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THE ROBERTS ARM GROUP, NEWFOUNDLAND: GEOLOGICAL NOTES ON A MIDDLE OR UPPER ORDOVICIAN ISLAND ARC ENVIRONMENT

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THE ROBERTS ARM GROUP, NEWFOUNDLAND: GEOLOGICAL NOTES ON A MIDDLE OR UPPER ORDOVICIAN ISLAND ARC ENVIRONMENT

Abstract

The Roberts Arm Group is a Middle or Upper Ordovician spilitized island arc assemblage of mafic and felsic volcanic rocks bounded on the north along the Lobster Cove Fault by oceanic tholeiitic basalt of the Lushs Bight Group. To the west it is faulted against the Mansfield Cove tonalite, a complex of older, deformed plutonic rocks, and to the southeast it is faulted against a presumably older oceanic island type assemblage comprising the Crescent Lake Formation (siltstone chert and greywacke) conformably overlain by titanium-rich basalts. The group is overlain unconformably by red beds of the Springdale Group of presumed Lower or Middle Silurian age.

The Roberts Arm Group is structurally divided into two steeply dipping, mostly west- to north-facing fault-bounded belts: a northwestern belt of island arc calc-alkaline basalts (relatively higher P_2O_5) and felsites, and a southeastern belt of island arc tholeiitic basalts (relatively lower P_2O_5). Movement of the belts with respect to one another is thought to be in large part rotational. This distribution suggests Middle or Upper Ordovician westward dipping subduction from a trench located near the east margin of Notre Dame Bay or along the east boundary of the Central Mobile Belt of Newfoundland. Westward overturning followed by eastward oroclinal bending of the Roberts Arm Group along the Lobster Cove Fault suggest that Roberts Arm volcanism was followed by right lateral movement along this fault. A westward shift of volcanism during early or middle Silurian times may be related to foreshortening of the Roberts Arm volcanic pile.

Résumé

Le groupe de Roberts Arm est un assemblage spilitisé d'arc insulaire, d'âge ordovicien moyen à supérieur, composé de roches mafiques et felsiques, et limité au nord, le long de la faille de Lobster Cove, par des basaltes tholéitiques océaniques du groupe de Lushs Bight. A l'ouest, une faille le sépare de la tonalite de Mansfield Cove, qui est un complexe de roches plutoniques déformées plus anciennes; au sud-est, une faille le sépare d'un assemblage océanique d'arc insulaire probablement plus ancien, comprenant la formation de Crescent Lake (siltstone, chert, et grauwacke), recouverte en concordance par des basaltes titanifères. Le groupe est recouvert en discordance par les red beds du groupe de Springdale, probablement d'âge silurien inférieur ou moyen.

La structure du groupe de Roberts Arm permet de le subdiviser en deux zones limitées par des failles, de forte inclinaison, de regard principalement ouest à nord; on distingue une zone nord-ouest de basaltes calco-alcalins issus d'un arc insulaire (caractérisés par une proportion relativement plus élevée de P_2O_5) et de felsites, et une zone sud-est de basaltes tholéitiques d'arc insulaire (caractérisés par une proportion relativement plus faible de P_2O_5). On suppose que le mouvement des zones l'une par rapport à l'autre est surtout un mouvement de rotation. Cette disposition nous suggère qu'à l'Ordovicien moyen ou supérieur a eu lieu un mouvement de subduction, dirigé vers l'ouest, à partir d'une fosse proche de la marge est de la baie Notre-Dame, ou bordant la limite est de la zone mobile centrale de Terre-Neuve. Un basculement vers l'ouest, suivi d'une flexion oroclinale vers l'est, du groupe de Roberts Arm le long de la faille de Lobster Cove semble indiquer que le volcanisme de Roberts Arm a été suivi d'un mouvement dextre le long de cette faille. Un décalage vers l'ouest du volcanisme au début ou au milieu du Silurien est peut-être lié à une contraction de l'ensemble volcanique de Roberts Arm.

INTRODUCTION

The Roberts Arm Group was selected as a potentially rewarding unit for detailed studies of physical volcanology, volcanic sedimentation, petrography and chemistry of volcanic rocks that would contribute to a better understanding of volcanic belts within the Appalachian Province, and of the relationships of economic mineral deposits to these belts. This paper presents a preliminary synthesis of the geological and chemical data from a part of the area under study not only as a progress report but also to provide a model that will be the object of testing during the final stages of investigation. The model suggests that the Roberts Arm Group as previously defined consists of rocks from two distinct volcanic assemblages, a titanium-rich volcanic assemblage on the southeast that has been faulted against titanium-poor volcanic rocks of the Roberts Arm Group proper on the northwest. This chemical difference may reflect juxtaposition of rocks of oceanic island setting against a Roberts Arm island arc assemblage.

Location and access

The Robert's Arm project area (parts of 2E5, 2E12, and 12H8) is limited on the south and north by 49° 18' and 49° 32'N; and on the east and west by 55° 33' and 56° 03'W. On the north it reaches a few hundred metres north of an east-west lineament (the Lobster Cove Fault) that runs from Grand Dismal Cove on the east shore of Triton Island to the southwest coast of Sunday Cove Island. On the west it is limited by Halls Bay and an irregular limit between South Brook and the junction of the creek from Loon Pond with Tommy's Arm River. On the southeast the border follows Tommy's Arm River as far north as Kippins Pond and thence follows an irregular path to Sops Arm and Great Denier Island. Geologically it encompasses those rocks previously considered to belong to the Roberts Arm Group as far south as the junction of Tommy's Arm River with the creek from Loon Pond, and it includes parts of the Hall Hill complex, Lushs Bight Group, Exploits Group, Springdale Group and plutons intrusive into these rocks.

Figure 1. View of south across Crescent Lake Valley west of Crescent Lake. (GSC 167045)

Access to the area may be attained either from the sea or along the Robert's Arm highway from the Trans Canada highway at South Brook. All parts of the area are within a day's working distance on foot from these routes and local logging roads.

Most of the area is thickly wooded (Fig. 1). Snow cover may persist on northwest- and north-facing slopes until the end of May or the first week in June. The writer prefers to be out of the woods by the first week in September when the local hunting season begins.

Geographical names used in this report are shown on Figure 2.

Previous work

The first geological reports on the Robert's Arm area were by Murray and Howley (1881, 1918). In the Robert's Arm area these were concerned with examination of mineral occurrences and with the geographic character of the coastal area. Mining of copper ore from the Crescent Lake mine was carried out in 1880 (Murray and Howley, 1918) and again in 1924 (Espenshade, 1937). Pyrite and some copper was mined from the Pilley's Island mine between 1889 and 1908 (Espenshade, 1937).

The first comprehensive mapping of the area was done by Espenshade (1937) between 1934 and 1936. He recognized the Lobster Cove lineament as a major fault and set up a stratigraphy which, with some modifications, is still used. Espenshade's mapping was continued inland by Hayes (1951a, 1951b) who recognized the existence of an important fault zone extending southwest and south from the Sops Arm area which he called the Burnt Creek fault zone (Fig. 18). Williams (1962, 1964, 1969) integrated the work of earlier geologists in the Notre Dame Bay region and carried out reconnaissance of previously unmapped areas. His suggested correlations provided the first comprehensive regional view of the geology of Notre Dame Bay. Several mining companies have examined the Robert's Arm area but the only published work consists of a compilation map with marginal notes (Dean and Strong, 1976) based in large part on work by Noranda, Exploration Co. Ltd.

Present work

Field work on which the present report is based was carried out from a base at Robert's Arm during the summers of 1974, 1975 and part of 1976 Bostock (1975, 1976). The writer was assisted in the field by Paul Code, Derek Wilton, David Scott, Marie Michaud, and Bohdan Podstawskyji.

PLEISTOCENE GEOLOGY

This section includes an account of some of the surficial features of the Robert's Arm area including glacial striae and eratics. These features reflect the predominance of north to eastward moving ice in the evolution of Pleistocene geology in the Robert's Arm area.

The northern part of the area is characterized by rounded rocky ridges reaching about 150 m above sea level. Drift cover is thin and discontinuous. Farther south the hills rise to over 200 m but are widely mantled by drift. This cover consists largely of pebbly to bouldery till with an abundant silty clay matrix that renders bush roads impassable soon after construction if adequate drainage is not provided. Characteristics of surficial deposits are displayed on surficial geology maps of the Robert's Arm and Springdale areas (Grant, 1973a, 1973b).

Ice movement across the area during the Pleistocene was complex as shown by glacial striae (Fig. 3). The most common striae are north-northeasterly directed swinging to east-northeast in the northeast part of the area. Near Halls Bay a northwesterly trending pattern, which is tangent to the pattern of main striae farther east, appears to be superimposed on possibly earlier striae parallel to the main set. This may reflect a late drawdown of ice into the Halls Bay depression. On Sunday Cove Island the main striae have been found superimposed upon an earlier northwest or southeast set that cannot be due to late drawdown into Halls Bay. Similar crossing striae, for which relative ages are not known, occur near Crescent Lake. It appears therefore that earlier ice moved across the grain of the country in a northwest or southwest direction. In the Loon Pond area, and farther south, where drift cover is relatively thick, till is thickest and outcrop is rare on the northwest side of lakes relative to the southeast sides. This suggests movement of late ice from the northwest but its implied age is apparently in conflict with age relations derived from intersecting striae in the northern part of the area.

Glacial erratics displaying a wide variety of lithologies, principally massive to gneissic hornblende gabbro, amphibolite, granites and volcanic rocks, are common. Counterparts to these lithologies outcrop widely in the Hall Hill complex, in the Springdale terrane and in the Lushs Bight terrane that occur respectively to the south, west and north of the map area. Sedimentary rocks including the Ordovician greywackes of the Exploits terrane to the east and south appear less common. Occasional erratics of irridescent anorthosite, some weighing several tons, were observed along the shores of Tommy's Arm. These could be of recent origin having been brought in from the north by icebergs which commonly appear in Notre Dame Bay during the spring and early summer months. It seems more likely however that they have been transported by glaciers from the Long Range mountains where anorthosite is known to outcrop within the Grenville gneiss complex (Baird, 1959).

The limited data collected suggest that northward- to eastward-moving ice was most effective in producing the striae that are preserved. Earlier ice transport of erratics from the west and northwest is suggested by the occurrence of anorthosite boulders and may be responsible for some of the striae intersecting the main pattern. Ice movement from the southeast in the Crescent Lake and South Brook regions has been suggested by Lundqvist (1965) but no affirmative evidence of this movement has been collected during the present study. More thorough analysis of striae and drift will be necessary to establish the direction and sequence of ice movements in the Robert's Arm area.

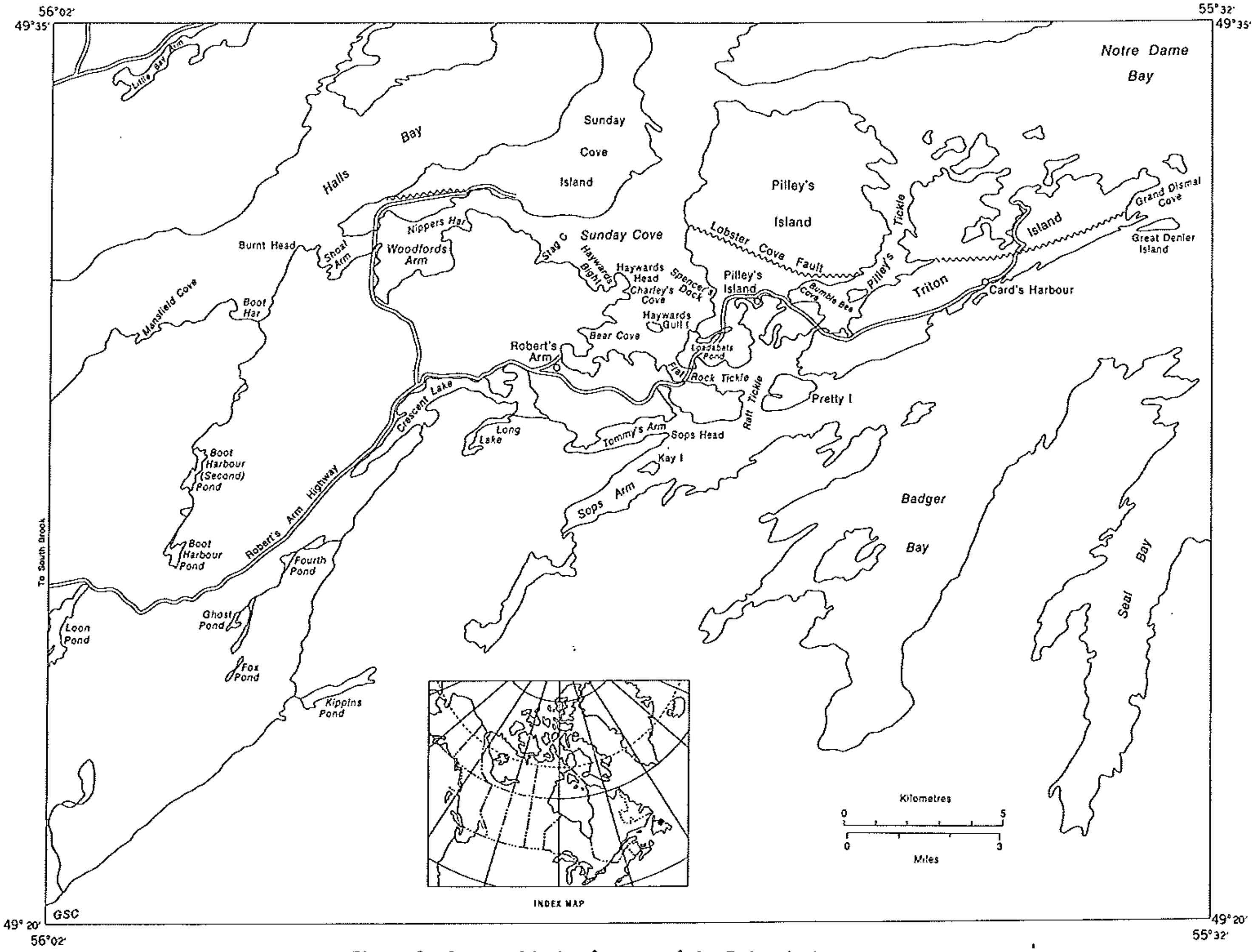

Figure 2. Geographical reference of the Robert's Arm area.

GENERAL GEOLOGY

The Robert's Arm area lies within the central part of the Appalachian orogen. Within this area, one plutonic complex, five major stratigraphic units, and one sizeable intrusion are represented. There are respectively: The Mansfield Cove complex on the west border of the area; the Lushs Bight, Exploits, unnamed, Roberts Arm, and Springdale groups; and the Sunday Cove granite which intrudes the Roberts Arm Group.

The Middle or Upper Ordovician Roberts Arm Group, which consists predominantly of volcanic rocks, occupies a central zone extending across the Robert's Arm area from northeast to southwest. The group is bounded laterally by faults that separate it from older rocks to the west, north, and southeast. Only locally, where remnants of the Silurian Springdale Group unconformably overly the Roberts Arm Group, is its stratigraphic relation to another major unit exposed to view.

The Robert's Arm area includes a sialic block, the Mansfield Cove tonalitic complex (Fig. 18; Currie, 1976), which bears many of the features of an older basement. This complex which in some respects resembles the Twillingate pluton (Williams and Payne, 1975; Williams et al., 1976) is perhaps most likely a relict from Hadrynian events.

The oldest supracrustal rocks known within the map area are lower Ordovician ocean floor tholeiitic basalts of the Lushs Bight Group. These rocks have been faulted against the Roberts Arm Group along the Lobster Cove Fault at the north margin of the map area; similar rocks underlie an extended area that forms the headlands and outer islands across northern Notre Dame Bay. They are spatially related to an area of high gravity and magnetic anomalies that lies along the northwest coast of the bay (Miller and Deutsch, 1976) and are believed to include the upper part of an ophiolitic suite similar to that exposed at Betts Cove (Smitheringale, 1972; Upadhyay and Strong, 1973).

The Exploits Group, which includes an extensive assemblage of Middle Ordovician rocks, borders the map area on the east. The contact zone is structurally complex, no datable fossils have been found within the map area, and little detailed work has been done on it. Its relationship to the Roberts Arm Group is therefore unknown. The western part of Exploits Group consists largely of clastic sediments which may according to Williams (1969) coarsen upwards and which include Silurian conglomerates. Changes in sedimentation reflect early contributions from a remote volcanic island terrane with increasing contributions from deep-seated sources indicated by plutonic pebble conglomerate. Little known basic volcanic rocks are concentrated in the lower part

Table of Formations

Era	Period	Formation	Lithology	Thickness
Cenozoic			Gravel, sand, silt, till	
Great unconformity				
Paleozoic	Lower or Middle Silurian	Springdale Group	Red beds: sandstone, siltstone, conglomerate	180 m (600 ft)
	Angular unconformity			
	Upper Ordovician or (?) Silurian		Gabbro	
	Not in contact. Cut Roberts Arm Group and volcanics of unknown age.			
	Middle or Upper Ordovician		Mafic and felsic dykes	
		Intrusive contact. Cut Sunday Cove pluton and older rocks. Probably of different ages.		
		Sunday Cove pluton	Granodiorite, quartz monzonite, quartz diorite	
		Fault contact		
		Roberts Arm Group	Northwest fault belt (calc-alkaline suite): basalt, felsite, pillow lava, breccia, ash flows greywacke, siltstone, tuff, gabbro	5000 m (15 000 ft)
			Fault contact	
			Southeast fault belt (tholeiitic suite): basalt, pillow lava, breccia, tuff; some greywacke, siltstone, and minor felsite and gabbro	3000 m (10 000 ft)
	Fault contact			
	Age unknown		Basalt, pillow lava, breccia, tuff, some greywacke, chert, siltstone, gabbro	1400 m (4500 ft)
		Crescent Lake Formation	Siltstone, shale, chert, greywacke	150 m(?) (500 ft)
	Fault contact			
	Middle Ordovician	Exploits Group	Slate, shale, greywacke, some conglomerate, basalt, pillow lava, minor limestone	
	Fault contact? (covered by sea)			
	Lower Ordovician	Lushs Bight Group	Basalt, pillow lava, breccia; some tuff, chert	
	Not in contact			
	Lower Ordovician or older		Metavolcanic rocks possibly related to Lushs Bight Group included within Mansfield Cove complex	
	Remobilized contact			
Upper Hadrynian or (?) Lower Paleozoic			Mansfield Cove tonalitic complex	

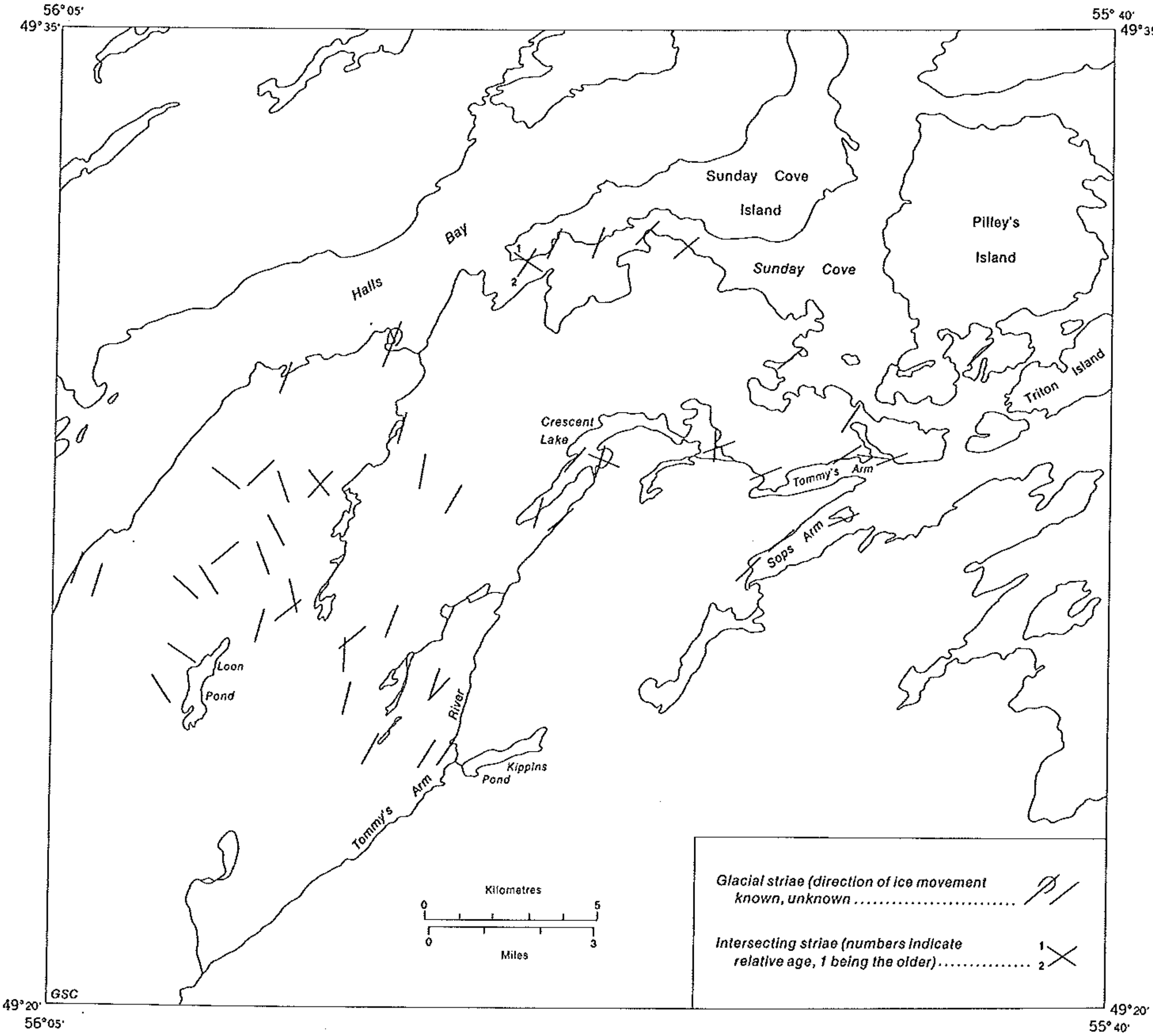

Figure 3. Glacial striae of Robert's Arm area.

of the western section (Wild Bight Group). Basic and some felsic volcanics are present near the western margin of Exploits Group where they may represent local volcanism atypical of younger parts of the group elsewhere, or they may form parts of infaulted blocks derived from an oceanic island assemblage exposed farther west (south and east of Crescent Lake).

An unnamed group of rocks of uncertain age, which consists of the Crescent Lake Formation (silty shales with some greywacke and chert) conformably overlain by westward facing, titanium-rich, oceanic island type basalts and some quartz porphyry, is in fault contact with Exploits Group to the east at Sops Arm (Fig. 18) and with Roberts Arm Group to the west. The unnamed group is interpreted as part of a shale basin overlain by isolated mafic volcanics and faulted into place either as an independent fault belt or as an outlying edge of the Exploits basin. No fossils have been found in the group. Scarce plutonic pebble conglomerate and coarse clastic sediments, lateral concentration of volcanic breccia, and the chemistry of the basalts themselves suggest an isolated volcanic island or sea mount environment.

The Middle or Upper Ordovician Roberts Arm Group occurs in two steeply dipping, predominantly northwest-facing belts bounded by faults. These fault-bounded belts are hereafter referred to as fault belts. The southeastern fault belt consists of island arc tholeiite-type basalt whereas the northwestern belt comprises both felsic and basic volcanic rocks of island arc calc-alkaline type, and is faulted against the Mansfield Cove complex to the west. The northwestern belt has been intruded and metamorphosed by the presumably synvolcanic Sunday Cove granodiorite. Both belts have been complexly buckled and broken at their northern ends and locally the northwestern belt is folded, but deformation has not been of a penetrative character. The unconformity between the Roberts Arm Group in the northwest belt and the Springdale Group crosses structural trends in the Roberts Arm Group indicating that this deformation was probably largely pre-Lower or Middle Silurian.

Thus the Roberts Arm Group is seen as containing the products of a Middle or Upper Ordovician island arc that developed for a short time along the east margin of an

Hadrynian plutonic block. Because of its peculiar expression in fault-bounded belts the original arc has been telescoped into sections (fault belts). The occurrence of basalts comparable to arc tholeiites in the eastern of these belts, with calc-alkaline rocks in the western belt, suggests that the related subduction was westward dipping from a trench the remnants of which perhaps persist in the Dunnage Mélange of eastern Notre Dame Bay or in similar rocks along the east margin of the Central Mobile Belt. Compression from the east was presumably responsible for westward overturning of the Robert's Arm flows, and later for right lateral movement along the Lobster Cove Fault. Unnamed rocks including basalts comparable to oceanic island basalts may well be older than the Roberts Arm Group but their contact is faulted and relative displacement unknown. Uplift and a westward shift of volcanism that produced the terrestrial volcanics of the Springdale Group west of the map area were presumably associated with foreshortening of the Robert's Arm volcanic pile.

The Lobster Cove (Chanceport) Fault, a regional structure stretching across Notre Dame Bay from New World Island on the east to Halls Bay on the west, is at least partly post-Springdale in age. Various interpretations have been made for this fault, the latest being that of Dean and Strong (1977) who suggested that it is a folded thrust that moved Lushs Bight Terrane over younger rocks to the southeast. There appears to be no fundamental reason however for believing that the fault is not transcurrent with predominantly right lateral movements commencing in association with westward to northward overturning of the Roberts Arm Group and persisting into Silurian times. Eastward oroclinal bending of the Roberts Arm Group where it approaches the fault from the southwest is consistent with this view.

The Springdale Group of fine to coarse grained red beds occur as truncated, northward facing to northward overturned wedges cut off by the Lobster Cove Fault and lying unconformably on the Roberts Arm Group. These red beds are lithologically similar to Lower to Middle Silurian rocks in the Botwood area and are correlated with the red bed and terrestrial volcanic sequence of the Springdale Group south and west of the map area. They were presumably deposited over most of the map area during uplift that followed Robert's Arm marine volcanism.

Lushs Bight Group

The name, Lushs Bight Group, was proposed by Espenshade (1937) for basic volcanic and pyroclastic, and some sedimentary, rocks exposed north of the Lobster Cove Fault mostly on Sunday Cove, Pilley's and Triton islands. In his usage the Lushs Bight Group together with the Cutwell Group to the north formed the Pilley's Series. Subsequent workers, notably MacLean (1947) and Williams (1962), extended the name, Lushs Bight Group, to include similar rocks in Notre Dame Bay east and west of the original area north of the Lobster Cove Fault. Williams (1967, 1969) proposed the term 'Headlands Group' to include "all the dominantly mafic volcanic assemblages that apparently form a continuous belt along the headlands and islands of Notre Dame Bay...". Horne and Helwig (1969) used the informal term 'Lushs Bight terrane' to apply to rocks of an area essentially the same as that underlain by the Headlands Group and bounded on the south by the Lobster Cove Fault Zone. Strong and Payne (1973) proposed the term 'Lushs Bight Supergroup' to apply to rocks of the Lushs Bight terrane "generally referred to as the Lushs Bight Group". In the Pilley's Island area this latter usage involves two established groups, one of which has the same name as the proposed encompassing supergroup. In the present study the term "Lushs Bight Group" is used in the original definition (Espenshade, 1937) with the Lushs Bight-Cutwell boundary as modified by Williams (1964, 1969). This accords with the usage of Dean and Strong (1977). The phrase "Rocks of the Lushs Bight terrane" will be used in preference to Lushs Bight Supergroup.

The Lushs Bight Group in the Pilley's Island area has been described by Espenshade (1937) and by Strong (1973), and is estimated by the latter to be 1500 m (5000 ft) or more thick on Pilley's Island. Although the group is considered to be mostly southward facing no continuous section through it has been recognized. In the present study only parts of the group close to the Lobster Cove Fault on Sunday Cove Island and on the western to central parts of Pilley's Island have been examined.

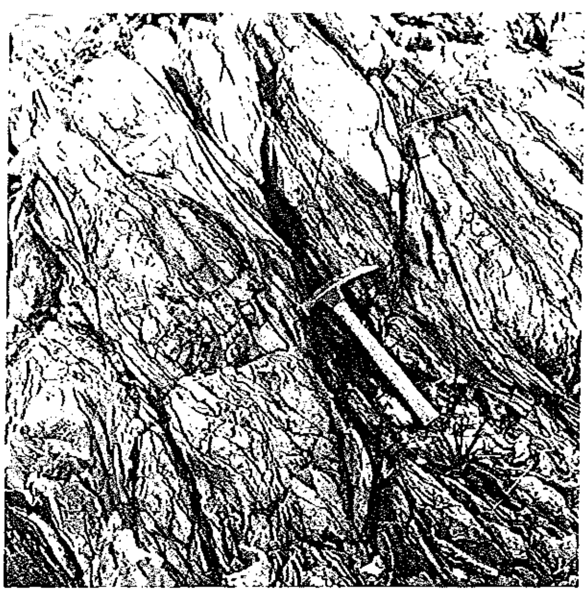

Figure 4A. Highly sheared pillow lava of Lushs Bight Group on the west coast of Sunday Cove Island. (GSC 167207)

Figure 4B. Sheared pillow lava of Lushs Bight Group on the west coast of Pilley's Island. (GSC 167101)

On the west coast of Sunday Cove Island schistose pillow lava and metabasalt predominate with lesser amounts of green chloritic schists, schistose volcanic breccia, and minor greywacke and chert. Original bedding is rarely evident but was seen to strike east-southeast and to dip steeply south at one point. Mostly it has been obscured by an easterly striking, mostly steep north-dipping schistosity. Local mineral lineation and boudin axes plunge steeply, and kink bands, noted at one locality, strike 290 and plunge 85 degrees.

On the west coast of Pilley's Island similar rocks are exposed but they are less sheared and altered (compare pillow lavas in Fig. 4A and 4B). Schistosity, and bedding where preserved, trend easterly and dip moderately south. Rocks on the east coast of Pilley's Island appear to be still less altered and deformed.

The age of the Lushs Bight Group in the Pilley's Island area is only approximately known. Fossils of definite Ordovician age, possibly lower Middle Ordovician, were reported by Williams (1969) from the Cutwell Group on Little Bay Island. This age was supported, although not confirmed, by Strong and Kean (1972) on the basis of fossils found in the Cutwell Group on Long Island. MacLean (1947) reported a single brachiopod in the upper part of the basal pillow lava of the northwest Western Arm section northwest of the present study area. This brachiopod was interpreted as fairly definitely Canadian (Early Ordovician), probably late Canadian. On the basis of these fossil ages and correlation of the Lushs Bight Group with rocks to the northwest, Williams (1962) suggested that the Lushs Bight Group may be of Early Ordovician age and older than the Cutwell Group. Horne and Helwig (1969) re-emphasized the tentative nature of this interpretation.

Exploits Group

The term 'Exploits Series' was originally applied by Heyl (1936) to a thick sequence of volcanic and sedimentary rocks in the Bay of Exploits area. Espenshade (1937) believed the Exploits Series to be essentially equivalent to his Badger Bay Series and both were included in Exploits Group as employed by Williams (1962). However, Williams (1964) later removed the upper two units (Crescent Lake Formation and Roberts Arm volcanics) from Exploits Group because he considered these rocks to be atypical of Ordovician rocks in the group farther east.

Following Williams (1969) the Exploits Group is subdivided into Wild Bight Group, Beaver Bight Formation, Shoal Arm Formation, Gull Island Formation, Julies Harbour Group and Burtons Head Group. Relationships between some of these units are however poorly known and Williams (1969) has suggested that the Burtons Head Group, which contains intercalated volcanic rocks, may in the west be partly equivalent to the Gull Island and Shoal Arm formations in the east. On the other hand basaltic rocks currently under investigation by the author, which overlie the Crescent Lake Formation south and east of Crescent Lake, are chemically distinct from similar rocks in the Roberts Arm Group proper to the north and west, to which they have been previously assigned, and may be more clearly related to basalts (not yet investigated chemically) in the Burtons Head Group. For this reason the basalts between Tommy's Arm and the southwest end of Crescent Lake are referred to informally as an unnamed group of rocks that may form an independent assemblage or may be related to the Burtons Head Group within the Exploits Group.

The northwestern limit of the Exploits Group is, in view of the foregoing discussion, in doubt. For purposes of this report it is placed at a fault (the Burnt Creek Fault of Hayes, 1951b) along the northwest side of Sops Arm and to the southeast of the limit set by Williams (1964). Volcanic rocks at Sops Head, northwest of the fault, appear to pass southwestward by facies change through volcanic clastics to more normal sediments of the Crescent Lake Formation. The Sops Head volcanic centre thus implied would be consistent with an oceanic island setting deduced for these rocks on the basis of petrochemistry. With this exception no major changes in sedimentation were recognized in the section northwest of the Burnt Creek Fault (Fig. 18). Southeast of the fault however, greywacke containing roundstone conglomerate, limestone and volcanic conglomerate are present in addition to siltstones more typical of the Crescent Lake Formation, and the rocks are less deformed. Dean and Strong (1976) included units in the vicinity of Sops Head and Tommy's Arm, both to the northwest and to the southeast of the Burnt Creek Fault, in a mélange which they called the Sops Head Complex. This complex, it was suggested, "can be correlated stratigraphically and lithologically with the Boones Point Complex to the east". The writer prefers the former interpretation with division between Exploits Group and an unnamed group to the northwest along the Burnt Creek Fault. However, it must be emphasized that the basis for this division rests on mapping a small part of the contact zone along Sops Arm and does not include any familiarity on the writer's part with Exploits Group farther east.

The Exploits Group of western Notre Dame Bay is composed mainly of some 3000 m (9800 ft) (based on unit thicknesses given by Espenshade, 1937) of fine to coarse, immature clastic sediments with basic lavas and agglomerate near the base (Wild Bight Group) in the east, and with intercalated volcanic rocks and minor limestones near the top (Burtons Head Group) in the west. Rocks described here as belonging to the Exploits Group consist of greywacke, dark grey slaty siltstone, greenschist, basalt, pillow lava, volcanic breccia, conglomerate and minor limestone. They occur along the northwest shore of Sops Arm, and on the south shore of Kay Island.

The predominant lithology is grey-white to buff weathering, grey-green greywacke with siltstone and dark grey slate interbeds. Bedding varies in thickness from laminae to 2.5 m (8 ft) or more. Chips of slate, grey siltstone and greenish cherty rock are commonly present and roundstone conglomerates are prominent near the head of Sops Arm and on Kay Island. Roundstones are chiefly up to 15 cm (6 in) in diameter and are concentrated in beds or scattered through greywacke. They are composed principally of quartz diorite or granodiorite but locally felsite is a prominent constituent. On the north shore there is a bed of volcanic conglomerate up to about 15 m (50 ft) thick, consisting of quartz dioritic roundstones up to 46 cm (18 in) in diameter but including more mafic clasts (Fig. 5) in a dense green matrix.

Less abundant are pillowed to massive basalt flows, and associated breccia and greenschist. These rocks appear to be concentrated in a band that includes a minor grey limestone bed up to 1.5 m (5 ft) thick and the above described volcanic conglomerate. This limestone lies approximately parallel to the shore for about one half mile. It may correlate with calcareous beds on the shore opposite the southwest end of Kay Island and limestone in a block included in basalt on Kay Island. Rock from this horizon was collected for examination for microfossils but no fossil material was found. A similar result was obtained for material collected earlier, probably from the same locality (Williams, 1969).

Stratigraphic sequence in the rocks at Sops Arm is indicated by graded beds and in places by scour and fill structures. These suggest that the rocks lie chiefly on the northwest limb of a northward plunging anticline. Minor folds consistent with this structure plunge nearly due north at roughly 45 degrees on the shore opposite Kay Island. A fault or zone of structural complexity probably separates Kay Island from the mainland.

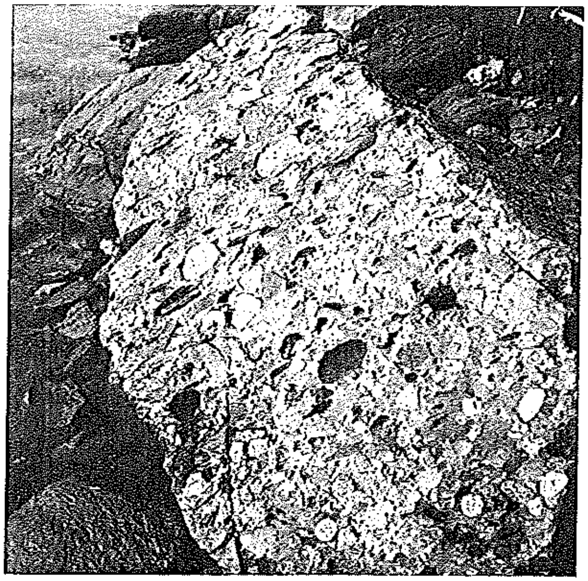

Figure 5. Plutonic cobble conglomerate with volcanic matrix in Exploits Group on the northwest shore of Sops Arm. (GSC 167283)

The northwest contact of the Exploits Group is defined by a fault which reaches the coast about one quarter mile south of Sops Head. On approaching the fault from the north basalt, greenschist and felsite are contorted and show east-west trends in foliation and minor folding discordant with structure both to north and south. Inland a prominent lineament trends southwestward to join eventually with the fault suggested by Williams (1969) as the boundary of the Exploits Group. Discordance of strike between greywacke on the shore and basalt inland at the head of Sops Arm suggests that a southward splay from this fault may form the contact at that point.

The age of the Burtons Head Group, which forms the upper unit of the Exploits Group in the west, is considered to be Middle Ordovician on the basis of the identification of graptolites at two localities (Williams, 1969). No identifiable fossils have been found in the limestone on the north shore of Sops Arm either by previous workers (Williams, 1969) or during the present study. Williams (1969) has suggested that conglomerates farther east may be of Silurian age and by analogy some or most of the rocks here indicated within Exploits Group might also be of Silurian age.

Unnamed Group

The Crescent Lake Formation and volcanic rocks south and east of Crescent Lake, which formerly were assigned to the Roberts Arm Group, are here considered as a separate group yet unnamed. These rocks are set aside because chemical analyses of the basic rocks from a section some 10 700 m (35 000 ft) across, encompassing most of the volcanic rocks formerly included in the Roberts Arm Group, have shown that the basalts south of Crescent Lake are distinctly titanium-rich in comparison to those to the north. Recent investigations of the petrochemistry of basalts (Pearce and Cann, 1973) suggested that this difference in titanium content may reflect a major change in petrogenetic environment in which the volcanic rocks evolved. Investigation of these rocks however is still in progress, and both the regional integrity of the chemical difference and the projection of boundaries between the two chemical types remain to be established. Nevertheless, the boundary at the line of section falls along a prominent lineament, that of Crescent Lake valley, which can be interpreted as a major fault. This lineament can be traced completely across the area mapped during the present study, and together with the proposed fault through Sops Head, may define a fault-bounded belt characterized by basalts of distinctive titanium-rich petrochemistry. Alternatively, although there is no other evidence to support this speculation, titanium-rich chemistry may characterize basalts down into the Burtons Head Group (Exploits Group). In either case the existence of a major fault through Crescent Lake associates the Crescent Lake Formation with the basalts to the south of Crescent Lake rather than with the Roberts Arm Group.

Crescent Lake Formation

The Crescent Lake Formation was originally defined by Espenshade (1937) who placed it beneath the Roberts Arm volcanics and at the top of his Badger Bay Series. This sequence was accepted by Hayes (1951a, 1951b). Williams (1964, 1969) included the Crescent Lake Formation within the Roberts Arm Group. The formation is here considered to lie in a separate fault belt conformably beneath the titanium-rich volcanics with which it is therefore grouped. The possibility remains however that the titanium-rich volcanics are similar to unanalyzed volcanics in the Burton Head Group (Exploits Group), and that the Crescent Lake Formation may more correctly belong within the Exploits Group.

The Crescent Lake Formation along its southeastern margin, consists of deformed friable grey fissile shales with some beds, lenses and tectonic remnants of slate-chip-bearing greywacke. A strong foliation is developed particularly in the east. Greywacke is predominant immediately to the west of infaulted (?) volcanic rocks on the peninsula south of Tommy's Arm. Farther to the northwest and beneath the titanium-rich basalts (as shown by pillow tops) the shales are commonly greener. Still farther to the west and mostly between Tommy's Arm River and Crescent Lake, the formation is composed of red- and buff-weathering banded cherty siltstones and greywacke (Fig. 6). In a few places graded beds are present but over most of its exposure the formation lacks indications of stratigraphic sequence.

The Crescent Lake Formation is in most places deformed. Along the north shore of Tommy's Arm isolated noses of minor folds and refolded foliation are locally evident. Similar deformation in similar lithologies is suggested inland along strike where the rocks are less well exposed. Farther to the west cherts and siltstones commonly show chaotic folding locally suggesting slump folds; axial cleavage is less well developed, and minor fold axes, although apparently in places showing consistent trends over limited domains, appear to show little regional pattern. Many axes of minor folds are steeply plunging perhaps reflecting lateral movement on neighbouring faults (Fig. 7).

Major folding of the Crescent Lake Formation was interpreted by Espenshade (1937) and by Hayes (1951a, 1951b) near the mouth of Tommy's Arm River at Crescent Lake. There a band of sediments, continuous for some miles to the southwest, appears to plunge eastward beneath the basalts. Pillows on the north limb of this structure clearly face northwards, but in the vicinity of the supposed fold nose those on the south limb are too sheared to be definitive. Farther west however, pillows indicate that the basalts both north and south of the band of sediments are northward facing. This structural configuration indicates that a fault probably follows the south margin of the aforementioned sedimentary band and extends eastward to meet the Crescent Lake-Tommy's Arm fault beneath Crescent Lake. Thus the lithologic sequence to the north of the fault, in which basalts overlie a slice of the Crescent Lake Formation, is the same as that to the south and suggests that both Crescent Lake Formation and basalts have been repeated by faulting.

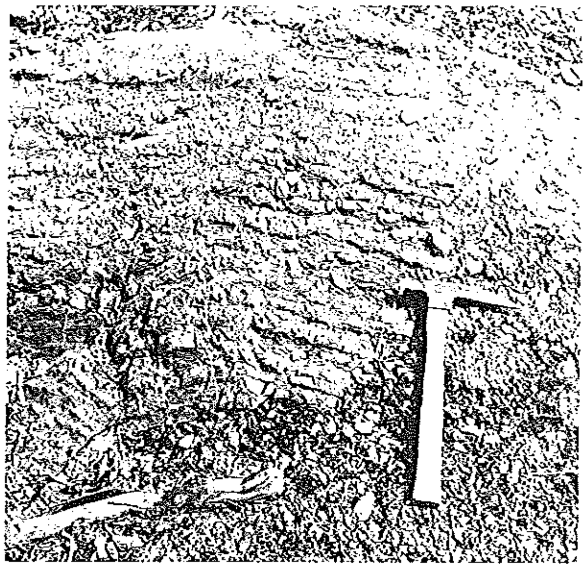

Figure 6. Banded cherty siltstone of Crescent Lake Formation north of Tommy's Arm River. (GSC 167251)

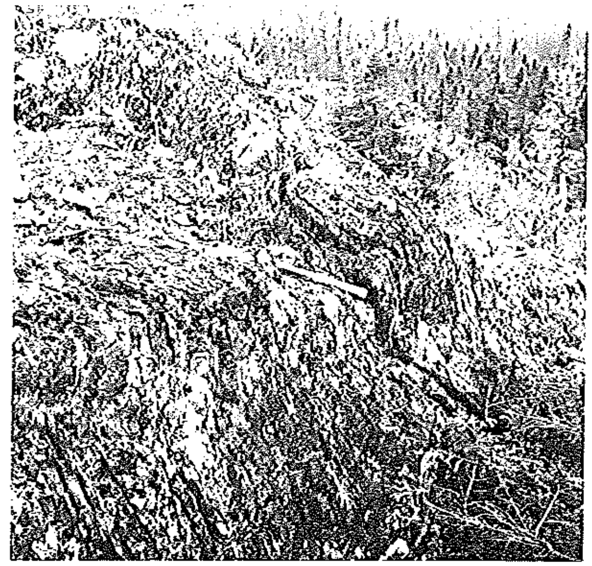

Figure 7. Steeply plunging minor folds typical of the Crescent Lake Formation north of Tommy's Arm River. (GSC 167257)

No fossils have been found in the Crescent Lake Formation. It is thought to be in fault contact with rocks of the Burtons Head Group to the southeast, and to the northwest it is overlain conformably by the titanium-rich basalts that are probably faulted against the Roberts Arm Group. The age of the formation is therefore unknown.

Titanium-rich volcanic rocks

Titanium-rich volcanic rocks (Fig. 19), which occur south and east of Crescent Lake, were previously considered to be part of the Roberts Arm volcanics (Espenshade, 1937) and the Roberts Arm Group (Williams, 1969). These rocks are probably in fault contact with the Roberts Arm Group to the west and conformably overlie chert, siltstone and greywacke of the Crescent Lake Formation. They form a northwestward facing pile up to 1400 m (4500 ft) thick that has been partly repeated by faulting.

The titanium-rich volcanics consist of green to dark grey basalts, green pillow lavas, pillow breccias and some thin bands of intercalated fine clastic and cherty sediments, some felsic volcanic and/or hypabyssal rocks, and minor tuffs. Commonly the basalts are non-amygdular but in places amygdules are numerous. Dark grey basalts that form a substantial part of the hills between Crescent Lake Valley and Tommy's Arm River appear to be less altered than intercalated green pillow lavas and volcanic rocks farther southeast. The chemistry of these rocks indicates that they have been spilitized but no petrographic work has been done on them.

The volcanic breccias comprise fragments of purple and green basic volcanic rocks mostly 20 cm (8 in) in diameter or less in a greenish, commonly foliated matrix containing dark green, presumably once glassy, chlorite-rich chips. In places the larger fragments are rounded with chilled margins resembling those of pillows so that the breccias resemble isolated pillow breccias of Quadra Island (Carlisle, 1963). These breccias occur in minor layers throughout the volcanic pile but are concentrated in larger bodies south of Long Lake and northwest of Kippins Pond. Both concentrations occur where exposures of the Crescent Lake Formation are unusually extensive perhaps indicating that breccia concentrations are related to the margins of extensive basalt accumulations.

Felsic volcanic rocks within the titanium-rich basalts are concentrated in the western part of the unit southwest of Crescent Lake and on the peninsula south of Tommy's Arm. Minor bodies a few feet thick occur at widely scattered intervals throughout the titanium-rich basalts. Some of these small bodies, and possibly all of them, are dykes or sills. The larger felsite bodies are pale green to pale pink or pale purple, very fine grained rocks commonly containing corroded but recognizable phenocrysts of quartz which in places reach 5 mm in diameter. Plagioclase phenocrysts are typically present. In their quartz-phyric texture they differ from large felsite bodies in the Roberts Arm Group that commonly contain abundant quartz amygdules but rarely exhibit recognizable quartz phenocrysts. Smaller felsite bodies are aphanitic to fine grained, buff-pink to pale grey, and commonly aphyric. Some contain pyrite finely disseminated, and others show flow banding.

Interflow sediments are in large part cherts and siltstones similar to those found in the Crescent Lake Formation. In places green or purple-red tuffaceous siltstones commonly accompanied by volcanic breccia lenses are present. These thin sedimentary units within the basalts tend to be less deformed than the Crescent Lake formation.

Pillow lavas, local scour and fill structure, and in places graded beds indicate that the titanium-rich volcanic rocks face northwest. Near Long Lake beds and pillows indicate that the rocks are dipping within a few degrees of vertical, but farther to the southwest they dip in general steeply northwest.

The contact between the titanium-rich volcanics and the Crescent Lake Formation is considered to be conformable because where the contact is approached from the southeast there is a recognizable change in colour of the shales from grey to green probably reflecting an influx of basic volcanic detritus shortly before the first basalts were laid down. Basalts and breccias furthermore locally appear to intertongue with the shales. The upper contact between titanium-rich basalts and the Roberts Arm Group is thought to be a fault because:

1) The contact, indicated by changes in chemical composition, lies along a pronounced lineament, that of Crescent Lake Valley.

2) Within the southwestern part of Crescent Lake Valley volcanic rocks are shattered and bedding in sedimentary interbands shows deflections atypical of the structure elsewhere.

3) Shearing and structural discordance are clearly indicated on the north shore east of Tommy's Arm where foliation locally cuts across the trend of pillow lava immediately inland at angles close to 90 degrees. This fault zone, the Tommy's Arm fault zone, apparently splays southwest along a number of lineaments after entering Tommy's Arm from the east. Crescent Lake Valley is the most westerly of these lineaments.

The relationship between the titanium-rich basalts that have been analyzed, and unanalyzed basalts lying to the southeast, such as those at Sops Head and within the Burtons Head Group, is not known. It is possible that the Sops Head volcanics represent an early phase or a down-faulted outlier of the titanium-rich basalts distinct from lavas in the Burtons Head Group (Exploits Group) or it may be that the volcanism in the upper part of the western Exploits Group is all of one titanium-rich type. Further sampling aimed at clarifying these relationships is planned.

Roberts Arm Group

The Roberts Arm Group of Middle or Upper Ordovician age, consists of an assemblage of predominantly basic volcanic rocks that includes intercalated felsites and interflow sediments. Scattered throughout the group, but locally concentrated in major lenses are basic volcanic breccias, mostly pillow breccias.

The term, Roberts Arm volcanics, was used by Espenshade (1937) to apply to massive and pillowed basalt with intercalated red and green cherts that occurred at the top of his Badger Bay Series. Also included with these volcanics were the "purple and green rhyolite flows and tuffs" of Pilley's Island. Williams (1964, 1969) used the name, Roberts Arm Group, to include both the Roberts Arm volcanics and the Crescent Lake Formation. In the present work the Roberts Arm Group includes the mafic and felsic volcanic rocks, and intercalated sediments, that are separated from titanium-rich volcanics on the south and east by the Crescent Lake-Tommy's fault. In the north the group is in part unconformably overlain by the Springdale Group and in part separated from the Lushs Bight Group by the Lobster Cove Fault. On the west the Roberts Arm Group is faulted against older granodioritic rocks of the Mansfield Cove complex, but farther south (southwest of the present map area) the Roberts Arm Group apparently passes westward into a basalt-hornblende gabbro-aplite complex (Hall Hill complex), the development of which may have been partly penecontemporaneous with effusion of the Roberts Arm lavas (Currie, 1976).

The Roberts Arm Group is divided into two predominantly west- to northward-facing fault-bounded belts by the Sunday Cove Fault. Subsidiary blocks of reversed facing direction occur in the Haywards Head area and west of Boot Harbour Pond. Both reversed blocks can probably be correlated with rocks in the northwestern fault belt, but although some speculative correlation can be made, no certain means of correlating between the two main fault belts has been found. Allowing for these complications the thicker northwestern fault belt in its broadest exposed section reaches a thickness of about 4600 m (15 000 ft). Close to 3000 m (10 000 ft) are represented in the southeastern fault belt.

The Roberts Arm Group consists primarily of spilitized basalts, pillow lavas, volcanic breccias, some chert, siltstone and greywacke, and some possible distal marine ash flow deposits. Thick accumulations of keratophyre occur discontinuously in the upper part of the northwest fault belt and similar rocks are present as minor bodies in other parts of the group. The thicker accumulations are here referred to as felsic volcanic centres with an appropriate geographic name (Fig. 2) for clarity of reference. This is not meant to imply that all the felsitic rocks of each centre were necessarily derived from one volcanic vent or that two or more centres could not have been derived from the same vent, connecting areas having been covered by the sea, etc. Minor limy beds occur west of Haywards Bight, on Haywards Gull Island, and on Pretty Island. Included within the group are scattered small bodies of altered gabbro that are probably at least in part sills emplaced penecontemporaneously with effusion of the Roberts Arm Group.

Basalts of the Roberts Arm Group are green to dark grey, aphanitic to medium grained and equigranular to porphyritic. Porphyritic basalts are distinctly more common than in the titanium-rich basalts southeast of the Crescent Lake-Tommy's Arm Fault. Phenocrysts are of albite or both albite and clinopyroxene and in places reach 5 mm in length. Amygdules are common to abundant in many flows and are composed mostly of carbonate, but epidote, chlorite and pumpellyite are also common. In pillow lavas amygdules are commonly concentrated in several zones about the periphery of pillows and especially on the upper side providing an indication of stratigraphic sequence (Fig. 8). Non-amygdular flows are perhaps most common in the fault belt southeast of the Sunday Cove Fault. Red to grey or greenish chert is widely present in the intersticies between pillows and commonly thin bands of finely bedded chert, siltstone and greywacke separate flows. Stratigraphic sequence may be discerned where cut and fill structures are present and where the unconsolidated sediment has been forced upward into contraction cracks in overlying massive basalts.

Volcanic breccias are mostly pillow breccias made up of angular fragments of green and purple pillows 30 cm or less in diameter in a matrix of chloritized glass chips of variable size, commonly with more or less abundant carbonate (Fig. 9). In places basalt clasts are rounded and amygdular with chilled

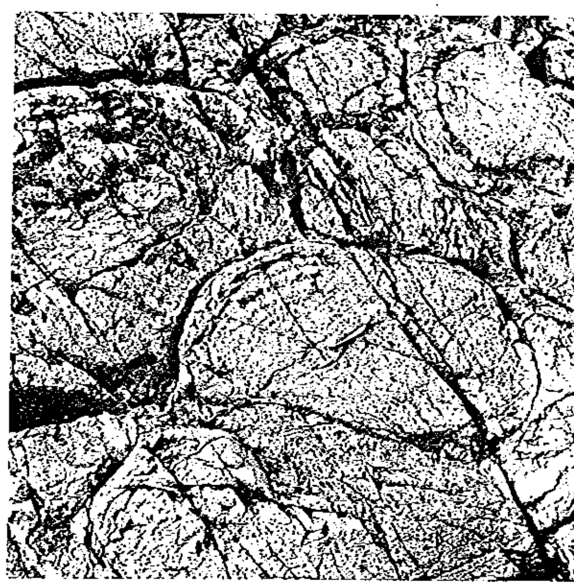

Figure 8. Pillow lava of the Roberts Arm Group, northwest fault belt, showing amygdule concentration at pillow tops. Bedding is parallel to the pocket knife and faces toward the upper left corner of the photograph. (GSC 167146)

margins, and are smaller than normal pillows; in places hyaloclastite beds with basalt fragments sparsely distributed or of small size are present, and more rarely breccia beds show sorting and grading (Fig. 10).

The breccias occur in beds up to several metres thick throughout the Roberts Arm Group but they are concentrated in large bodies in the northwestern fault belt where up to 600 m (2000 ft) of breccia with some intercalated basalt are present locally. Local association of these large breccia bodies with felsitic centres and the fact that some breccia bodies are slightly discordant with the adjacent lavas may indicate that some of them developed on slopes adjacent to local uplift that preceded or accompanied felsic volcanism.

Felsitic rocks (keratophyres) are pink to brown, grey, green, or rarely almost black. They are fine grained to aphanitic or in places glassy and invariably contain albite phenocrysts mostly up to one or two millimetres in length. Quartz is commonly abundant in amygdules but quartz phenocrysts are rare.

Most felsites are structureless but at some localities a breccia of greenish to brownish fragments in pink or orange, fine grained felsic matrix is present (Fig. 11). Such breccias grade into more common mottled pink and green felsites in which the darker fragments are no longer distinct. Similar breccias occur in zoned felsite dykes on the southwest coast of Sunday Cove Island. Here an outer zone of brownish felsite grades into a pink core locally containing brown fragments in varying stages of assimilation. Rarely, as for example on Pilley's Island south of Spencer's Dock, the felsites show contorted flow banding (Fig. 12). In places brown to purple, dense glassy felsite forms large amoeboid lenses in greenish, friable, more altered felsite. Near the margins of felsite piles, dark brownish, quartz-amygdular felsites of intermediate chemical composition show pillow-like structures commonly 2 to 2.5 m (6 to 8 ft) in diameter (Fig. 13).

The felsic rocks occur in tabular bodies in places up to 10 or more metres thick which may be separated by thin basaltic pillow lavas or by beds of sediment. Only rarely can the felsites be been to intrude the enclosing beds and most are therefore considered to be flows and extrusive breccias rather than sills. Currie (1976) has suggested that felsites at the north end of Loon Pond granitic pluton (immediately south of the present study area) are mostly intrusive. Chemical analyses of 8 samples taken across this body show widely varying soda/potash ratios typical of keratophyre.

Distinctive buff-weathering green to pinkish rocks thought to be submarine ash flow deposits are present southwest of Boot Harbour Second Pond. These rocks are commonly massive or vaguely foliated but in places they include beds or lenses of fine breccia and beds of siltstone. Quartz grains up to 3 mm in diameter form up to several per cent of the rock. Rock fragments in breccias include felsite and chert chips. In thin section the rock is seen to be composed of angular quartz fragments or rounded corroded grains up to 3 mm, plagioclase as subhedral fragments or glomerocrystic clusters, and chips of chert and felsite in a fine grained siliceous chloritic and epidote-bearing matrix. Some quartz grains are partly enclosed by quartz, resembling haloes about quartz phenocrysts in some volcanic rocks (see for example, Bostock, 1966).

Interflow sediments consist chiefly of chert, siltstone and greywacke in thin beds. Cherts are multicolored in shades of red-brown to salmon pink, buff, cream, blue to yellow green or black. In places they contain scattered pyrite euhedra. Greywacke beds are chiefly fine grained but locally grains are up to 3 mm in diameter. Quartz is identifiable in most of the coarser beds and in one area, at the northeast end of the large sedimentary lens northeast of Boot Harbour Second Pond, coarse feldspar grains are evident. Chert chips, commonly displaying bleached rims, are widely present.

Minor beds of limy sediment occur at the west side of Haywards Bight and on Haywards Gull Island. At the former locality a band of cherty, pink-weathering, carbonate-rich sediment, 7.5 m (25 ft) thick lies between pillow lava flows (Fig. 14). Carbonate forms only about 30 per cent of most beds but in a few it forms over 50 per cent and some lenses of nearly pure carbonate are present. On the south shore of Haywards Gull Island brown weathering carbonate lenses up to 10 cm (4 in) thick occur in red-brown cherty siltstone. A ten-foot limestone bed is reported by Dean and Strong (1976) on the northwest coast of Pretty Island. No microfossils have been found in samples from any of these localities.

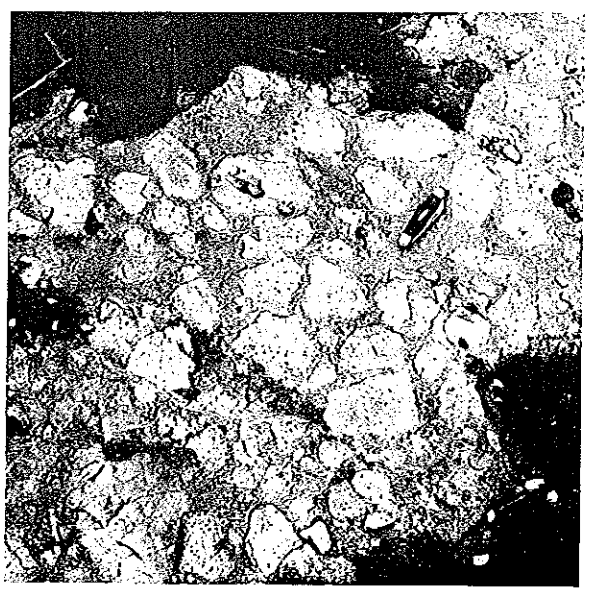

Figure 9. Massive, poorly sorted pillow breccia in the Roberts Arm Group. (GSC 167178)

Figure 10. Bedded pillow breccia showing sorting of pillow fragments into beds of different fragment size in the Roberts Arm Group. (GSC 167174)

Figure 11. Mottled felsitic breccia in the Roberts Arm Group showing darker, greener fragments with ameoboid to angular outlines in a pink felsitic matrix. "Fragments" in most mottled breccias are gradational into matrix. (GSC 167200)

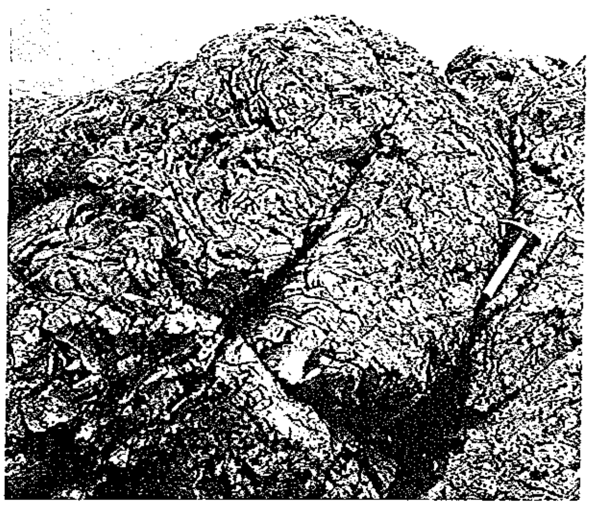

Figure 12. Flow banded felsite in the Roberts Arm Group near Spencer's Dock, Pilley's Island. (GSC 167131)

Small sill-like bodies of grey-green, medium to fine grained gabbro are interleaved locally with the basalts of the Roberts Arm Group and are probably penecontemporaneous with them. Some are layered and in one body at Burnt Head, 44 layers showing alternate gradational and sharp contacts were counted (Fig. 15). Each layer is about 15 cm (6 in) thick. Unlike other bodies of this group a well formed columnar structure is developed.

A limited number of flow direction indicators have been found within the Roberts Arm Group. These include soft-sediment deformation and disharmonious folds at the lower contacts of basalt flows, lava tube structures, and cross-bedded tuffs and greywacke. All suggest a predominant flow direction from east to west and north to south.

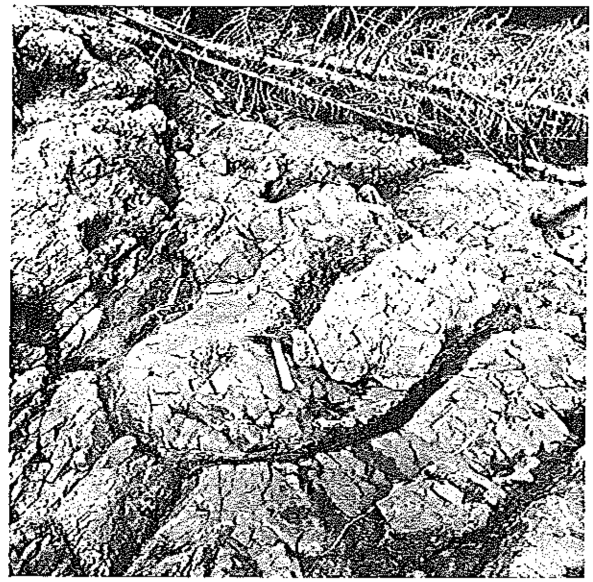

Figure 13. Felsitic pillow lava in the Roberts Arm Group west of Haywards Point showing large pillows with altered rims. Altered rims are succeeded inwards by a quartz-amygdule-rich zone. (GSC 167094)

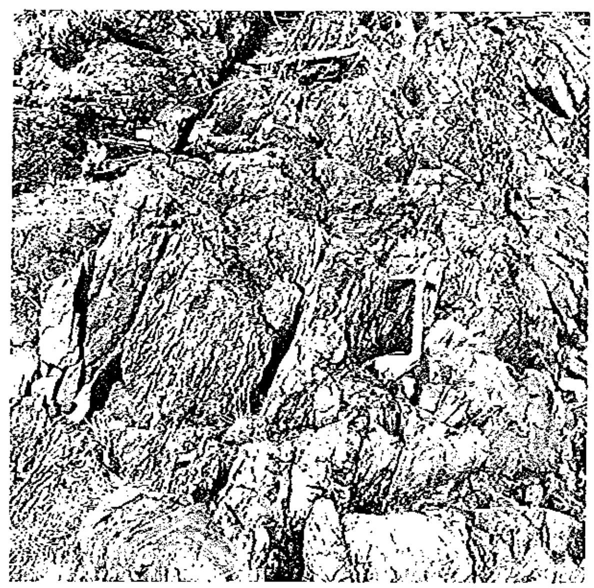

Figure 14. Siliceous-calcareous beds between basalt flows of the Roberts Arm Group west of Haywards Bight. (GSC 167095)

No fossils have been found in the Roberts Arm Group and it is bounded at its base by faults. The group is unconformably overlain by presumed Lower or Middle Silurian red beds of the Springdale Group. A Rb/Sr isochron study of volcanics from the calc-alkaline suite from southwest of Boot Harbour Pond and on Pilley's Island together yielded the following age (R.K. Wanless, pers. comm. 1977): 448 ± 7 Ma with an initial strontium ratio of 0.7063 ± 0.0005 ($\lambda^{87}Rb = 1.42 \times 10^{-11} y^{-1}$). Accordingly the age of these Roberts Arm volcanics is Middle or Upper Ordovician (Geological Society of London, 1964).

Figure 15. Near vertical, columnar, layered basalt sill in the Roberts Arm Group at Burnt Head. (GSC 167192)

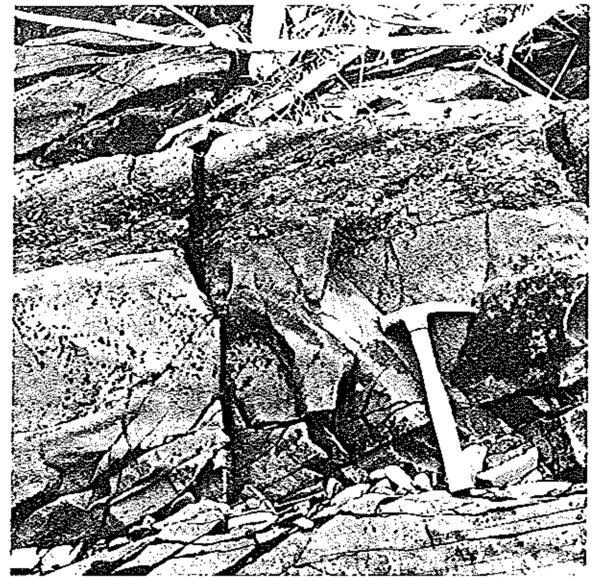

Figure 16. Springdale Group red beds on the west coast of Pilley's Island. (GSC 167104)

Springdale Group

The term, Springdale Formation, was first used by Espenshade (1937) for red beds in the Springdale and Pilley's Island areas. MacLean (1947) elevated the formation to group status in the Little Bay area where it was found to include volcanic units. Kalliokoski (1953, 1955), mapping to the southwest of the present map area, found the group to be predominantly composed of volcanic rocks.

The Springdale Group is exposed within the present map area on Sunday Cove Island and on Pilley's Island. At these localities only two hundred metres or less of red beds are preserved against the Lobster Cove Fault. Similar rocks extend along the fault onto Triton Island to the east and presumably to the Springdale area to the west.

On Sunday Cove Island and Pilley's Island the group comprises about 185 m (600 ft) of red siltstone and sandstone with conglomerate (Fig. 16) and locally talus-like breccia along its contact with the Roberts Arm Group. Siltstone and sandstone occur in beds from laminae to 0.6 m (2 ft) in thickness. Crossbedding indicates current flow both from east and west. Intraformational conglomerate (mud-chip breccia) was observed at one locality. Clasts in conglomerates, which reach about one metre (3 ft) in diameter on the east coast of Pilley's Island comprise felsite, basalt, chert, siltstone, sandstone and dioritic rock.

The contact between Springdale and Roberts Arm groups is exposed at several places on central and western Pilley's Island where it is clearly unconformable. Recent road construction northeast of the old Pilley's Island mine has exposed about 55 m (180 ft) of section with up to 10 m (35 ft) of basal breccia containing intercalated sandstone near the top and overlain by red siltstones. The basalt below the unconformity has limonitic colour banding outwards from fractures and breccia fragments are banded subparallel to fragment edges. Matrix of the breccia is sandy with a sideritic carbonate cement. On Bumble Bee Bight conglomerate containing boulders up to 0.3 m (1 ft) in diameter in places directly overlies the basalt whereas in other places siltstone forms the first beds above the Roberts Arm Group. Locally minor faults in the volcanics do not penetrate the conglomerate and siltstone. On Pilley's Tickle conglomerate with boulders up to 1 m (3 ft) in diameter directly overlies altered basalt of the Roberts Arm Group.

No fossils have been found in the Springdale Group within the Pilley's Island Area. Previous workers have generally considered the group to be Silurian based on lithologic similarity to Llandovery-Wenlock rocks in the Botwood area far to the east.

Plutonic Rocks

Mansfield Cove pluton

The Mansfield Cove pluton lies along the western margin of the map area where it is in fault contact with the uppermost Roberts Arm flows of the western fault belt. It consists chiefly of heterogeneous greenish grey, quartz-rich, foliated tonalite and granodiorite with local concentrations of inclusions composed mostly of more mafic rocks. It is abundantly intruded by more or less altered north-northeast-striking, steeply dipping basic dykes (Fig. 17) and by a few less altered basalt dykes. A very fine grained felsitic phase locally resembling mylonite is present in places along the margin of the pluton south of Mansfield Head where it is in contact with metabasalt and microgabbro. A complex plutonic breccia zone is well exposed along Halls Bay at the contact between tonalite and basaltic rocks.

The age of the Mansfield Cove plutonic complex is unknown from stratigraphic arguments since it is separated by the Mansfield Cove Fault from the Roberts Arms volcanics. Its strongly foliated texture and complex internal variations, which contrast with other rocks in the area, suggest that it is older than these rocks. Currie (1976) has suggested that the complex forms basement on which at least a part of the Roberts Arm Group was deposited, and furthermore because the dykes cutting the complexes are steeply dipping, the fault block in which the complex occurs has not been rotated in the same way as have the fault belts to the east where the Roberts Arm Group is exposed.

A single zircon determination from a sample collected by K.L. Currie on the highway 2.5 km (1.5 miles) west of Loon Pond yielded a mildly discordant age pattern with the $^{206}Pb/^{207}Pb$ age of 594 Ma, a minimum for the tonalite (R.K. Wanless, pers. comm. 1977). The actual age is probably late Hadrynian.

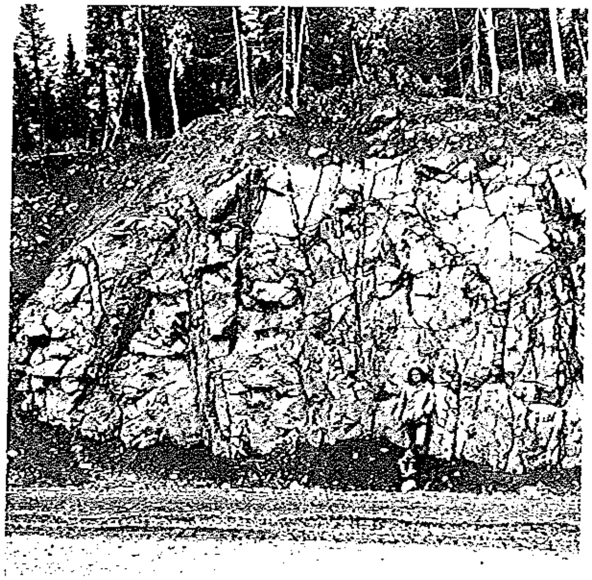

Figure 17. Altered basic dykes cutting tonalite of the Mansfield Cove complex along the Robert's Arm highway. (GSC 167147)

Sunday Cove pluton

The Sunday Cove pluton underlies the peninsula between Shoal Arm and Woodford Arm and extends for some 4.8 km (3.5 miles) south-southwest of Shoal Arm Point before pinching out against the Sunday Cove Fault. Along its western and northern contacts and extending to the south shore of Sunday Cove Island the pluton is bordered by a contact metamorphic aureole in which the basalts are converted to amphibolite. The extension of this aureole northward suggests that the pluton underlies most of the sea-covered area between the mainland exposures and Sunday Cove Island.

The Sunday Cove pluton consists of massive pink to grey-white, medium to fine grained, biotite-chlorite granodiorite, but includes more basic and hybrid phases that are most commonly encountered in its eastern regions near the Sunday Cove Fault. Over much of its exposure the granodiorite appears altered with saussuritized feldspar and mafic minerals converted to chlorite. Similar granodiorite and dioritic rocks are poorly exposed north of Boot Harbour Pond where they occur in fault slices formed by splays from the Sunday Cove Fault.

The Sunday Cove pluton would lie beneath the Burnt Head felsic volcanic centre if the volcanics and pluton were to be rotated to the horizontal. Dykes of felsite intrude the intervening basalts. Furthermore some fine grained parts of the intrusion resemble some of the coarser felsitic dykes. Thus there is reason to suppose that the Sunday Cove pluton occupies the magma chamber from which the felsites to the west and north were derived and is of the same age as the Roberts Arm Group, i.e. Middle or Upper Ordovician.

Gabbro plutons

Two gabbro bodies somewhat less altered than the smaller and finer grained bodies that occur widely scattered throughout the Roberts Arm Group, are present on the east coast of Pretty Island and north of Crescent Lake. Additional small bodies of unknown size are poorly exposed about one mile west of the south end of Boot Harbour Pond, near Fox Pond, and north of Fourth Pond.

The gabbro is mostly massive dark grey-green and composed of clinopyroxene and partly saussuritized plagioclase up to 4 mm in diameter. Near the margins of the two larger bodies grain size is finer and the gabbro appears to include or interfinger with basalt. At least one gabbro dyke was seen to intrude basalt.

METAMORPHISM

The rocks of the Robert's Arm area have been regionally metamorphosed only to subgreenschist grades. A greater proportion of grey (less altered?) basalts occurs in the upper, western to northern parts, of each fault belt in the Robert's Arm area and a greater proportion of greener (more altered?) basalts in the eastern to southern parts of the same belts. Examination of a limited number of thin sections from Roberts Arm basalts has suggested that spilitization involving the alteration of original basalt mineralogy (except clinopyroxene) to calcite, epidote, chlorite, albite and pumpellyite is ubiquitous. Prenite is less common but has been found by microscopic examination in rocks from widely scattered localities.

A limited aureole of contact metamorphism some 180 to 210 m (600 to 700 ft) wide based on field observations appears in the basalts adjacent to the Sunday Cove pluton, but similar metamorphism is absent in the rocks adjacent to the faulted east contact of the pluton. Within the aureole spilites of the Roberts Arm Group have been converted to fine grained dark green amphibolite.

Similar amphibolites surround a small body of granodiorite north of Boot Harbour Pond within a fault lens formed by southward splaying of the Sunday Cove Fault. In the northern part of this lens hybrid rocks consisting of grey, pyrite-bearing felsite, altered basalt and minor chert are present. Amphibolites may also be present along the northwest contact of the granitic rocks northeast of Boot Harbour Pond but no outcrop was found in this area. It is possible that a right lateral movement of 3 km or so is expressed along the splay faults that bound these lenses on the northwest. If so the granitic and metamorphic rocks in this area are likely derived from the southeast (lower) part of the Sunday Cove pluton.

STRUCTURE

The Roberts Arm Group is structurally divided into two faults belts. In the southwest part of the map area these fault belts are apparently little complicated by later deformation, but in the northwest they have been bent and buckled so that the dividing fault is more difficult to trace. Within each belt the rocks are steeply dipping, and face predominantly west to north; but two blocks with reversed facing direction are present within the northwestern belt.

The Roberts Arm Group is internally divided into two fault-bounded belts by the Sunday Cove Fault which is clearly defined on the west by truncation of the Sunday Cove pluton and its metamorphic aureole. East of Woodfords Arm the trace of the fault is less clear. Discontinuity in the attitude of beds suggests that the fault splays eastward and that some movement has been taken up along the lineament south of Woodfords Arm to Stag Cove. South of this lineament the southeastern fault belt has buckled as shown by a few sharply discordant pillow and bedding trends, and the northwestern fault belt has been rotated southeastward across the eastward pinching, broken end of the southeastern belt. The main fault break as here envisaged extends along an irregular path from south of Woodfords Arm to near Robert's Arm. Attitudes are discordant across its northern end whereas farther southeast it separates felsite-free basalts of the southeastern fault belt from the felsite-rich section to the northeast.

East of Robert's Arm felsite bodies appear in the basalts all the way south to Crescent Lake-Tommy's Arm Fault and it is not clear whether the original distribution of felsitic volcanism was such as to allow the felsites to transgress the present fault belts or whether this region represents a section of the northwest fault belt that has been infaulted from the north and east. That it to say, either felsitic volcanism locally transgressed from one belt to the other, or it was everywhere concentrated within the calc-alkaline belt which has locally been doubled up by fault movements. Chemical differences between the arc tholeiite and calc-alkaline basalts should eventually permit a choice to be made between these two hypotheses. In the latter, and perhaps more likely one, movement occurred along various faults in the tickles south of Pilley's Island and between Crescent Lake and Bear Cove, which allowed insertion of the southern felsite-bearing block against the Crescent Lake-Tommy's Arm Fault. Quartz-carbonate veins, which occur on either side of the lineament between Crescent Lake and Bear Cove, may have filled fractures produced by fault movement. Such an hypothesis accounts for the rugged topography near and west of Robert's Arm due to erosion on intersecting fractures and shear zones. It also accounts for the conjugate lineaments formed by bays and valleys about Robert's Arm that resulted from compression of the independent Robert's Arm fault block, and it explains the presence of the large felsite bodies south of Flat Rock Tickle and a few small felsites at the east end of Crescent Lake where volcanic stratigraphy farther west suggests few felsites should exist. Farther east on Triton Island no felsites have been reported (Espenshade, 1937), and this would suggest that the eastern limit of the Robert's Arm fault block lies along Pretty Tickle. Important faults postulated in the Robert's Arm area are reviewed in Figure 18.

The southeastern fault belt consists of steeply dipping to vertical volcanic rocks and sediments in which indicators of stratigraphic sequence everywhere face to the northwest. At the base of the belt the Crescent Lake Fault is mostly nearly parallel to bedding but the upper limiting fault transects the bedding while maintaining the overall width of the belt. This suggests thickening of the section northeastward and together with indicators of southwestward flow suggests the shoaling of the sea to the northeast. At its northeast end the belt is thought to pinch out as a result of complex faulting but it may continue on Triton Island.

A thick unit of cherty siltstone and greywacke lies in the upper part of the southeastern fault belt. This unit thins northward and finally pinches out against the Sunday Cove Fault. Near the pinchout coarse quartz-feldspar-bearing greywackes were observed and perhaps indicate proximity to shore and to a felsic volcanic centre. The unit at its south end is poorly exposed but is much thicker. It is believed to pinch out southward by interdigitation with basalt rather than by fold plunge because outcrops of basalt and siltstone are interspersed and interfingering was observed at the scale of a few feet at one outcrop, but there is no doubt that the unit has been deformed. The contact drawn on the map has been "stylized" to fit the pattern of outcrop and this interpretation.

The northwestern fault belt is composed of steeply dipping to vertical beds and flow units that face mostly to the west and north. East- and south-facing rocks occur south of Boot Harbour Second Pond, near Haywards Head and southern Pilley's Island, and along Raft Tickle.

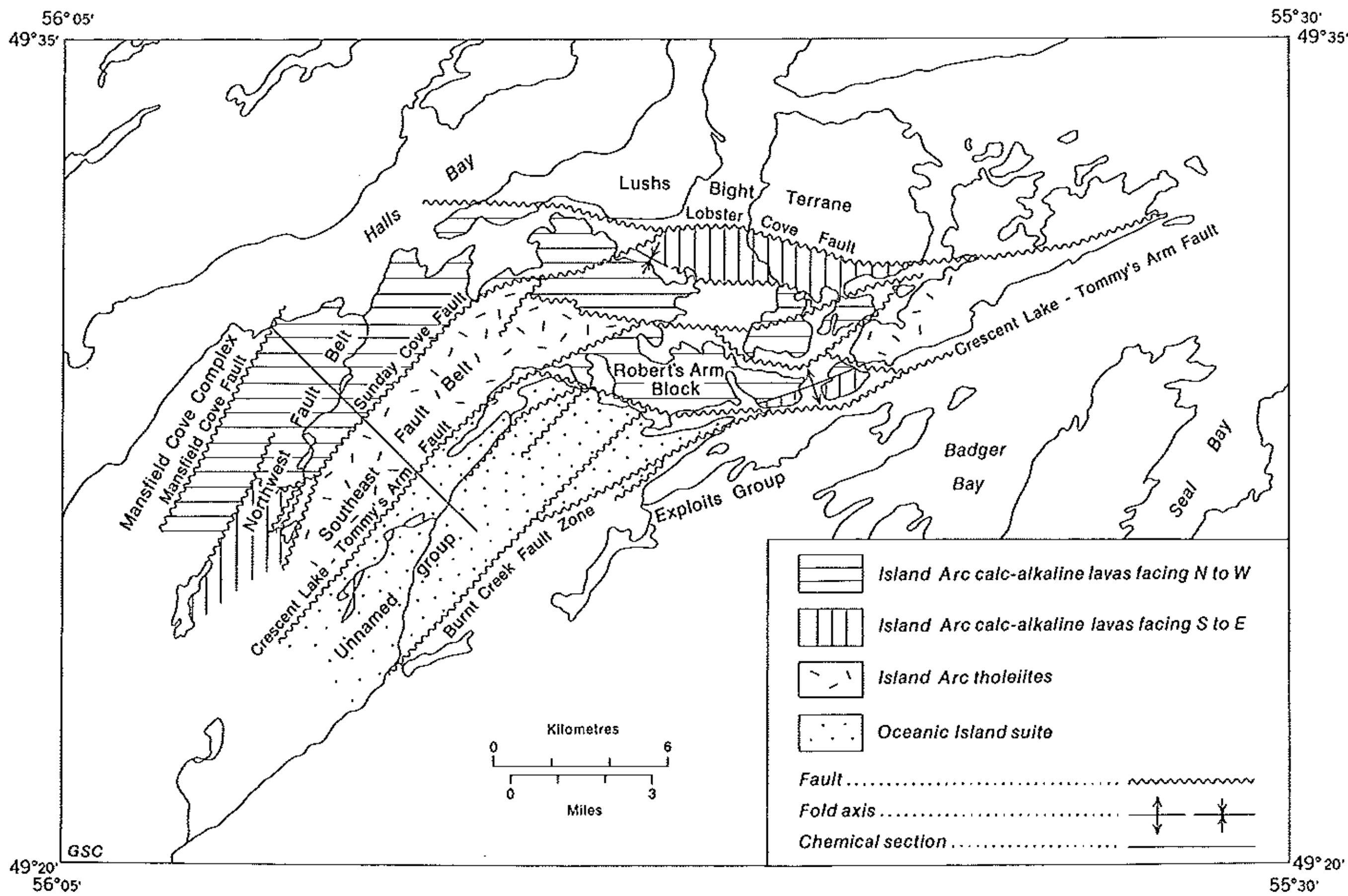

Figure 18. Major faults in the Robert's Arm area.

Immediately south of Boot Harbour Second Pond the Sunday Cove Fault splays forming several fault lenses. In the more easterly lens plutonic and metamorphic rocks are brought to the surface. To the southwest of this splay the rocks are steeply dipping and trend parallel to those in adjacent belts to the east and west, but are eastward facing over a stratigraphic interval of about 1800 m (6000 ft). Immediately to the north beds swing west and cut across trends to the south suggesting the presence of a sharply westward curving splay from the Sunday Cove Fault. Still farther west outcrops and indicators of stratigraphic sequence are few but pillow lava suggests that the rocks are again westward facing. A fault extending north-northeast from Loon Pond has been postulated to explain this discontinuity. It is an interesting observation that the southeast-facing fault block thus defined apparently bears the same stratigraphic relationship to the Loon Pond granitic pluton south of the map area as correlative volcanic rocks farther north bear to the Sunday Cove pluton.

On the northwest coast of Haywards Head numerous exposures of pillow lava face southwest. These are separated from northeast-facing rocks to the south by a lineament through Charley's Cove. On the headland to the west, between Haywards Bight and Stag Cove, pillows on the coast trend north and dip to the east. It seems likely that the axis of a tight, southeast-plunging syncline west of Haywards Bight projects east-southeast to a fold axis or fault separating face to face basalt blocks at Charley's Cove. This axis trends eastward toward the vicinity of Spencer's Dock on Pilley's Island.

On Pilley's Island north of the fault through Loadabats Pond very few reliable indicators of stratigraphic sequence have been found (in contrast to the abundant north-facing pillows immediately to the south). One south-facing pillowed flow is suggested in the basalts north of Pilley's Island mine and this flow faces south, dipping beneath the mine felsites. Altered basalt occurs at the bottom of drillholes through the mine felsite and this implies that a substantial block in the mine area and farther north is southward facing. Pillows in the bluffs along the highway through the village of Pilley's Island face north and are slightly overturned. It appears therefore that the axis of a northward overturned syncline lies between these bluffs and the mine area. The westward pinchout of the mine felsite supports the view that this syncline has an eastward plunge. The structure at Haywards Bight and that in the Pilley's Harbour area are therefore similar and suggest the existence of a northward overturned syncline crossing Sunday Cove between them.

CHEMISTRY OF THE ROBERTS ARM VOLCANIC ROCKS

Chemical studies (Strong, 1973; Scott, 1976) show that some of the basalts of the Roberts Arm Group resemble those of modern island arcs. Their conclusions were restricted however, by the limited structural and stratigraphic information available to them. The present study on the other hand, has been made of a section showing minimal structural disturbance and maximum width of exposure. It was intended, as far as possible, to include the majority of basalt types present, including both the unnamed and Roberts Arm Group, in their proper stratigraphic sequence. The study shows that, although the rocks are altered, they can be subdivided into three distinctive types, each occurring predominantly in its own structural belt, and each characteristic of its own tectonic setting. Furthermore, the study suggests that the environment in which alteration of the unnamed basalts took place was not the same as that in which alteration of basalts of the Roberts Arm Group proper occurred.

A section through both fault belts of the Roberts Arm Group and the titanium-rich basalts about one mile west of the west end of Crescent Lake has been sampled for petrochemical study (Fig. 18). Five- to ten-pound samples of each lithology present were collected including basalt or pillow lava at two points at least 1.5 m (5 ft) apart at each station. Sample stations were set at 150 m (500 ft) intervals. Veined material was avoided but because amygdules are present in most parts of the Roberts Arm Group amygdular rocks were collected. In addition each of the major accumulations of felsitic rocks were sampled at approximately 300 m intervals along the coast. These accumulations are referred to as centres with appropriate geographic names (Fig. 2) even though most of them probably represent more or less distal parts of centres the eruptive orifices of which are not exposed. The samples have been analyzed in laboratories of the Geological Survey of Canada by X-ray fluorescence and wet chemical methods for the major rock-forming elements. Trace element analyses are in progress.

Preliminary analyses of the data collected indicate the existence on the southeast side of the volcanic sequence formerly the major part of the Roberts Arm Group, of a distinct titanium-rich basalt unit which is termed the titanium-rich volcanic rocks of this report (Fig. 19). The data also indicate that basalts of the northwest fault belt of the Roberts Arm Group are richer in P_2O_5 than are the rocks of the southeastern Robert's Arm fault belt. The distinction can be improved if basalts from the upper two stations of the southeastern fault belt are included with those of the northwestern belt. This suggests that the P_2O_5-rich rocks predominant in the west belt may have overlapped the P_2O_5-poor rocks of the eastern belt. No systematic variations showing similar high confidence levels have been found for major and minor elements other than Ti and P.

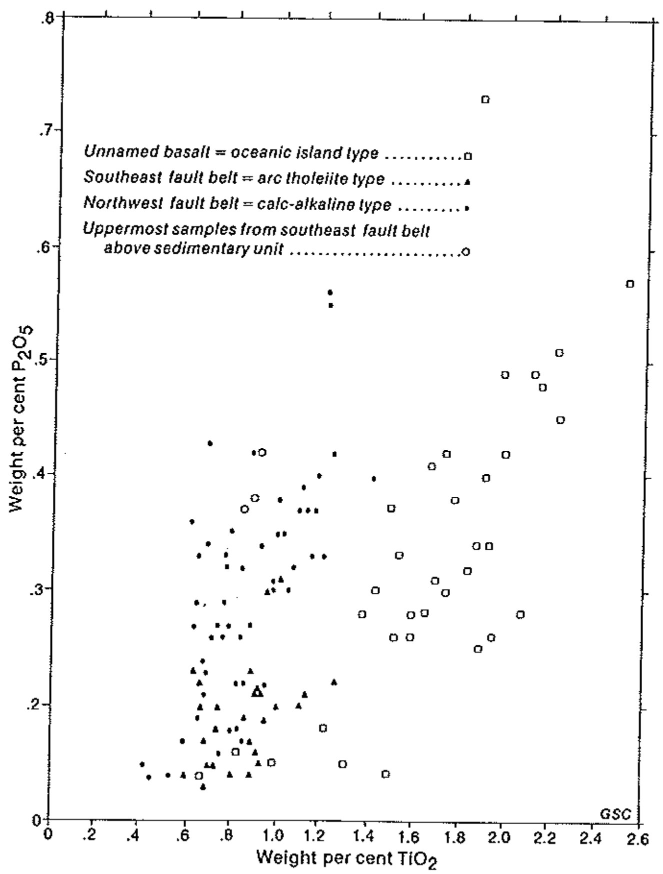

Figure 19. P_2O_5 vs. TiO_2 weight per cent plot for basalts in a section through the unnamed group and the Roberts Arm Group.

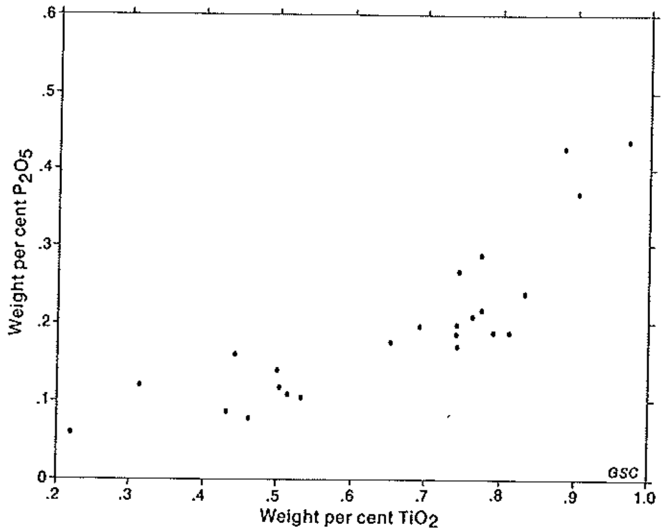

Figure 20. P_2O_5 vs. TiO_2 weight per cent plot for felsites from the Mansfield Cove Section and Centre.

Examination of the immobile elements Ti and P in felsic rocks of the sample section suggests that the contents of these elements vary for the most part sympathetically, and furthermore that the Ti and P compositions of the samples tend to fall within three fields defined in a general way by high, medium, and low concentrations of these elements (Fig. 20). Consideration of the stratigraphic positions of the samples (Profiles, Fig. 21A and 21B) suggests that there is a pattern reflecting variation in felsite composition with time (level within the volcanic pile). Two partly overlapping lines of ascent are shown in Figures 21A and 21B because both samples collected along shore and along the sample section are illustrated. It is seen that although the amplitude of TiO_2 and P_2O_5 variations in the duplicated part of the section varies, the pattern is similar. Samples from felsite within the titanium-rich basalts, from the southeast fault belt of the Roberts Arm Group, and at the bottom of the northwest fault belt, fall in the low group.

In the central part of the northwest belt samples plot in the intermediate group and a slight rise in Ti and P contents is evident in the massive felsite near the base of the Mansfield Cove centre. In the upper half of the massive felsite interval (where interleaved basalts are few) Ti and P fall to a minimum but rise again to a maximum where interleaved basalt again appear. From that point upward in the section basalt and felsite are interleaved and Ti and P fall, first to intermediate and then to low levels. The similarity of the overlapping parts of the two sections through the Mansfield Cove felsic centre, separated by about 1000 m, suggests that the Ti and P distribution reflects some widespread property of original felsic volcanism as opposed to local variations in alteration. This property may be variation in original magma composition.

Comparison of the Mansfield Cove data with less detailed data from other volcanic centres indicates that felsites from a section through the centre at Burnt Head fall in the middle and high Ti and P groups whereas felsites from sections through other centres fall in the low and intermediate groups. As both Mansfield Cove and Burnt Head centres may have been fed from a magma chamber occupied by the Sunday Cove pluton, whereas other centres, with the possible exception of the Loon Pond centre, have no obvious subjacent magma chamber, it is possible that high Ti and P felsite compositions are related to partial differentiation in a shallow magma chamber whereas lower contents of these elements reflect rise of magma from deeper levels. Investigation of the Ti- and P-bearing minerals of the felsites may provide further information regarding the origin of these variations.

Alteration of chemically analyzed rocks can be characterized by comparison with Hughes' (1972) igneous spectrum which portrays the range of alkali compositions within which normal (unspilitized) igneous extrusive rocks may be expected to lie. Preliminary comparisons of the basalts along the section suggest that about 60 per cent of the rocks have compositions that are outside the range of normality for unaltered igneous rocks and therefore are severely altered. The data further indicate that basalts from the Roberts Arm Group tend to be enriched in potash whereas the titanium-rich basalts of the unnamed group are more commonly soda-enriched. Thus both the igneous development and the environment of alteration appear to have been different for the Roberts Arm Group and the unnamed group.

Felsites, like the basalts, are shown by comparison with the igneous spectrum to be in large part severely altered. Those from the Spencer's Dock-Pilley's Island Harbour area (near the old Pilley's Island mine) are distinctly more altered than felsites from other centres and they show enrichment in potash. Those from the Burnt Head centre show least departure from the igneous spectrum, and other centres are intermediate.

DISCUSSION

Structural evolution of the Robert's Arm area

Although most of the Roberts Arm Group has not been penetratively deformed, its deformation has nonetheless been complex. This can be seen in examination of progressively younger features including first the deformation of the Roberts Arm Group itself, second the structural relations between Roberts Arm and overlying Springdale groups, and finally the displacement of the Roberts Arm and Springdale groups along the Lobster Cove Fault.

Preliminary synthesis of geological data from the Robert's Arm area has suggested that the Roberts Arm Group is divided into two principal, steeply dipping, fault-bounded belts within which the strata face mostly west to north. The mechanism by which the rocks attained this configuration, whether primarily by folding, by thrusting, or simply by faulting and tilting, is not known. Following development of the fault belts the rocks in the northern part of the area were broken and buckled by eastward bending about approximately vertical axes. This disruption was likely accompanied by insertion of the Robert's Arm fault block along the Crescent Lake-Tommy's Arm Fault from the northeast and resulted in the apparent thickening (doubling up) of the northwestern fault belt about and to the south of Sunday Cove. Northward overturned folding of the Roberts Arm Group along Tommy's Arm and farther east appears to involve both felsite-bearing rock sequences of the Roberts Arm block and presumed felsite-free rocks of Triton Island, and is therefore thought to be still later.

The Roberts Arm-Springdale unconformity crosses structural trends in the Roberts Arm Group on Pilley's Island and involves an angular discordance in dip of 35 degrees or more on Sunday Cove Island. This and the absence of Springdale rocks in the cores of the synclines within the Roberts Arm Group suggests that deformation of the Roberts Arm Group likely preceded deposition of the Springdale Group. By this hypothesis steep dips and northward overturning of the Springdale Group along the Lobster Cove Fault are due largely to downturning of strata in the vicinity of the fault during periods of fault movement.

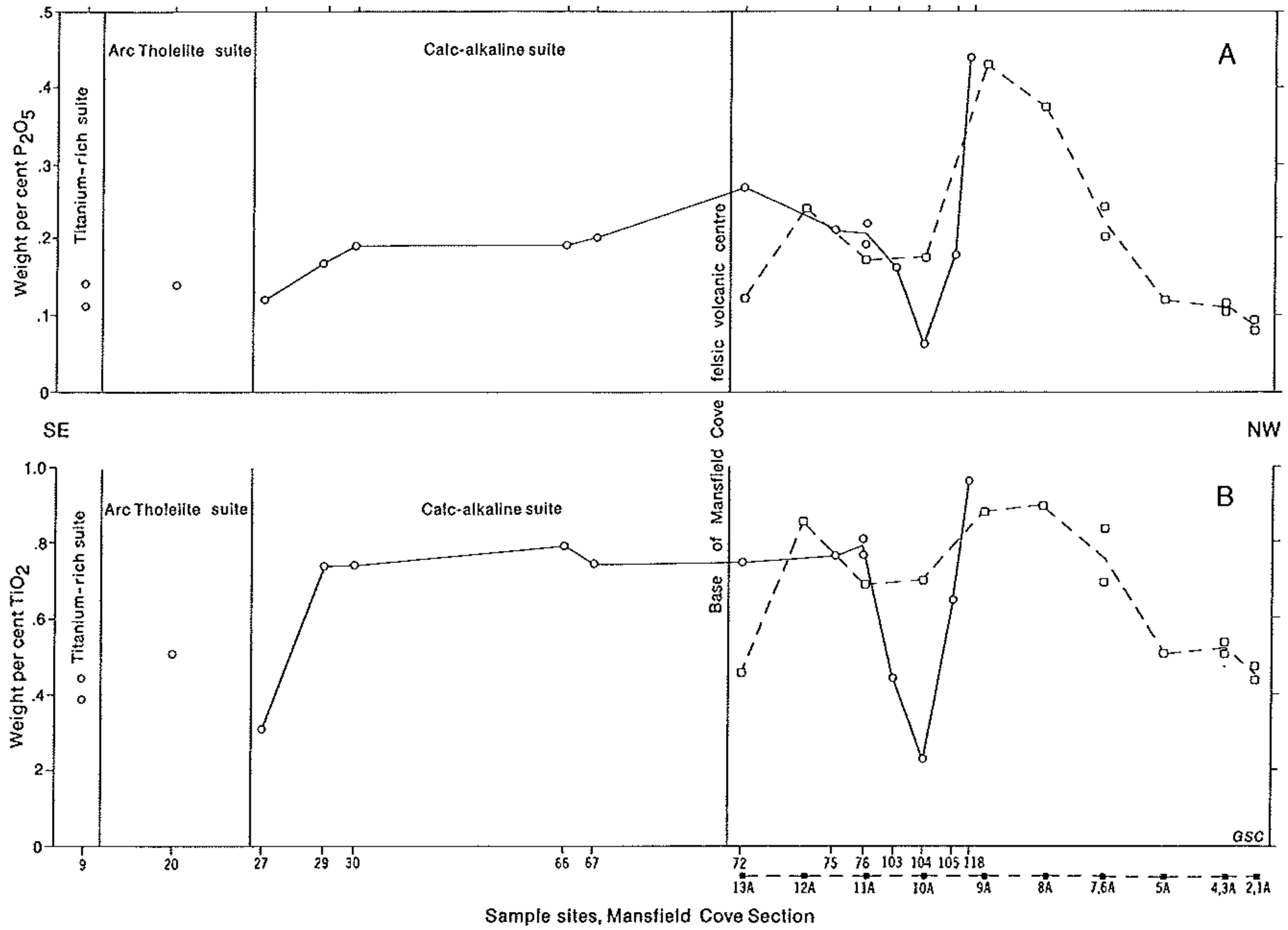

Figure 21. Phosphorus and titanium profiles for felsites from the Mansfield Cove Section and Centre.

The Lobster Cove Fault has been variously interpreted by previous workers as a thrust (MacLean, 1947), or as a transcurrent fault (Espenshade, 1937; Kay, 1969). The most recent interpretation (Dean and Strong, 1977) suggests that the fault is a thrust with movement from the northwest mostly during the Silurian and that it was later folded to attain its present steep dip. The writer regards the fault as likely primarily a transcurrent fault of right lateral displacement the movement along which may be associated with development of northwestward overturned folds in the Roberts Arm Group. Progressive strain initially accomodated by northwestward overturned folding and movements on faults such as the Crescent Lake-Tommy's Arm Fault farther south was, during and after deposition of the Springdale Group, to an increasing degree accomodated by movement on the Lobster Cove Fault. This view, of course, depends upon the precise timing of movements on the Lobster Cove Fault relative to Roberts Arm deformation, a relationship which is at present not well known.

Chemical composition and tectonic setting

The relationship between tectonic setting and composition of modern basic volcanic rocks has been investigated by Pearce and Cann (1973), and has been applied by others to the interpretation of ancient volcanic terranes (Gale and Roberts, 1974; Wilkinson and Cann, 1974; Floyd and Winchester, 1975; Furnes and Faerseth, 1975; and others). These authors have had some degree of success in recognizing ancient basalts from four major tectonic settings: volcanic arc, ocean floor, oceanic island, and continental platform. In particular certain immobile elements: Ti, Zr, Nb, Y, and P have been found to retain their relationships through partial alteration of their host basalts. Although Strong (1977) reported a less than satisfying correlation between the chemical character of some ancient basaltic rocks and their tectonic setting as deduced from regional geology, nevertheless this method appears to have some applicability to the Roberts Arm Group.

Data from basalts of the Robert's Arm area are as yet incomplete but those for TiO_2 and P_2O_5 permit some speculation to be made. The TiO_2 vs. P_2O_5 plot (Fig. 19) clearly discriminates between basalts of the three major fault belts. Basalts of the titanium-rich unit are comparable to those of within-plate basalts (Pearce and Cann, 1973) but inasmuch as they occur well within the central mobile belt of Newfoundland they seem most likely to have evolved in the oceanic island setting rather than on the continental platform. Amygdular flows exist within the titanium-rich unit and these may indeed be associated with a local build-up of basalts on the seafloor, however, it has not been possible with the present data to relate these amygdular basalts clearly to a specific part of the sequence in which they occur.

Basalts of the Roberts Arm Group proper are distinctly lower in TiO_2 than are those of the previous group and they resemble basalts of plate margin origin. The presence of numerous felsic volcanic centres and a probable sialic basement to the west, together with other chemical characteristics (Strong, 1973) suggest that the Roberts Arm Group was formed in an island arc environment. The present data however are not sufficient to eliminate the possibility that the Roberts Arm Group basalts of the southeastern fault belt are ocean floor tholeiites. Indeed, in their low P_2O_5 contents they more closely resemble the Lushs Bight ocean floor tholeiites (Strong, 1973). Scott (1976), however, working on the chemistry of spilitic basalts of the southeast fault belt along the Port Anson road, found these rocks to have high contents of Ni, Cr, Ba and Sr, and low contents of Ti, Zr, and Y. He compared them to tholeiites on the island of Guam in the Marianas arc. Scott's work provides further evidence of the reality of the southeast fault belt and of its evolution in an island arc tholeiite setting.

Regional speculation

The Roberts Arm Group, as described in this report, is exposed in two fault belts that, because of their steep dips, provide two vertical sections through the group. These sections are elongate parallel to the regional volcanic belt of which they form a part, and are therefore probably parallel to the elongation of the original Roberts Arm volcanic pile. In their chemistry the rocks resemble those of modern island arcs in some important respects, those of the southeastern belt being comparable to island arc tholeiites, and those of the northwestern belt to calc alkaline island arc basalts. Beyond these comparisons a stratigraphic correlation involving overlapping of rocks of the northwestern fault belt onto those of the southeastern one can be inferred. From this correlation, two speculations as to the location of the trench and the direction of subduction which gave rise to Roberts Arm volcanism can be made.

The stratigraphic relationship between the fault belt sections is obscured by the Sunday Cove Fault which separates them; however, three observations relating to their correlation can be made: (1) The uppermost (northwest) part of the southeastern belt, stratigraphically above the prominent sedimentary lens, is P_2O_5-rich like rocks in the calc-alkaline belt to the northwest. This indicates that calc-alkaline rocks of the northwest belt are at least partly younger than tholeiitic rocks of the southeast belt. (2) Coarse clastics at the north end of the prominent sedimentary lens contain clasts suggestive of felsic volcanism implying that calc-alkaline volcanism was in progress when the sediments were laid down. This supports the chemical correlation of (1), and together these observations suggest that strike slip movement on the Sunday Cove Fault was not very large. (3) The Sunday Cove granite and its metamorphic aureole (in the northwest belt) are truncated by the Sunday Cove Fault and no similar rocks appear in the southeast belt. Indeed, no rocks above subgreenschist facies have been recognized in this belt. This suggests that rocks southeast of the fault were not much more deeply buried than those to the northwest and that rotation of the belts along axes approximately parallel to their length has been largely responsible for the present structure.

On the basis of these observations it is suggested that the Roberts Arm volcanic pile is exposed in two longitudinal sections, and that these are displaced from one another by several kilometres measured at right angles to the original elongation of the pile. The sections thus show that tholeiitic volcanism largely preceded calc-alkaline volcanism which overlapped it from the northwest.

In modern island arcs (Jakes and Gill, 1970) evolution of island arc tholeiites tends to precede that of calc-alkaline volcanics and the calc-alkaline rocks accumulate on the side of the arc remote from the trench. Tholeiites on the trench side of the arc overlie a zone of shallow focus earthquakes and are separated from the trench by a volcanically inactive zone or arc-trench gap of some 100 to 200 km. It is clear however, that the Roberts Arm Group, and the intervening rocks of the arc-trench gap as well, have been deformed and foreshortened since Roberts Arm volcanism, and that the preserved remnants of the associated trench may be substantially closer at hand. Rocks that may have been deposited in a trench associated with the Roberts Arm Group appear in the Dunnage mélange on the islands and headlands of eastern Notre Dame Bay, or in similar rocks along the eastern margin of the Central Mobile Belt of Newfoundland.

The TiO_2-rich basalts of the oceanic island suite that lie to the southeast of the Roberts Arm Group appear to be slightly more altered and are possibly more deformed than the Roberts Arm Group. In the absence of other evidence it seems most likely that they are older than the Roberts Arm Group and are part of the arc-trench gap assemblage on which the leading edge of the Roberts Arm arc tholeiites was deposited.

The above hypothesis suggests that the Roberts Arm Group evolved during the regime of a westward dipping subduction zone. Subduction-related volcanism in the Robert's Arm area was followed by westward overturning of the Roberts Arm flows and eventually by predominantly right lateral movement along the Lobster Cove Fault and subsidiary faults that splay southwestward from it. Possibly eastward oroclinal bending and buckling of the Roberts Arm Group south of Sunday Cove Island arose from drag along the fault zone. Foreshortening of the Roberts Arm volcanic pile, which accompanied this deformation was associated with uplift and perhaps with a westward migration of volcanism now expressed in Silurian terrestrial volcanics of the Springdale Group. Movement along the Lobster Cove Fault continued after Springdale volcanism eventually bringing ocean floor crust of the Lushs Bight Group into juxtaposition with the Roberts Arm Group.

ECONOMIC GEOLOGY

Sulphide occurrences in the Robert's Arm area have been summarized in Bostock (1975, 1976) and no additional occurrences have been examined since then. Recognition of the chemically distinct nature of the fault belts however permits classification of these occurrences according to the fault block or belt in which they occur.

Mineral occurrences of the northwestern fault belt including massive pyrite-chalcopyrite and pyrite-sphalerite-galena of the Pilley's Island mine area are associated with large felsic volcanic centres. Similar centres are present throughout the fault belt but the one which includes the Pilley's Island mine shows significantly greater alteration and enrichment of felsites in potassium than do the rocks of any of the other centres. This is perhaps discouraging so far as prospecting for volcanogenic ore deposits associated with other felsic centres in the belt is concerned. Altered rocks of the Pilley's Island area to the northeast of the old mine appear to terminate against the Lobster Cove Fault but in the southwest near Spencer's Dock they pass beneath Sunday Cove. The offshore area west of Spencer's Dock thus appears to be a favourable area for prospecting in the northwestern fault belt.

Very few mineral occurrences are known within the southeastern fault belt. Minor disseminated pyrite and chalcopyrite are present in basalt and sediments along the Robert's Arm highway south of Boot Harbour Pond.

In the titanium-rich volcanics base-metal sulphide occurrences have been drilled in the Ghost Pond area but have not yet been examined as part of the present study. These occurrences and sulphide gossans south of Tommy's Arm appear to be associated with small felsite bodies within the basalts.

Quartz-carbonate veins with associated chalcopyrite, sphalerite and galena occur along the northwest margin of the Robert's Arm fault block and at its western end. These occurrences include the old Crescent Lake mine. They may represent remobilization of ore metals originally deposited in association with felsic volcanic rocks and subsequently redeposited along fractures opened as a result of faulting accompanying emplacement of this block.

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