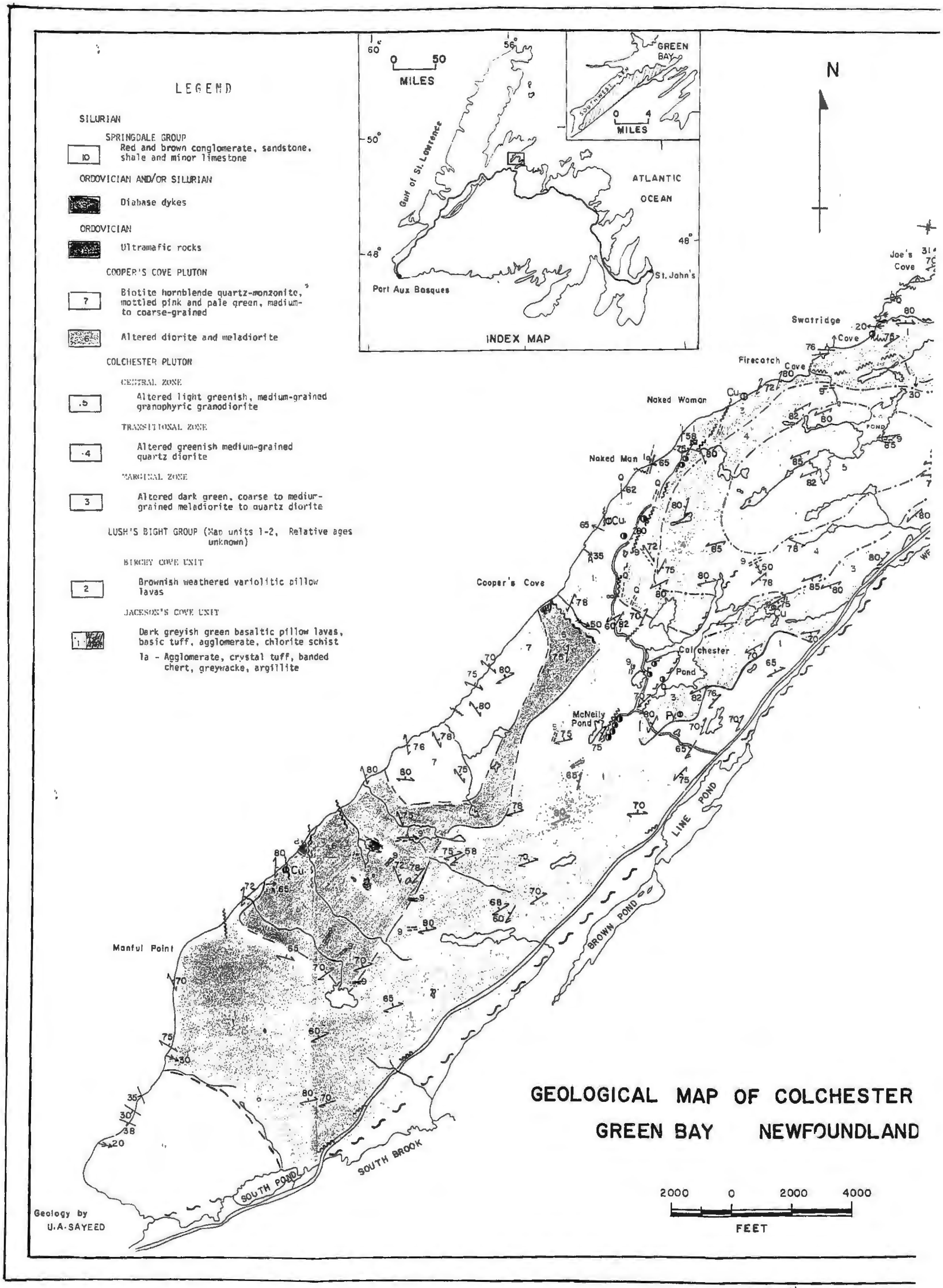
LEGEND
SILURIAN
SPRINGDALE GROUP
10 Red and brown conglomerate, sandstone, shale and minor limestone
ORDOVICIAN AND/OR SILURIAN
Diabase dykes
ORDOVICIAN
Ultramafic rocks
COOPER'S COVE PLUTON
7 Biotite hornblende quartz-monzonite, mottled pink and pale green, medium- to coarse-grained
6 Altered diorite and meladiorite
COLCHESTER PLUTON
CENTRAL ZONE
5 Altered light greenish, medium-grained granophyric granodiorite
TRANSITIONAL ZONE
4 Altered greenish medium-grained quartz diorite
MARGINAL ZONE
3 Altered dark green, coarse to medium-grained meladiorite to quartz diorite
LUSH'S BIGHT GROUP (Map units 1-2, Relative ages unknown)
BIRCHY COVE UNIT
2 Brownish weathered variolitic pillow lavas
JACKSON'S COVE UNIT
1 Dark greyish green basaltic pillow lavas, basic tuff, agglomerate, chlorite schist
1a - Agglomerate, crystal tuff, banded chert, greywacke, argillite
MILES
Gulf of St. Lawrence
ATLANTIC OCEAN
Port Aux Basques
St. John's
INDEX MAP
GREEN BAY
SOUTHWEST
N
Joe's Cove
Swatridge Cove
Firecatch Cove
Naked Woman
Naked Man
Cooper's Cove
Colchester Pond
McNeily Pond
Manful Point
LINE POND
BROWN POND
SOUTH BROOK
SOUTH POND
GEOLOGICAL MAP OF COLCHESTER
GREEN BAY NEWFOUNDLAND
2000 0 2000 4000
FEET
Geology by
U.A. SAYEED

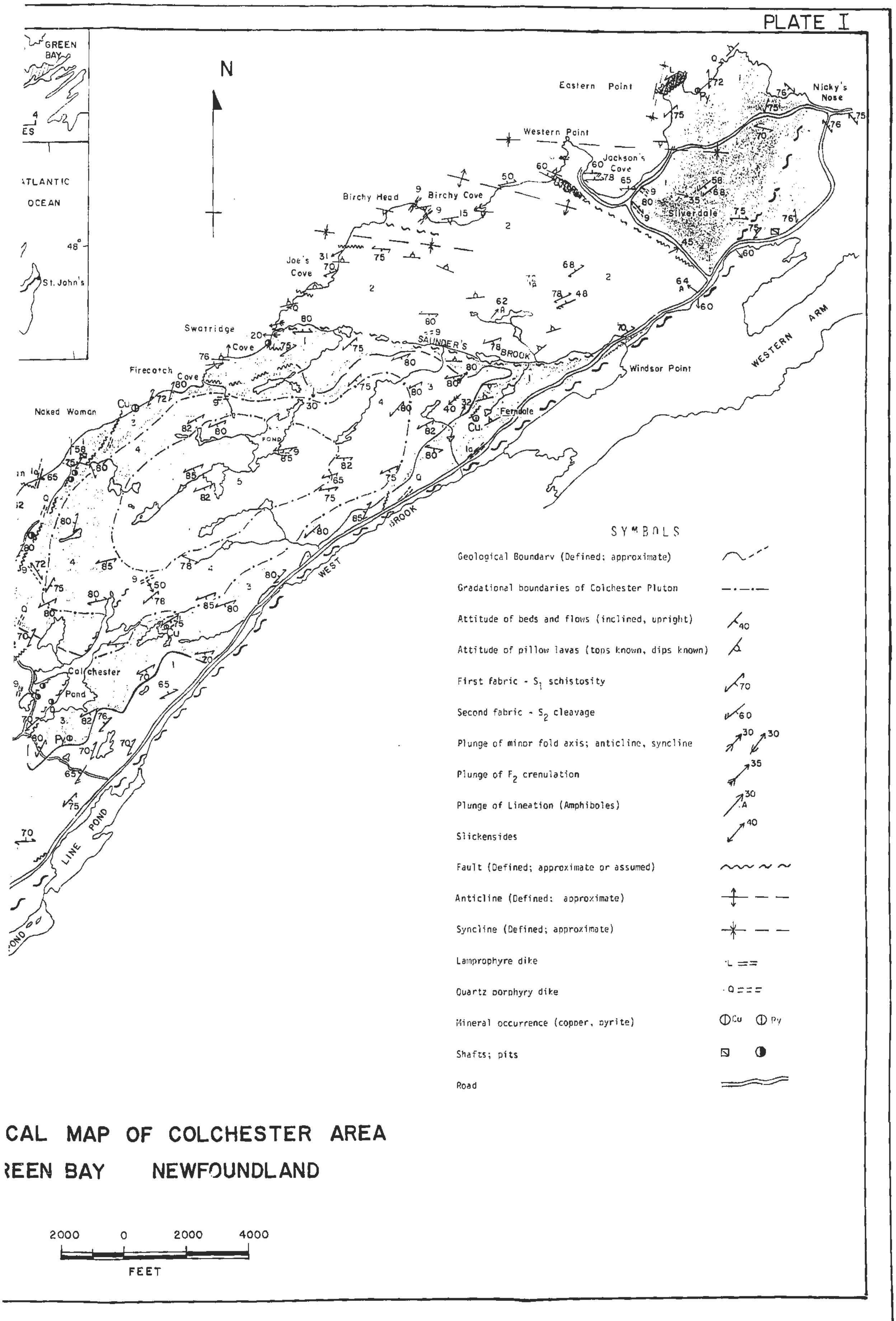
PLATE I
GREEN BAY
ATLANTIC OCEAN
48°
St. John's
N
Eastern Point
Nicky's Nose
Western Point
Jackson's Cove
Birchy Head
Birchy Cove
Silverdale
Joe's Cove
Swatridge Cove
Firecatch Cove
SAUNDER'S BROOK
Windsor Point
WESTERN ARM
Naked Woman
POND
Ferndale
WEST BROOK
Colchester Pond
LINE POND
SYMBOLS
Geological Boundary (Defined; approximate)
Gradational boundaries of Colchester Pluton
Attitude of beds and flows (inclined, upright)
Attitude of pillow lavas (tops known, dips known)
First fabric - S1 schistosity
Second fabric - S2 cleavage
Plunge of minor fold axis; anticline, syncline
Plunge of F2 crenulation
Plunge of Lineation (Amphiboles)
Slickensides
Fault (Defined; approximate or assumed)
Anticline (Defined: approximate)
Syncline (Defined; approximate)
Lamprophyre dike
Quartz porphyry dike
Mineral occurrence (copper, pyrite)
Shafts; pits
Road
CAL MAP OF COLCHESTER AREA
EEN BAY NEWFOUNDLAND
2000 0 2000 4000
FEET