THE GEOLOGY OF THE WESTERN ARM GROUP, GREEN BAY, NEWFOUNDLAND

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by

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ABSTRACT

The Western Arm area is underlain by mafic volcanic rocks of early Ordovician age, comprising the Lush's Bight Group succeeded conformably by the Western Arm Group. The Lush's Bight Group is composed of monotonous altered pillow basalts of great but unknown thickness. The study shows that the alteration, which dies out at the top of the Group, is an early event probably related to inherrent heat in the volcanic pile. The Western Arm Group, defined in this study, consists of a lower tuff formation, a middle pillow basalt formation and an upper formation comprising a lower tuff, and an upper agglomerate member. The tuffs are waterlain and include basic, intermediate and dacitic varieties with interbedded slump-breccias and minor chert and argillite horizons.

Intrusion of gabbroic sills and a small quartz diorite pluton pre-dated a regional deformation. Evidence suggests that the intrusive rocks form a suite genetically related to the volcanism.

A sub-vertical penetrative cleavage is zonally developed in the lower part of the succession but dies out below the middle of the Western Arm Group. A series of sinistral faults are sub-parallel to the cleavage and are believed to have developed during the folding. Folds are on a large scale, and the Western Arm Group is inferred to lie on the south limb of a major ENE-trending syncline. Metamorphism related to the folding was mainly limited to growth of chlorite and fibrous amphibole on the cleavage planes.

Two major dextral wrench faults post-date the folding, and may be related to the Birchy Lake fault and the Cabot fault system.

Comparison with other areas suggests that the Western Arm Group may be correlated with the Cutwell Group and with the Snooks Arm Group.

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INTRODUCTION

Location, Access and Topography

Some 13 square miles in the Western Arm - Southern Arm area of the Green Bay District, western Notre Dame Bay, were mapped on a scale of 1 inch to 1000 feet between mid-July and the end of September, 1969 (Figure 1).

Harrys Harbour in the north of the area is served by an all-weather gravel road and a weekly CN coastal boat service. Access to the south is gained by a jeep track leading to Southern Arm from the community of Beachside, formerly Wild Bight. Most points in the central part of the area can be reached from the three fiord-like Arms with the use of a small boat.

The topography is dominated by a submerged glaciated valley and ridge system upon which both structure and lithology have exerted control. The strong northeasterly grain of the country reflects erosion along chlorite-schist fault zones. A prominant EW to ENE trending ridge about 800 feet high which dominates the central part of the area is the topographic expression of a thick basalt formation. The rugged nature both of the study area and the country to the south contrasts with the generally low-lying undulating terrain found further west, although rock type and structure (exclusive of the Western Arm Group) appear identical. Another peculiarity is the steplike arrangement of "erosion levels" of three fault-bounded blocks between Clam Pond and Blow Me Down Hill. These "erosion levels", most apparent on aerial photographs, become progressively higher southwards and are separated by steep fault-line scarps. There is some evidence (p.16) that an exhumed pre-Springdale Group, or pre-Carboniferous erosion surface displaced by rejuvenated movement on old faults has exerted considerable control on the present topographic configuration, and may account for some of the features noted above. Inland exposure is moderate to good and coastal sections are excellent.

Previous Work

The earliest geological work in this region was that of Murray in 1864 (in Murray and Howley, 1881) who referred the volcanics to the middle division of the "Quebec Group", and first recognized the spatial association of copper mineralization with rocks of this type, both in Newfoundland and throughout Canada. He considered this relationship to be a useful factor in future exploration (op. cit., p. 32; cf. Williams, 1963).

MacLean (1947) mapped the Springdale Peninsula on a scale of 1 inch to 1 mile, and correlated the rocks, dated by him as lower Ordovician, with the Lushs Bight Group (Espenshade, 1937). He described a lower division, the "Little Bay Head Section", consisting of 15,000 feet of pillowed metabasalt, overlain conformably by the "Western Arm Section" totalling 13,000 feet, in which a thick tuff formation and a higher pyroclastic formation were interlayered with two pillow basalt formations (see Table II).

The area was subsequently included in regional studies on a 1 inch to 4 mile scale by Williams (1962) and Neale and Nash (1963). These workers appear to have generally agreed with MacLean, although Neale and Nash inferred that there had been more repetition of beds by tight folding than he recognized. 1 : 50,000 mapping by Neale (in prep.) in the Kings Point area included the western part of the "Western Arm Section" and resulted in some divergence from MacLean's (1947) interpretation. In the block north of Clam Pond, Neale inferred a plunging syncline apparently from air-photo study (this the writer found to result from intersection of NE-trending structural lineaments with E-W trending lithologically controlled trends). Relations within the same block led Neale to believe that there was no valid reason for subdividing the Lushs Bight Group into the two main "Sections".

Papezik (1957) investigated sulphide showings and carried out detailed geological mapping in the Rushy Pond area, and later examined the Norris Prospect (Papezik, 1963). Peters (1970) mapped the Harrys Harbour Section for a B.Sc. thesis at M.U.N.

Present Study

This study was undertaken in order to elucidate the stratigraphy and structure of a part of the Lushs Bight Group in which stratified pyroclastics are known to occur, with a view to applying the knowledge so gained to problems in the economically more important areas of monotonous pillow basalts which constitute the "Little Bay Head Section". Very little is known about the structure and stratigraphy of the "Little Bay Head Section", in which the producing Whalesback copper mine is located, despite much intense study by BRINEX geologists. This is due principally to the lack of identifiable bedding, stratigraphic tops and, most of all, good marker horizons in the basalts.

Acknowledgements

The work was supervised by Dr. M. J. Kennedy who suggested the problem, and to whom special thanks are due for many suggestions and helpful criticisms. Gratitude is expressed to British Newfoundland Exploration Limited for employment as a temporary geologist during the course of field work, and in particular to H. R. Peters for encouragement, discussion, and access to unpublished BRINEX reports. The writer was ably assisted in the field by Ray Coish, Frank Blackwood and Chester Knight. Dr. R. Neville kindly processed a rock specimen in a fruitless search for microfossils. Thanks are also due to Dr. E. R. W. Neale, Dr. H. Williams, Dr. D. F. Strong, Dr. D. A. Bradley, H. Upadhyay and many others for useful discussions of both local and regional problems. Tenure of a Memorial University Fellowship while at M.U.N. is gratefully acknowledged.

CHAPTER II

GENERAL GEOLOGY

Regional Setting

The area lies in the Central Palaeozoic mobile belt of the Newfoundland Appalachians, one of three geological provinces (Figure 1, inset) defined on the basis of distinct Precambrian and early Palaeozoic geological histories (Williams, 1964a). The Central mobile belt is bordered by two north-easterly trending belts of late Precambrian to (?) Cambrian metasediments resting on remobilized gneissic basement (deWit, in prep.), deformed, metamorphosed and intruded by granitic rocks probably in late Cambrian times (Williams et al., 1970). The northwest orthotectonic belt is represented on the Burlington Peninsula by the Fleur de Lys, Pacquet Harbour and Cape St. John Groups which together comprise the Fleur de Lys Supergroup, and also the Burlington Granodiorite (Figure 1; Kennedy and Phillips, in press; Kennedy, in prep.).

The wide paratectonic central zone of the mobile belt is characterized by thick pre-Silurian, mainly Ordovician, mafic volcanic and clastic sequences which contrast sharply with the thin shallow water facies developed on the stable Western and Avalon platforms (Williams, 1969). No continental-type basement to the volcanics in central Newfoundland has been recognized, and Wilson (1966) suggested that these rocks were deposited on a simatic ocean floor. However, related volcanic sequences rest on the marginal metamorphics of the Burlington Peninsula (Baie Verte and Snooks Arm Groups, Figure 1) though recent work suggests that these may, in part (Snooks Arm Group), represent allochthonous sheets of oceanic-type crust (Upadhyay et al., in press).

0 5 10
MILES
Fleur-de-Lys
Baie Verte
WHITE BAY
NOTRE DAME BAY
Cape St. John
Snooks Arm
Betts Cove
Green Bay
Little Bay
Halls Bay
Badger Bay
New Bay
Bay of Exploits
Triton I.
LUKES ARM FAULT
Kings Point
Springdale
Botwood
Newfoundland
WESTERN PLATFORM
CENTRAL MOBILE BELT
AVALON PLATFORM
Lush's Bight terrane
Roberts Arm Gp.
Exploits Gp.
Lush's Bight Gp.
Pyroclastics
Mafic pillow lavas
Fleur de Lys Supergroup

The Ordovician sequence in the Central mobile belt occurs in two structurally distinct areas separated by a major E-W trending structural discontinuity, the Lukes Arm Fault zone (Figure 1, inset; Horne and Helwig, 1969). South of this fault generally younger volcanics including much sedimentary material are represented (Williams, 1964a). North of the fault dominantly volcanic rocks of lower to middle Ordovician age constitute the "Lush's Bight terrane" (Horne and Helwig, 1969). The study area lies in the western part of this terrane.

The Ordovician rocks are affected by the "Taconian orogeny", regarded as a series of mild continued medial to end-Ordovician disturbances (Williams, 1969). Silurian red-beds and volcanics are confined to south of the Lukes Arm Fault in this region, and represent a marked island-wide change in conditions at the end of the Ordovician (Williams, 1967). The main folding, metamorphism and period of granite intrusion, the "Acadian orogeny", is dated as late Devonian (Williams, 1969).

Summary of the Geology

Ordovician volcanics which underlie the area are divided into the "Little Bay Head Section" (MacLean, 1947) composed of monotonous altered pillow lavas of great but unknown thickness, overlain conformably by the Western Arm Group comprised of two thick pyroclastic formations with an intervening formation of fairly fresh pillow basalts (Table I). The tuffs are waterlain and include basic, intermediate and dacitic varieties with interbedded slump-breccias and minor chert and argillite horizons. The Western Arm Group is essentially equivalent to the "Western Arm Section" of MacLean (1947) but the older terminology has been formalized on the basis of redefinition of the constituent lithostratigraphic formations (see Table II). In addition, the term Lushs Bight Group which originally included both major divisions in the area (MacLean, 1947) is restricted in this report to the Little Bay Head Section. The Western Arm Group is dated as lower Ordovician, (?) Arenigian ("Canadian", MacLean, 1947) and occurs in two isolated but correlatable sequences: (a) the "Main Outcrop" south of Western Arm, and (b) the "Harrys Harbour Section" in the north.

Gabbroic sills confined mainly to the stratiform tuffs, and a small quartz-diorite pluton predate a regional, probably Acadian, deformation. Evidence suggests that the intrusive suite forms a differentiated series genetically related to the volcanism.

One phase of regional deformation is represented by a zonally-developed, steep, NE-trending penetrative cleavage which dies out in the upper part of the succession. A series of sinistral chlorite-schist fault zones or "slides" have throws ranging from a few hundred to over 7,000 feet and are parallel to, and genetically related to the regionally developed cleavage. Folds are believed to be on a very large scale. The Main Outcrop strikes E-W, and faces north on cleavage-bedding relationships and evidence of stratigraphic tops; it is inferred to occupy the south limb of an easterly-plunging syncline. The "Harry's Harbour Section" has reached its present position by combined movements on two major dextral wrench faults, of which the Western Arm Fault is the larger

LITHOLOGY	LITHOSTRATIGRAPHIC CLASSIFICATION			AGE
Gabbro, porphyritic diabase; quartz diorite	Gabbro sills; Dolland Quartz Diorite			Early Ordovician (? Late Canadian)
Intrusive Contact				
Massive coarse agglomerate	Upper Member	Pyroclastic Formation (c.3, 600')	Western Arm Group	
Dacitic tuffs and ignimbrites; fine laminated and coarse basic tuffs; chert and minor argillite	Lower Member			
Dark grey pillow basalt	Black Basalt Formation (2,200')			
Basic and intermediate tuffs, fine banded tuff, minor chert and argillite. Coarse slump breccia. One or two basalt flow members near base.	Sedimentary Formation (2,400')			
Grey-black pillow basalt	Black facies	"Little Bay Head Section"	Lushs Bight Group	
UPPER LIMIT OF MAIN ALTERATION				
Pale to dark green altered pillow basalt	Main Facies			
Base Not Seen				

TABLE I: Table of Formations

having a throw of 3 1/2 miles. The wrench faults postdate the regional deformation and appear to have effected rotation of the Harry's Harbour Section to an easterly facing attitude.

Correlation with adjacent areas suggests that the Western Arm Group may be equivalent to the Snooks Arm Group,and to part of the Cutwell Group in the Pilley's Island area.

CHAPTER III

STRATIGRAPHY

The present study has served to clarify and largely confirm the reconnaissance work of MacLean (1947) whose stratigraphic nomenclature has been retained where possible. However, the constitution of the "Western Arm Section" as defined by MacLean has been modified in this report by the exclusion of the "Lower Black Basalt Formation", which is shown below to be part of the Little Bay Head Section, and redefinition of the overlying formations in the light of more detailed knowledge. The term "Western Arm Section" has therefore been abandoned and replaced by the formal designation "Western Arm Group" (Table II).

<table>
<tr><th colspan="2">Present Study</th><th colspan="3">MacLean (1947)</th></tr>
<tr><td colspan="2" rowspan="3">WESTERN ARM GROUP</td><td>Pyroclastic Fm.</td><td rowspan="4">Western Arm Section</td><td rowspan="5">Lush's Bight Group</td></tr>
<tr><td>Up. Black Basalt Fm.</td></tr>
<tr><td>Sedimentary Fm.</td></tr>
<tr><td rowspan="2">LUSH'S BIGHT GROUP</td><td rowspan="2">"LITTLE BAY HEAD SECTION"</td><td>Lr. Black Basalt Fm.</td></tr>
<tr><td colspan="2">Little Bay Head Section</td></tr>
</table>

TABLE II: Relationship of revised stratigraphic terminology to that of MacLean (1947).

Some ambiguity arises with the new terminology as the Western Arm Group has been included up to now in the Lush's Bight Group. The Western Arm Section and Little Bay Head Section were both originally correlated by MacLean (1947) with the Lush's Bight Group, defined in the Pilley's Island area and believed to be underlain by the Cutwell Group (Espenshade, 1937). However, Williams (1962) has shown that the Cutwell Group is younger than the Lush's Bight Group, and the Cutwell Group is probably equivalent in part to the Western Arm Group (see p.53). Therefore, it is proposed that the Western Arm Group be excluded from the Lush's Bight Group with which the Little Bay Head Section above is correlated in this report (Table II).

"Little Bay Head Section" (Lush's Bight Group)

The Little Bay Head Section as described in this report has been expanded to include the "Lower Black Basalt Formation" of MacLean (1947) since the contact between the two map units is a metamorphic, and not a normal stratigraphic one. The two units are both parts of the same sequence of pillow lavas, but the "Little Bay Head Section" type is more altered and paler in colour than the "Lower Black Basalt Formation" of MacLean. The two lithologies are described below as the 'main facies' and the 'black facies' respectively. The informal designation as "Section" is still retained for this extensive area of monotonous, essentially basaltic pillow lavas, since the structure and stratigraphy are still largely unknown.

Main Facies

These altered basalts are largely non-vesicular and occur in a variety of green and grey-green shades with diffuse epidote veining common. The pillows are of two types: (a) a 'cellular' type with no interstices, the pillows evidently having been in a plastic condition and able to mould themselves easily against the underlying shapes; (b) the normal rounded type with concave-triangular or quadrilateral spaces (in cross-section) where three or more pillows touch. These interstices may be filled with spalled-off material or pale green chert.

In thin section the basalt has a microporphyritic texture consisting of small laths of andesine (An_{34}) and subhedral clinopyroxene grains in a groundmass of fibrous amphibole, chlorite, plagioclase microlites (much corroded by the amphibole) and a scattering of sphene granules and minor epidote. Epidote generally occurs in coarser aggregates rimmed with fine granular sphene. Some interstitial pools of quartz and limpid albite are strained and pre-date a cleavage defined by preferred orientation of fibrous amphibole and chlorite and accentuated by sinuous streaks of fine granular sphene. Many of the plagioclase laths are bent. Thin calcite-epidote-quartz veinlets are cut and kinked by the cleavage. At least some of the alteration, therefore, pre-dates the regional deformation.

Two small lenses of broken pillow breccia occur north of the west end of Clam Pond. The fragments consist of rounded and angular blocks of lava, with dark chilled borders, generally about 3 inches across but ranging up to 12 inches in size. Some isolated pillows were seen. The pillow fragments contain laths of plagioclase and clinopyroxene microphenocrysts usually associated in subophitic clots, scattered in a brownish devitrified tachylitic groundmass characterized by indistinct coalesced spherulites with sphene-enriched borders. The matrix of the breccia is a broken-crystal tuff containing much dusty epidotic material with sinuous trails of sphene defining a cleavage which augens around mineral grains and patches of epidote replacement.

Intercalated pyroclastics have only been recognized at two localities: northwest of Clam Pond a two foot-thick chert band overlies pockets of coarse tuff filling in irregularities between pillows, and north of Langdown Cove a 12-15 foot thick fine crystal tuff horizon can be followed for 700 feet along strike. These outcrops accord with the regional strike and dip of the overlying 'black facies' and the Western Arm Group, as do the following primary features:

(a) Flow banding noted locally on the north side of Southern Arm;
(b) Bedding of the pillows (facing north on cleavage) seen in some good cliff sections. Some reliable indications of pillow tops were also obtained.

In general, there is no evidence for a structural or stratigraphic break with the 'black facies' and the Western Arm Group.

Black Facies

The black facies is a dark grey to black basalt with red or green chert common in the interstices. The basalt is dark grey to black in colour and usually magnetic to a variable degree. Individual flows 30 to 50 feet thick with crude columnar jointing are seen in a cliff section north of Clam Pond. 'Tops' from the shape of pillows can in places be reliably obtained when 'bedding' is visible. Two cherty horizons about 20 feet thick have been noted near the east end of Clam Pond.

In places the basalt is fairly fresh and consists chiefly of clinopyroxene and labradorite (An_{64}) showing typical intergranular and subophitic textures with intersertal pools of chlorite. Generally, however, there has been much alteration to chlorite, epidote and uralitic hornblende. The interstitial alteration products marginally corrode plagioclase laths which are zoned, turbid and more sodic -- An_{33} -- than in the fresher rock, reflecting progressive albitisation under the influence of low grade metamorphism. Amoeboidal patches of quartz replace the groundmass and in places poikilitically enclose altered plagioclase laths (Figure 2, a and b). A good cleavage defined by aligned chlorite and fibrous uralite tends to augen around some of the larger grains of epidote, and the quartz blebs are strained and have developed some sutured sub-boundaries. Thus, as in the 'normal facies' the main alteration appears to pre-date the regional deformation. The alteration in the former map unit is mainly to epidote while in the latter chlorite predominates accounting for the colour distinction between the two types.

An irregular area showing patchy red staining concentrated around pillow margins is seen north of Clam Pond and presumably indicates oxidation at some stage. Nearby an outcrop of pillows with concentric "onion skin" structure (Plate IV, Figure b) were noted. This structure may be the product of spheroidal weathering. These features suggest that the present topography at this locality may be close to an exhumed erosion surface, part of that inferred to exist beneath red-beds at King's Point. The red beds are apparently unconformable upon Lush's Bight volcanics (MacLean, 1947; Neale, in prep.) and may be either of Silurian or of Carboniferous age (see p. 46). Some of the geomorphic peculiarities of the area described in Chapter I may be explained by the above interpretation.

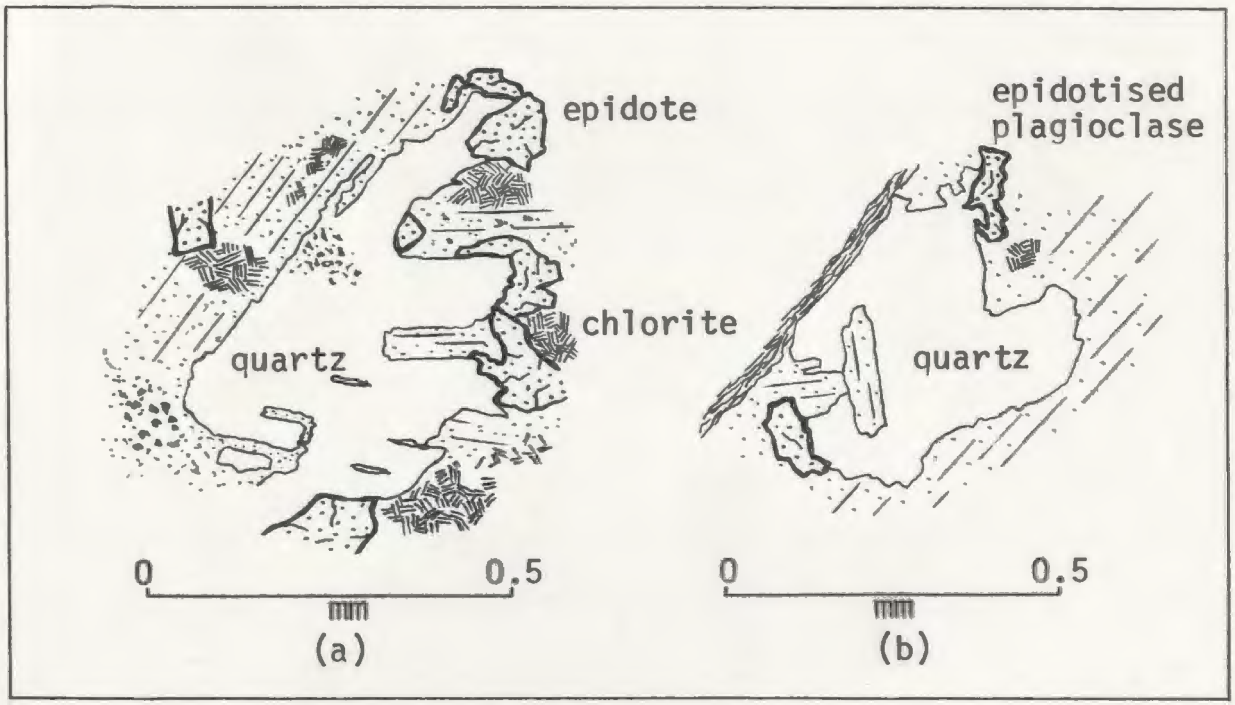

Figure 2: Quartz replacing plagioclase in 'black facies' basalt of the Little Bay Head Section. Enclosure by quartz of two small aligned plagioclase relics in fig. (a) could be explained by 'cut effect'. Aligned chlorite flakes in fig. (b) represent the cleavage. Drawn from thin sections.

Significance of the Main Facies and the Black Facies

Bird and Dewey (1970) have assigned the Lush's Bight Group (presumably that part known as the "Little Bay Head Section") to the Precambrian. MacLean (1947) interpreted the Western Arm Section as conformably overlying the Little Bay Head Section and the present study corroborates this. There appears to be no structural or stratigraphical discordance between the groups. Thus, the Little Bay Head Section must remain assigned to the lower Ordovician, though lower parts of the sequence could be of Cambrian age.

The difference between the greenish hued 'normal facies' of the Little Bay Head Section and the overlying black facies, which is conformable with the Western Arm Group, reflects a general upward decrease in alteration and deformation. The actual contact marks a change from dominant epidotic alteration below to chloritic above. The contact may be either gradational as in the area north of Clam Pond, or sharp as along the north side of Southern Arm. In the former area there is a large lens-shaped transitional zone in which the black facies shows increased epidotic veining and greenish patches of epidotisation from small spots to areas many feet across, thus merging with the 'normal facies' type.

The 'front of epidotic alteration' is irregular and bears no relation to the direction or intensity of cleavage, and is in fact displaced by the sinistral faults which are believed to be related to the cleavage. This agrees with the textural evidence described above which shows that epidotisation predated the regional deformation. It, therefore, appears that the characteristic green colour of the 'normal facies' lavas developed as a result of primary deuteric alteration within the volcanic pile and not as the result of regional metamorphism. In the 'black facies' and Western Arm Group the degree of chloritisation increases directly with increasing deformation and is therefore related to a mineral growth phase which accompanied the deformation.

South of the area mapped, Papezik and Fleming (1967) noted the presence of two lithologies in the Little Bay Head Section: the common green metabasalt or "Whalesback type" in which epidote is prominent, and a subordinate dark greenish grey, more recrystallised rock named the 'St. Patrick's type' characterised by a greater proportion of chlorite. Analyses show the St. Patrick's type to have spilitic affinities. Slight chemical differences were believed to stem from two original lava types, since the mineral assemblages were assumed to have formed under identical conditions of isochemical low Greenschist Facies metamorphism. The writer considers that in view of the probable deuteric origin of the epidotisation it is not necessary to postulate two lava types, and that the 'St. Patrick's type' represents localised zones which escaped the primary alteration.

WESTERN ARM GROUP

A. MAIN OUTCROP

SEDIMENTARY FORMATION (c. 2,400')

Best developed and exposed in the vicinity of the two Skeleton Ponds, this formation is comprised mainly of waterlain basic tuffs and extends for nearly 8 miles along strike to Hennessy Island without significant change. The lower half of the formation consists of two tuff members interlayered with basalt flows and is succeeded by an approximately equivalent thickness of varied tuffs including two prominent slump breccia horizons. Although the tuffs are essentially basic, there is evidence of minor intermediate and acid volcanicity.

Lower Tuff Member (125')

This member is comprised of massive fine to coarse greenish tuff with scattered angular fragments of fine tuff. Bedding surfaces are occasionally marked by abrupt changes in grain size. Thin units up to 2 feet thick of banded and finely laminated pale green chert and silicified fine tuff occur chiefly near the base. These bands often show 'pull-apart' and slump structures and in places have been channeled (Plate V, fig. a). Cross sections of ripple marks were noted at two localities.

In thin sections the tuffs consist of subrounded vitrophyric basalt fragments, broken subhedra of fairly fresh clinopyroxene and slightly turbid plagioclase (An_{34}), irregular patches of chlorite rimmed with epidote and probably replacing tachylyte, many chlorite-filled pumiceous scoria and some fragments of reworked fine tuff. The matrix is composed of altered felspar and pyroxene chips, granular epidote, felted chlorite with interstitial undulose albite and some quartz. A good cleavage is defined by sinuous trails of dark brown amorphous material (epidote and sphene?) augening around mineral grains and fragments. These trails probably represent flattened pumiceous slivers which have taken up most of the flattening (Plate 1, fig. a). The fine-grained tuffs are composed of tiny pyroxene chips and limpid zoned grains of albite in a matrix of felted tremolite-actinolite, epidote chlorite and calcite.

Lower Flow Member (200-400')

This basalt is grey and generally massive or poorly pillowed. Locally a web of siliceous-epidotic veins outline subpolygonal blocks suggesting incipient flow-brecciation.

Middle Tuff Member (150-200')

About 10 feet of banded red cherts crop out locally at the base of the member, but the main part is comprised of fine to coarse grained basic tuff beds 2 to 10 feet thick. The tuffs alternate with banded cherty silicified tuff horizons, green cherts and more rarely black slaty argillite. It was probably from this member that MacLean (1947) obtained a single brachiopod shell, stated to belong to the subfamily Acrothelinae and the genus Discotreta and to be "fairly definitely Canadian, probably Late Canadian" in age. The writer was unable to make any additional fossil finds.

Upper Flow Member (400-500')

The Upper Flow Member is generally well pillowed. Pale green and mottled white chert is common in the interstices and in pockets a few feet across. Crude flow banding and variolites were noted locally.

Upper Tuff Member (c. 1500')

A distinctive slump-breccia unit generally occurs at the base of the member. It is a chaotic rock consisting of angular to subrounded blocks, averaging 10 inches but ranging up to 3 feet in size, composed of varied tuffs and lavas in a tuffaceous matrix. Shreds or rafts of banded tuff and red chert often showing complex slump folding are common (Plate VI, figs. a and b). The volcanic clasts include porphyritic amygdaloidal basalt, some andesitic types with pilotaxitic texture, silicified dacite, fine tuff, jasper and devitrified palagonite fragments now composed of felted fine-grained chlorite. Lenses and tongues of flow-brecciated basalt (Plate V, fig. b) occur in and appear to grade into the slump breccia. In the west, the top of this breccia is marked by a high incidence of red chert blocks and shreds, and it is consistently overlain by a few feet of red cherty argillites. The unit probably originated as a slump breccia or submarine lahar (volcanic mudflow).

The overlying rocks consist chiefly of massive beds of medium-grained green basic crystal lithic tuff 15 to 20 feet thick with intercalations up to 4 feet thick of banded green chert and fine tuff. The tuffs are petrographically similar to those in the Lower Tuff Member. In the west near the middle of the sequence a 15 foot thick silicified dacitic horizon occurs, underlain by slumped fine tuffs. The rock is pale mottled green in colour and in thin section is seen to consist of a cherty microcrystalline quartz mosaic with scattered subrounded quartz phenocrysts showing some secondary enlargement and relic plagioclase replaced by a mosaic of albite. Relic clasts are vaguely outlined by patches of sericite, carbonate and prismatic zoisite overgrown by epidote. The alteration predates the regional deformation as a weak cleavage forms augen around and cuts epidote grains, and in places modifies the texture of the groundmass quartz-mosaic. The overlying tuffs locally contain clasts of black chloritic material rarely up to 4 inches in size which may represent devitrified glassy fragments.

The upper part of the member is poorly exposed but near the top scattered outcrops of a slump breccia resembling the basal unit occur and probably represent one continuous horizon. Banded cherts become more common towards the top, and north of West Pond two units including tuff and minor grey argillite up to 40 feet thick have each been traced for 2000 feet along strike.

BLACK BASALT FORMATION (c. 2,200')

This formation is comprised of monotonous dark grey pillow basalts, and as a whole is almost undeformed. Strikes, dips and 'tops' can occasionally be obtained from the form and attitude of the pillows. The basalt consists of small subhedral augite phenocrysts in a groundmass of plagioclase microlites, subophitic clinopyroxene, small patches of interstitial chlorite (relic intersertal texture) and accessory sphene. Very thin veinlets of prehnite and epidote are common. In a few places the rock is porphyritic containing euhedra of labradorite-bytownite (An_{70}) and augite up to 5 mm in size (Plate 1, fig. b). The basalt is commonly magnetic and can consequently be readily differentiated from the 'normal facies' of the Little Bay Head Section on aeromagnetic maps (G.S.C. Map Nos. 4449G, 1969 and 4450G, 1969).

PYROCLASTIC FORMATION (c. 3,600')

Lower Member (c. 800')

The Lower Member is characterised by acidic tuffs and a number of dacitic horizons, probably ignimbrites. A succession has not been established since the Member consists of many poorly exposed segments preserved between more resistant porphyritic gabbro sills dissected by many faults. The aggregate thickness is probably in the order of 800 feet.

The common lithologies include pale grey-green cherts, acidic crystal tuffs, banded and laminated fine green tuffs with minor grey argillite intercalations (well seen in Middle Arm -- see Plate V, c, in MacLean, 1947) and pale grey dacites and dacitic breccias believed to be ignimbrites. The crystal tuffs consist chiefly of slightly abraded plagioclase euhedra (An_{35}) with their long axes lying parallel to bedding, subangular quartz grains, broken euhedra of hornblende, some of augite and a few small lithic fragments. Minor interstitial material is composed of quartz, chlorite and epidote with some scattered radial aggregates of prehnite. The probable ignimbrites are composed of abraded euhedral plagioclase (An_{34}), deeply embayed bipyrimidal quartz, hornblende and smaller fragments of these minerals with scattered iron ore in a very fine-grained compaction-foliated and banded matrix of felsitic material (Plate II, fig. a). This material contains finely comminuted epidote. Lenticular fragments of similar felsitic material can be distinguished and possibly represent collapsed and devitrified pumice. They tend to be draped or welded around the phenocrysts (Plate II, fig. a). Pale grey silicified breccias composed of similar material with some chunks of tuff included are common in the upper part of the Member; the fragments (averaging 1 cm across) are elongated parallel to bedding in adjacent tuffs. It is not clear whether the primary elongation is due to the original shape of the fragments or has resulted from compaction of pumice; it is not due to tectonic flattening since no related tectonic fabric is seen, and the plane of flattening is parallel to bedding.

Upper Member (c. 2,800')

The Upper Member is comprised of about 2,800 feet of unbedded and remarkably uniform basaltic agglomerate -- a few lenses of tuff up to 40 feet thick occur. The blocks are generally rounded and consist of dark grey green porphyritic basalt containing abundant coarse euhedral pyroxene phenocrysts (Plate II, fig. b) in a matrix of basaltic tuff. Sorting is very poor and the blocks average 3 to 10 inches across but commonly range up to 3 feet across. Some are partly rounded and partly angular, and this has been found to be due to the fragmentation of larger originally rounded blocks. In consequence, the rock often strikingly resembles a broken-pillow breccia (see Plate VII, fig. a). This is unlikely since the fragments lack chilled edges and some blocks show a planar flow texture defined by flattened amygdules striking into and truncated by the margins of the blocks.

The blocks generally consist of euhedral clinopyroxene and some sausseritised plagioclase (An_{58}) phenocrysts in a groundmass of plagioclase microlites, uralite epidote and chlorite, or of brownish microspherulitic devitrified material. Spherical and amoeboidal amygdules filled with chalcedony, chlorite and calcite are common (Plate II, fig. b). The tuff matrix is of fresh crystal and lithic fragments identical to the blocks in composition. In places the matrix is slightly calcareous and the blocks weather out. (Plate VII, fig. a).

West of the Dolland Quartz Diorite a few hundred feet of banded cherty tuffs showing some slumping overlie the agglomerate member and form the uppermost part of the Western Arm Group in the map area.

B. HARRY'S HARBOUR SECTION

On the north side of Western Arm a well exposed section of tuffs, cherts and flows is intruded by many gabbroic sills and extends from Rushy Pond to Green Bay Island. Only the lower (western) half of the succession was mapped. The base of the section is separated by a chlorite schist zone from strongly cleaved green pillowed metabasalts of the Little Bay Head Section. A thin-banded tuff horizon is included in these rocks one hundred feet or so west of the schist zone; the strike is conformable with the tuffs in the Harry's Harbour Section, though the dip is reversed. The same stratigraphic terminology is used for this Section as for the Main Outcrop since a correlation between the two sections can be established (Figure 3).

SEDIMENTARY FORMATION (c. 2,200')

Lower Tuff Member

A basal unit of pyroxene-crystal lapilli tuff is succeeded by a number of massive green tuff beds each 30 to 50 feet thick and intercalated with banded fine tuffs and cherts. The upper part is characterised by a higher proportion of banded tuffs, and includes some crystal-lapilli tuffs near the top.

Flow Member

The basalt is grey in colour and very well pillowed. Greenish or mottled reddish chert is common in the interstices.

Upper Tuff Member

The Upper Tuff Member is comprised of well-bedded medium and fine-grained greenish tuffs with minor cherts and slatey grey argillites. Banding and lamination in the fine-grained varieties is regular and parallel. Slump breccias are common near the base and top of the member, and consist of angular fragments of tuff and occasional red chert averaging 1 inch in size with scattered pieces of banded tuff up to 1 foot across, and larger rafts of banded tuff showing tight slump folds. The fragments are strongly flattened parallel to the cleavage. Silicification is widespread in both the tuffs and breccias, and when extreme, the outlines of fragments become indistinct and the breccias take on a mottled appearance.

BASALT FORMATION (1700')

The basalt is well pillowed and in places porphyritic (cf. Plate I, fig. b). West of the public wharf at Harry's Harbour some very fine examples of pillows with interconnecting necks and buds can be seen (Plate VIII, fig. a). The base of the formation includes a few isolated lenses of jasper. On the west shore of Salmon Cove near the top a lens of jasper measuring at least 40 feet long by 15 feet thick occurs. Three or more thin horizons of tuff,chert and argillite are interbedded with thin flow-banded flows at the top of the formation. A specimen of uncleaved dark grey siliceous argillite from one of these horizons on the west shore of Salmon Cove was processed and examined for HF resistant microfossils by Dr. R. Neville, but none were found.

UPPER PART OF THE SUCCESSION

Only a few hundred feet of the overlying rocks were mapped. A porphyritic gabbro sill has intruded along the upper contact of the Basalt

Formation and is succeeded by 100 feet of breccia and banded tuffs. A brief reconnaissance eastwards revealed a series of sills intruding tuffs with a general N-S strike, overlain by a massive coarse basaltic agglomerate of great but unknown thickness.

C. CORRELATION WITHIN THE WESTERN ARM GROUP

The relationship of the Harry's Harbour section to the main outcrop has, apart from the stratigraphic implications, an important bearing on the structure of the area. There is an obvious general correlation (Figure 3). The main differences are found in the Sedimentary Formation of each succession, viz.:

(a) Presence of only one flow member in the Harry's Harbour section.

(b) The Lower Tuff Member of the Harry's Harbour section is more than twice the aggregate thickness of the two lower tuff members in the 'main outcrop'.

(c) The tuffs in the Harry's Harbour section are finer and more thinly bedded on average than those of the 'main outcrop'.

(d) The slump-breccias in the former area are not as coarse or persistent as in the latter, though in both areas they occur at similar stratigraphic levels.

In addition, the Basalt Formation is considerably thinner in the Harry's Harbour area.

All those discrepancies are, however, mutually compatible, and each in itself suggests that the Harry's Harbour section was deposited further from the centre of volcanic activity and source of detritus than the main outcrop. The writer, therefore, considers that there is good evidence for correlation of the two isolated successions of the Western Arm

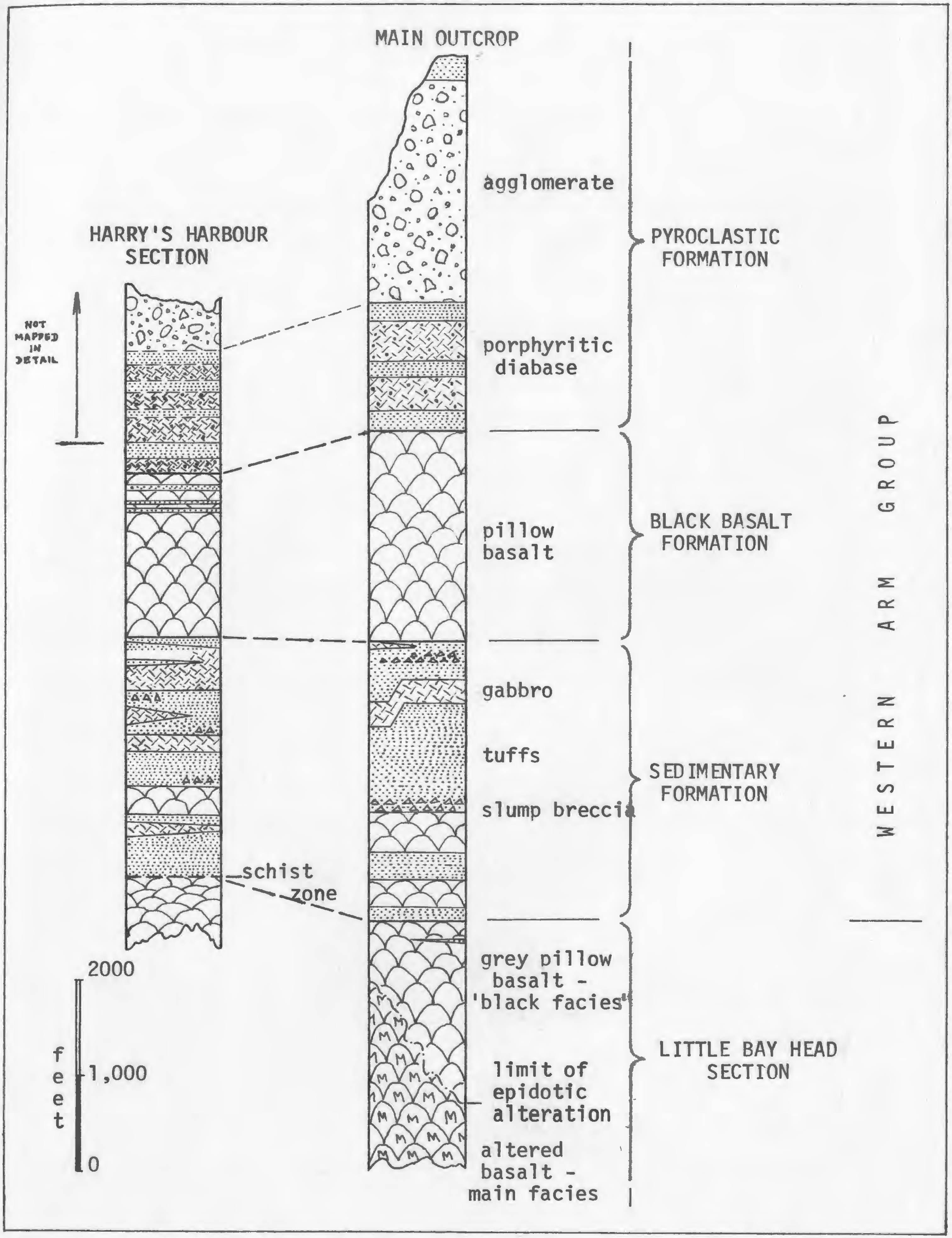

Figure 3: Correlation of the Harry's Harbour section and the main outcrop.

Group. On structural grounds, the Harry's Harbour section was originally to the west of the main outcrop before faulting, and MacLean (1947) observed that on Hennessey Island the lavas appear to have flowed from east to west.

D. DEPOSITIONAL ENVIRONMENT OF THE WESTERN ARM GROUP

Essentially uninterrupted and quiet eruptions of pillow basalt built up the Little Bay Head Section which contains very little clastic material. A deep sea environment is suggested by the work of McBirney (1963) who has shown that explosive submarine eruption of basalt is not possible at depths greater than 500 kms. Furthermore, conditions could have been oceanic since the lavas have the chemical characteristics of tholeiites (Papezik and Fleming, 1967) shown to be the dominant modern oceanic basalt type by Engels et al. (1965) and Melson and van Andel (1968).

The sudden influx of fresh pyroclastic material at the base of the Western Arm Group heralds the initiation of a nearby explosive volcanic source probably of island arc type since andesites and dacites are not found in the present day oceanic suite. The tuffs show evidence of a typical volcanic setting in which periods of quiescence preceded and followed periods of instability (seismicity) and active sedimentation. The fine tuff and chert units have extremely fine and parallel laminations in which cross-lamination is rare, but the lateral and vertical continuity is frequently destroyed by the slump features noted above. Fragments of fine tuff in the coarse massive beds suggest reworking and incorporation of the fine tuffs by such slump activity, and an initial palaeoslope creating instability, probably on the broad submarine flanks of an island arc is implied. Relatively shallow water conditions with periods of emergence are indicated during deposition of the Lower Member of the Pyroclastic Formation by the presence of ignimbrites in the sequence.

It was argued above that the Harry's Harbour section was laid down to the west of the Main Outcrop with evidence for an island-arc system somewhere in the east, and the palaeoslope was therefore presumably westward dipping. The change from coarse slump breccias in the east to finer in the west probably reflects progressive degradation of clasts as slumps moved downslope. Some would presumably have developed into westward-spreading turbidity currents, and it is interesting to note that the Snooks Arm Group, probably equivalent to the Western Arm Group (see Chapter VI) was deposited some miles further west and does in fact include some turbidite-type greywackes. A westerly source of at least part of the Snooks Arm Group is indicated by the presence of Fleur-de-Lys type clasts (Upadhyay, personal communication; Church, 1969), but this does not exclude the possibility of partial derivation from the east.

CHAPTER IV

INTRUSIVE IGNEOUS ROCKS

GABBRO AND PORPHYRITIC DIABASE

Many gabbroic sills up to 450 feet thick intrude the more accommodating stratified tuffs of the area, and together represent an important volume of rock. The sills show a textural variation from fine to coarse and porphyritic to non-porphyritic. The gradation is often seen within a single sill and usually takes place over about 100 feet. There is also a petrographic variation from types with orthopyroxene, rare olivine, clinopyroxene and calcic plagioclase, to coarser one-pyroxene, quartz-bearing types with more sodic plagioclase. Lenses and patches of coarse or pegmatitic rock with gradational contacts, and composed of interlocking long prismatic pyroxene and plagioclase crystals, in places occur in a massive fine or medium-grained host. Porphyritic diabase with zoned labradorite-bytownite euhedra are commonest in the Lower Member of the Pyroclastic Formation and pass locally from porphyries into non-porphyritic gabbro. Flow banding has been noted in the sills at a few places but is not common.

The two-pyroxene gabbro is composed of prismatic plagioclase ranging up to An_{72}, orthopyroxene grains often partly enclosed by larger subophitic grains of augite, and rare anhedra of olivine rimmed with granular opaque oxides and orthopyroxene. Alteration is generally slight, with minor uralitisation of pyroxene. The coarser gabbros are texturally distinct from the two-pyroxene types. The augite occurs as long prisms intergrown with slightly sausseritised plagioclase euhedra which have clear rims of albite, and subophitic texture is not well developed. Prominent opaque oxide is intergrown with the pyroxene in skeletal forms, and quartz occupies interstices between augite and plagioclase (Plate III, fig. a). Minor constituents include accessory apatite and secondary acicular zoisite. One thin section shows radial sheaves of stilpnomelane nucleated along grain boundaries and fractures.

The euhedral plagioclase phenocrysts (av. 44 mm) in the porphyritic diabases range up to An_{72} and are strongly zoned. The groundmass consists of medium-grained intergrown subhedral augite and plagioclase, and contrasting patches of fine-grained felted plagioclase laths, uralite, epidote, chlorite and rare aggregates of prehnite.

The sills are locally weakly cleaved and hence predate the regional deformation. The following features suggest that intrusion took place shortly after deposition of the enclosing volcanics.

(a) Calcite-filled vugs near the top of one sill have flat bases which are parallel to the contacts of the sill (Fig. 4a). The vugs show that the sill and hence the enclosing tuffs were horizontal at the time of intrusion.

(b) Some xenoliths of tuff have wispy swirled outlines, others are gently buckled tabular portions of discrete beds (Fig. 4b). Both types suggest that the tuff was in a soft unconsolidated condition when incorporated.

(c) The basal contact of one sill east of Nickeys Nose Cove has an irregular lobed form which suggests load-casting into unconsolidated tuffs beneath.

(d) Fragments of diorite and gabbro incorporated in agglomerate of the Pyroclastic Formation lithologically resemble, and may be related to the intrusions in the Western Arm Group.

It follows that the gabbro sills were probably contemporaneous with the volcanism, and may represent offshoots of feeder dykes and plugs.

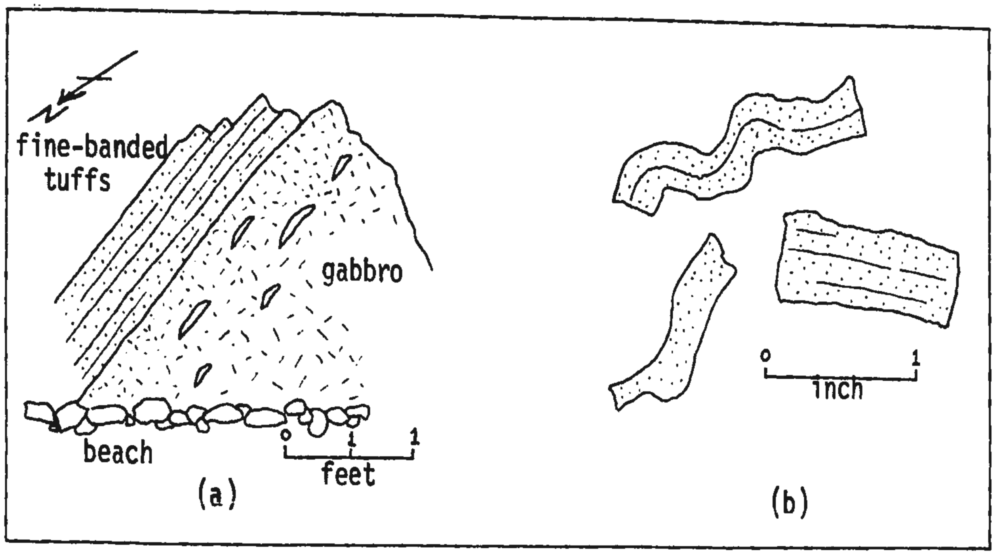

Figure 4: (a) Calcite-filled vugs aligned parallel to the upper contact of a gabbroic sill. Note the flat bases and convex tops of the vugs. Field sketch. Locality: shore, 1000 feet E of Nickey's Nose Cove.

(b) Tabular xenoliths of fine-grained tuff in gabbro sill. Field sketch. Locality: south shore of Harry's Harbour.

THE DOLLAND QUARTZ DIORITE

A small quartz diorite pluton, previously named the "Dolland Arm Head Quartz Diorite" (MacLean, 1947), intrudes agglomerates and tuffs of the Pyroclastic Formation on the south shore of Western Arm. The southern contact is discordant and may be faulted since there is shattering of the Pyroclastic Formation close to the inferred position of the contact. The dominant lithology is an even grained mesocratic to leucocratic quartz diorite but gabbro and dacite are locally represented. Striking features of the intrusion are autobreccias, primary flow fabrics and primary jointing. Xenoliths of tuff and diorite and contemporaneously intruded basic dykes also occur.

Petrography

The quartz diorite is composed of interlocking euhedral-subhedral sausseritised plagioclase prisms (An_{32-36}) with interstitial quartz (15%) and xenoblastic patches of hornblende moulded against the plagioclase (Plate III, fig. b). The hornblende in places poikilitically encloses quartz blebs and is often partly or completely chloritised. Occasional biotite, associated with opaque oxides is also almost completely chloritised. Minor prehnite is interleaved with the chlorite along cleavage planes and also occurs in a few thin veinlets. The chlorite also includes patches of sagenite associated with iron ore.

Near the southern contact of the body the quartz diorite grades into a megascopically similar, though more mesocratic gabbroic type (colour index 50), containing clinopyroxene mantled with hornblende and uralite, calcic plagioclase (An_{60}) and very minor quartz. Late stage interstitial biotite associated with opaque oxides is more common than in the quartz diorite. A banding spaces at 5-10 mm intervals and defined by trains of hornblende and minor quartz was seen in one outcrop. The hornblende poikilitically encloses flow-oriented plagioclase microlites which are identical to randomly oriented microlites in the gabbro between the bands. The restriction of flow-oriented microlites to within the hornblende suggests that the hornblende was late-magmatic, crystallised from a residual hydrous liquid. The localisation of the residual liquid along discrete parallel planes may have been induced by incipient cooling joints, since the banding is parallel to a well-developed set of primary joints described below.

The quartz diorite appears to grade into a local pale grey strongly flow-banded dacite in the northeast part of the intrusion (Plate IX, fig. b).

The dacite consists of euhedral zoned plagioclase phenocrysts, partly replaced by calcite and chlorite, with some rounded quartz phenocrysts in a fine-grained felsitic groundmass containing chlorite, sericite and fibrous hornblende. The zoned plagioclase phenocrysts vary from An_{70} in the cores to An_{50} near the margins, and many are veined with albite.

Autobreccias

The autobreccias are best exposed along the northern sector of the shore section. Two types are distinguished chiefly on the basis of their contact relations. The "Type I" breccias have gradational contacts with the quartz diorite and consist of blocks of diorite, pyroxenite and fine-grained basic volcanics, floating in a matrix of leucocratic diorite. The fragments are angular with some rounding at corners, and show "edgewise" relationships (Plate VIII, fig. b). Some of the fragments are partly or almost completely assimilated, remaining as ghost-like relics. "Type II" is distinguished by its occurrence as dykes having sharp contacts with the country rock, by a higher degree of angularity and less assimilation of the fragments, and by a lighter-coloured matrix than shown by "Type I".

The diorite breccias are believed to result from the collection of late-stage fluids in dilated fractures which intersected wall rocks and deeper levels of the intrusion. Considerable mobility of the residual fluids is indicated by the assemblage of xenoliths, and this mobility may have been caused by closure of the original fractures by subsequent compression, resulting in forceful intrusion to higher levels. The "Type I" breccias may have been formed when the diorite was a crystal mush, as suggested by the gradational contacts and resorbed xenoliths, and the "Type II" at a later stage (cf. Sutton, 1970).

Primary flow fabrics and jointing

Flow banding has been noted at many widely scattered localities. It consists of wispy leucocratic bands up to 1 inch thick in a uniform dioritic host (Plate IX, fig. a), or alternating mafic and leucocratic bands 1/4 to 1/2 inch thick. Northwest of Dolland Arm Head the dacitic facies shows regular banding and complex flow folding (Plate IX, fig. b). The flow banding has a roughly uniform orientation, striking oblique to the southern contact of the intrusion. A mineral flow-fabric with a similar orientation was noted at one locality.

A prominent set of joints has a similar but more regular attitude than the flow banding, and can be traced from north to south across the intrusion. In addition, one outcrop shows regular banding alternating with parallel joints. These features, together with the relationship of the joints to basic intrusions described below, suggest that the joints are primary; they are probably related to cooling of the intrusion.

Contemporaneous basic intrusions

Three diabase intrusions are seen in the shore section. One is irregular in form and contains euhedral pyroxene phenocrysts up to 3/4 inch across, with a few scattered pink felspar phenocrysts. It shows a streaky flow fabric partly defined by small strongly flattened calcitic amygdules. The dyke is chilled against the diorite, but the contact is very irregular with tongues and offshoots penetrating the diorite, and in places it intermingles intimately with the latter. Their contact relations suggest that intrusion took place before the diorite was entirely solidified. The other two intrusions are tabular bodies about 5 feet thick, and show similar contacts suggesting intrusion into a crystal mush. They appear to have been injected along the planes of the joint set described above, and have a strong flow fabric parallel to the contacts and joints. The core of each dyke is vesicular and is chilled against an outer non-vesicular part with two trains of stringy diorite xenoliths along the contacts with the inner zone. Intrusion in two pulses is suggested.

Xenoliths

Two types of xenoliths occur. Near the western end of the intrusion an outcrop is crowded with fine-grained basic stringy xenoliths with 'doughy' outlines; the xenoliths appear to have been in a plastic condition when incorporated. They could possibly represent inclusions of hornfelsed tuff. Occasional rounded xenoliths of coarse mafic to dioritic rock averaging 4 inches in size are more widespread, and may represent more completely assimilated material.

Age of the intrusion

The Pyroclastic Formation adjacent to the intrusion is uncleaved but is cut by occasional shear joints believed to have developed during the regional deformation; these also occur in the quartz diorite which, therefore, probably predates the folding. The variation from gabbro to diorite, and close lithological similarity of the Dolland Quartz Diorite to parts of the thick gabbro sills suggest that it is part of the same suite, and may thus be comagmatic with the lavas of the Western Arm Group.

The diorite fragments in the Pyroclastic Formation are lithologically identical to parts of this intrusion as well as to parts of the sills. The possible tuff xenoliths described above suggest that the country rock may have included some unconsolidated tuffs at the time of intrusion.

MINOR SILLS AND DYKES

Diabase

Dykes and sills of fresh dark grey or slightly altered greenish diabase generally less than 6 feet thick are widespread. They predate the regional deformation and are probably related to the volcanism. The fresh varieties contain plagioclase around An_{62}, but greenish dykes in the Little Bay Head Section contain much secondary epidote and chlorite and the plagioclase has a composition of about An_{31}, reflecting the influence of low grade metamorphism. Porphyritic types with slightly uralitised pyroxene euhedra up to 4 mm across are common around Western Arm.

Diatreme

On the northeast side of Salmon Cove a dyke 2 1/2 feet thick contains rounded or subhedral megacrysts of green pyroxene up to 2 inches in size, and rounded fragments of diorite up to 4 inches across in a grey tremolitic matrix. It is evidently a fluidised type of intrusion with lamprophyric affinities.

PETROGENESIS OF THE EXTRUSIVE AND INTRUSIVE IGNEOUS ROCKS

The change which took place near the base of the Western Arm Group from quiet, possibly oceanic, eruption of tholeiitic lavas to an alternation of tholeiitic and explosive andesite-dacite activity has been noted above. This change appears to mark the establishment of an island-arc system.

Field evidence for a comagmatic relationship between the various gabbro and quartz diorite intrusions and the volcanics of the Western Arm Group has been given. Similarly associated intrusives and lavas in the Snooks Arm Group are reported to be genetically related (Neale, 1957). The area thus appears to show a good example of differentiation of a basaltic magma from gabbro to diorite to dacite in the Dolland Quartz Diorite, and from basalt to (?) andesite to dacite in the pyroclastics. If, as suggested, this intrusive-extrusive suite is the product of an island arc environment, the rocks should have calc-alkaline affinities. No chemical data are available from the Western Arm Group, but the Colchester Pluton further west (see Figure 6), to which the Dolland Quartz Diorite is probably related (Sayeed, 1970; writer's observations), is reported by Sayeed (1970) to be calc-alkaline.

CHAPTER V

STRUCTURE

The earliest post depositional activity is represented by the prominent alteration in the Little Bay Head Section lavas and was not apparently associated with any structural event. One subsequent phase of inhomogeneous deformation with an associated penetrative cleavage is recognised. A series of faults parallel to the cleavage and having large apparently sinistral wrench displacements are believed to be slide zones related to this deformation. Related metamorphism was restricted to growth of fine chlorite and fibrous hornblende defining the cleavage, an L-S ($S > L$) fabric. Two large dextral wrench faults postdate the penetrative deformation, and a set of sinistral kink bands may have a second-order relationship to one or other, or both, of these faults.

MAIN DEFORMATION

Minor Structures

Fabric

A penetrative cleavage is zonally developed in the Little Bay Head Section and, to a lesser degree, in the Sedimentary Formation, but dies out in the upper part of the succession. In the Little Bay Head Section a fine phyllitic schistosity augens prominently around flattened pillows and is best developed at pillow margins. Inhomogeneous deformation is reflected in belts about 200 feet wide of weakly deformed rock flanked by zones of penetratively cleaved, strongly flattened pillow basalt which may pass locally into narrow chlorite schist zones. Some translation may have taken place across these minor zones by analogy with the slide zones described below. In the Sedimentary Formation the cleavage may be refracted by as much as 50° in passing from argillite to fine-grained tuff, and the sense of refraction suggests a large scale cleavage fan diverging upwards away from the core of a major syncline.

The cleavage is seen in thin section to be defined by fine-grained chlorite and fibrous tremolite-actinolite (see Plate I, fig. a). In hand specimen an extremely fine lineation lying in the S planes can occasionally be seen, and probably reflects a preferred orientation of the hornblende fibres. The fabric thus appears to be an L-S (S> L) fabric (Flinn, 1965). Reliable "strain gauges" are usually lacking but in some coastal outcrops the pillows are seen to be moderately to strongly elongated in the plane of cleavage. The strain, therefore, probably has a k value (Flinn, 1962) of about 1, i.e. it approximates to plane strain. The few readings obtained on mineral lineation and pillow elongation plunge steeply westwards, at about 90° to cleavage/bedding intersections, and fold axes therefore probably lie close to the Y strain axis (Figure 5,a).

Minor folds

Minor folds are rare even in structurally inhomogeneous interbedded argillite and tuff; this may be due to the controlling influence of the thick competent piles of lava coupled with the inferred position of the succession on the limb of a major fold. East of Nickey's Nose Cove some 3-inch thick tuff bands show fairly open asymetrical small scale folds with some thickening in the hinges (Figure 5, b). On the south shore of Harry's Harbour a fairly broad open fold has somewhat tighter minor folds developed in the hinge zone.

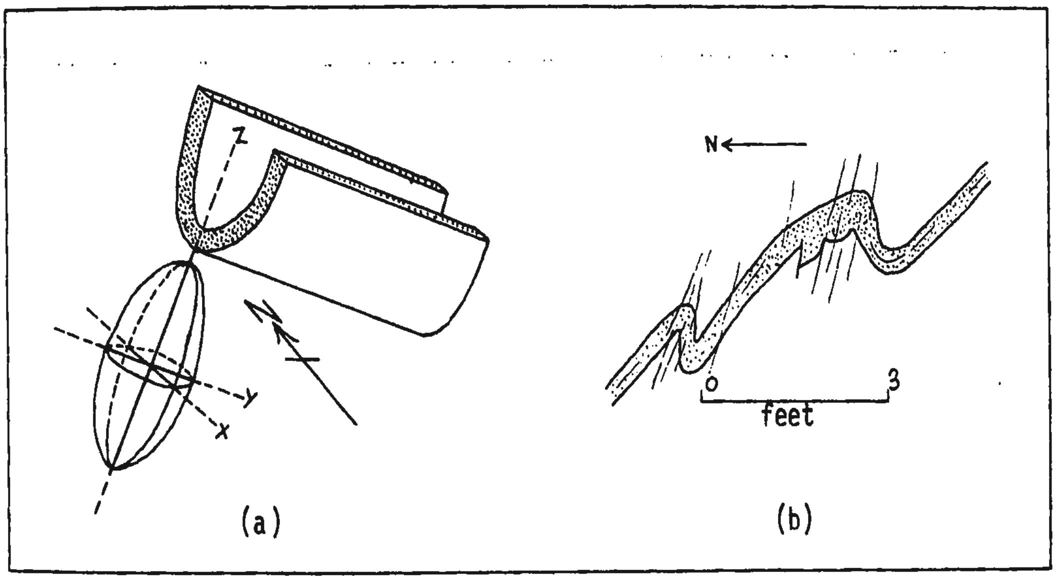

Figure 5: (a) Probable relationship between the deformation ellipsoid and folds in the Western Arm area. (b) Profile of minor folds in banded tuffs. Shore section, 1200 feet east of Nickey's Nose Cove.

Pre-consolidation slump folds are, however, common and may be distinguished from tectonic folds by means of several criteria: (a) the cleavage is generally non axial-planar, (b) they are chaotic with widely divergent fold axes, (c) association with undoubted slump breccias and soft sediment features (e.g. Plate VI, fig. a). Many slump folds have probably undergone some degree of tectonic tightening.

Major Structures

Folds

The 'main outcrop' of the Western Arm Group has a gently arcuate strike and dips N to NW at about 60°; the sequence also faces north with no duplication by folding shown by sedimentary 'tops' and consistent cleavage/bedding relationships. Cleavage/bedding intersections indicate that major folds plunge moderately NE (35°), and the angular relationships suggest that the succession is on the south flank of a moderately tight syncline, the wavelength of which must be in the order of at least 8 miles.

The Harry's Harbour Section is eastward facing and has been rotated to a NNW strike by wrench faulting, since the cleavage bears the same angular relationship to bedding as in the main outcrop.

Faults or slides

A series of NE trending faults with apparent sinistral displacements cut the main outcrop and are expressed as prominent lineaments. The largest, the Middle Arm fault, has a horizontal component of about 8000 feet and can be extrapolated for many miles south-westwards on aerial photos. The faults appear to be genetically related to the regionally developed cleavage which is parallel to them and which intensifies as the chlorite-schist fault zones are approached. They are, therefore, interpreted as slides (Bailey, 1910) related to the folding. Whereas the cleavage generally dies out below the Basalt Formation, the associated faults penetrate to higher stratigraphic levels, and some appear to terminate in the Pyroclastic Formation by means of compensation on many small scale faults, mainly in the Lower Member. For example, on the north shore of Middle Arm, 18 microfaults having an aggregate displacement of 12 inches were measured within a 6-foot length of strike.

The rusty schist zone at the base of the Harry's Harbour Section is a slide, and cuts across the Sedimentary Formation with the same sense of vergance as the cleavage.

The mechanism of sliding is not clear. The regionally penetrative fabric is developed in the plane of flattening, as shown by its relationship to flattened pillows, and the more schisty zones including the slides therefore represent belts of local intense flattening. But flattening alone, even if extreme, could not explain the very large apparent displacements observed, and some shearing must have occurred. It was inferred above that a large scale cleavage fan may be developed in the major fold, implying a systematic and symmetrical variation in local strain axes across the fold profile, due probably to an element of buckling in the deformation. Assuming regionally directed stresses perpendicular to the axial planes of major folds, local zones of intense flattening (schist zones) on the limbs related to rotated stress axes may have been close enough to the planes of maximum shearing stress related to the regional stress system for shearing to have taken place along them. The shearing would have occurred after much of the folding was accomplished, and splays to the main slide zones might be expected to locally transgress the cleavage. This interpretation is compatible with the observed sense of displacement across the slides in the Western Arm Group.

WRENCH FAULTING

Dominant strike-slip movements are assumed for the faults described below on account of their large horizontal components, straightness and lateral continuity. It is probable that both faults are related to development of the Green Bay Fault, referred to below (see Figure 4) which is inferred to have a dextral throw of about 14 miles. Warping of the cleavage in the Nickey's Nose Section (Peters, 1970) and in the Colchester Area (Sayeed, 1970) may be related to the wrench faulting.

South West Brook Fault

This fault truncates the main outcrop of the Western Arm Group and extends to the bottom of Western Arm as a prominent valley (MacLean, 1947), where on its west side MacLean's map indicates north-facing black basalts and pyroclastics which may represent the base of the Sedimentary Formation. A dextral throw in the order of 6000 feet may be tentatively inferred.

Western Arm Fault

The rotation of cleavage and bedding in the Harry's Harbour Section, which has the same sense of vergence as the main outcrop, suggests a dextral sense of movement to the Western Arm Fault. This apparent rotation is probably part of a warp comparable to that in the Nickey's Nose Section (Peters, 1970), since the strike appears to swing into an E-W trend in the southwest. If the pyroclastics west of the South Brook Fault are part of the Western Arm Group, then a throw of approximately 3 1/2 miles can be inferred. The Western Arm Fault extends westwards to Brown's Pond and beyond (MacLean, 1947; Sayeed, 1970); a wide chlorite-schist fault zone is exposed in places, and has also been intersected in diamond drill holes by Brinex.

Kink Bands

Relatively rare vertically dipping sinistral kink bands striking NW are developed in cleaved parts of the main outcrop, and may bear a second order relationship to the dextral wrench faults. The kink bands locally develop into an incipient strain slip cleavage in the chlorite schist slide zones.

Age of the Deformations

On the basis of previous work in the Green Bay District it would appear that the main folding in the Lush's Bight Group took place in middle or late Ordovician times, since near King's Point gently folded red beds, which have been included in the probably Silurian Springdale Group, overlie unconformably steeply dipping and cleaved Lush's Bight basalts (MacLean, 1947; Neale and Nash, 1963).

This conclusion, however, does not agree with the bulk of the evidence from the Central Mobile Belt, which shows no great structural break between Ordovician and Silurian rocks, but rather a mild Silurian transgression with a continuous record of deposition from the medial Ordovician to early Silurian times in the New Bay area (Williams, 1969). Moreover, no Silurian rocks are known elsewhere in Lush's Bight terrane north of the Lukes Arm Fault zone (Horne and Helwig, 1969) where generally older rocks and deeper structural levels appear to be exposed (see p. 7). The main basis for correlation of the King's Point red beds with the Springdale Group appears to be some palaeomagnetic evidence (Neale, in prep.), but H. R. Peters (personal communication) believes them to be of Carboniferous age (cf. Neale et al., 1960) since they are distinctly less indurated than Springdale Group lithologies and contain unidentified plant remains. The writer prefers the latter interpretation which would allow a post-Silurian, probably Devonian age for the strong deformation in the Lush's Bight Group in conformity with the evidence from elsewhere (e.g. Williams, 1969). The more open fold style and lack of penetrative cleavage in the Springdale Group is readily explained in terms of these rocks occupying a higher structural level, particularly as a comparable decrease in intensity of deformation up the succession has been demonstrated above within the Western Arm Group.

There is no direct evidence bearing on the age of the wrench faulting in the Western Arm area, but as these faults are probably related to the Birchy Lake - South West Arm (Green Bay) fault (Neale and Nash, 1963), in turn related to the Cabot Fault system (Webb, 1969), a late Acadian age with movement continued in post-Carboniferous time can be tentatively inferred. Limited rejuvenation of the earlier slides may have occurred during the wrench faulting, as MacLean reported drag folding of the schistosity in the slide zones. It was tentatively inferred above that a pre-King's Point red beds (Carboniferous ?) erosion surface may have been block faulted along the old fault lines.

METAMORPHISM

Two stages of metamorphism have been recognized. The earlier was responsible for prominent, mainly epidotic, alteration in the Little Bay Head Section rocks, predated the regional deformation and may have been a deuteric phenomenon. The later event was related to the deformation and resulted in definition of a fabric by limited, mainly chloritic, mineral growth. The principal effects of each event die out in the lower part of the Western Arm Group.

It has not been possible to adequately define each event. It is known that the earlier event resulted in growth of epidote and some silicification in the groundmass (Figure 2, a and b), and the later in growth of fine chlorite and fibrous amphibole, but the extent of other mineral transformations on each occasion is obscure. For example, it is not clear whether the progressive albitisation of the plagioclase is related to one or other or both of the events. Little can be said except that mineral parageneses are typical of low Greenschist Facies metamorphism.

CHAPTER VI

REGIONAL SIGNIFICANCE OF THE WESTERN ARM AREA

Stratigraphic Correlation

No direct correlation of the Western Arm Group is possible since no continuity of outcrop exists with rocks of apparently similar age and facies. Furthermore, very little is known about the stratigraphy of possible equivalents of the Group which occur in three structurally distinct domains:

(a) Burlington Peninsula
(b) South of the Lukes Arm Fault
(c) Lush's Bight terrane.

Burlington Peninsula

The unfossiliferous Baie Verte Group (Fig. 1) is lithologically similar to the Lush's Bight Group and has been assigned to the Ordovician by most workers (see Neale and Nash 1963,and references), though some structural evidence favoured a Silurian age (Neale and Kennedy 1967). Recent work tends to uphold the earlier interpretation (Kennedy and Phillips, in press).

The Snooks Arm Group (Fig. 1) dated as early Ordovician, occupies the northern limb of an easterly plunging syncline and consists of two greywacke, chert and argillite formations interlayered with three pillow lava formations (Neale 1957, 1958). The succession is structurally underlain by a screen of ultrabasic rock with an intervening sheeted dyke complex at Bett's Cove (Upadhyay et al., in press). The two sedimentary formations in the Snooks Arm Group contain turbidites and are apparently very similar to one another, in contrast to those in the Western Arm Group, though thicknesses are comparable. The differences may be accounted for satisfactorily by a facies change (see p. 30). In addition to the probable equivalence in age of the two Groups, there is a good structural basis for correlation. The outcrops of the two Groups are of closely comparable size and if fitted together fall neatly on opposing limbs of a major syncline. This fit can be achieved by assuming a dextral lateral throw of about 14 miles on the continuation of a very large fault extending from Birchy Lake to South West Arm (Neale and Nash, 1963) along which ultrabasics are reported from geophysical evidence (H.R. Peters, personal communication). Upadhyay et al. (in press) suggest that the succession exposed at Bett's Cove represents a cross-section of overthrust oceanic crust. If the correlation of the Western Arm Group with the Snooks Arm Group is valid, then it would appear that the great thickness of Little Bay Head Section basalts is represented by the relatively thin sequence consisting of ultrabasics, sheeted dyke complex and overlying pillow lavas at Bett's Cove. There must have been either excessive thinning of the oceanic crust westwards, or else a considerable thickness of pillow lavas has been cut out by faulting at Bett's Cove.

South of the Lukes Arm Fault

South of the Lobster Cove - Lukes Arm Fault systems (Fig. 6; referred to here as simply the 'Lukes Arm Fault'), the lowest division in the Exploits Group (formerly in this area the 'Badger Bay Series' of Espenshade, 1937) is the "Wild Bight volcanics" which conformably underlies rocks of Middle Ordovician age in the New Bay area (Williams, 1962; 1964b). The 'Wild Bight volcanics' may thus be equivalent in age to the Western Arm Group, and are of similar facies consisting chiefly of green agglomerate, tuff, green lava and chert (Williams, op. cit.). No thick pillow lava sequence comparable to the Little Bay Head Section is reported south of the Lukes Arm Fault. However, there is no evidence for a facies change across the fault since the oldest rocks known on the south side, the 'Wild Bight volcanics' appear to be somewhat younger than the Little Bay Head Section. The regional distribution of Ordovician and Silurian rocks about the Lukes Arm Fault strongly suggests a major component of downthrow to the south, though dextral wrench movements along the fault are generally postulated (Webb, 1969), often on tenuous evidence.

Fault bounded volcanics around Catchers Pond, near Springdale, lie south of the Lobster Cove Fault and include trilobites previously reported as Silurian in age (Neale and Nash, 1963), but recently redated as definitely of Lower Ordovician, and probably of Lower Arenig age (Dean, 1970). The volcanics vary from basalt to rhyolite in composition and have no known similarity with rocks in the Western Arm area.

Lush's Bight terrane

The Lush's Bight Group from Green Bay to Triton Island is bordered on the seaward side by a prominent belt of dominantly pyroclastic rocks having an apparent structural unity (Fig. 6). The following discussion suggests that this belt may prove with future work to form a distinct stratigraphic division overlying the Lush's Bight Group and correlatable in part with the Western Arm Group.

Rocks on Red Island Peninsula and Halls Bay Head (Fig. 4) were correlated by MacLean (1947) with the Western Arm Group, and subsequent work by Donohoe (1968) on Halls Bay Head tends to substantiate this.

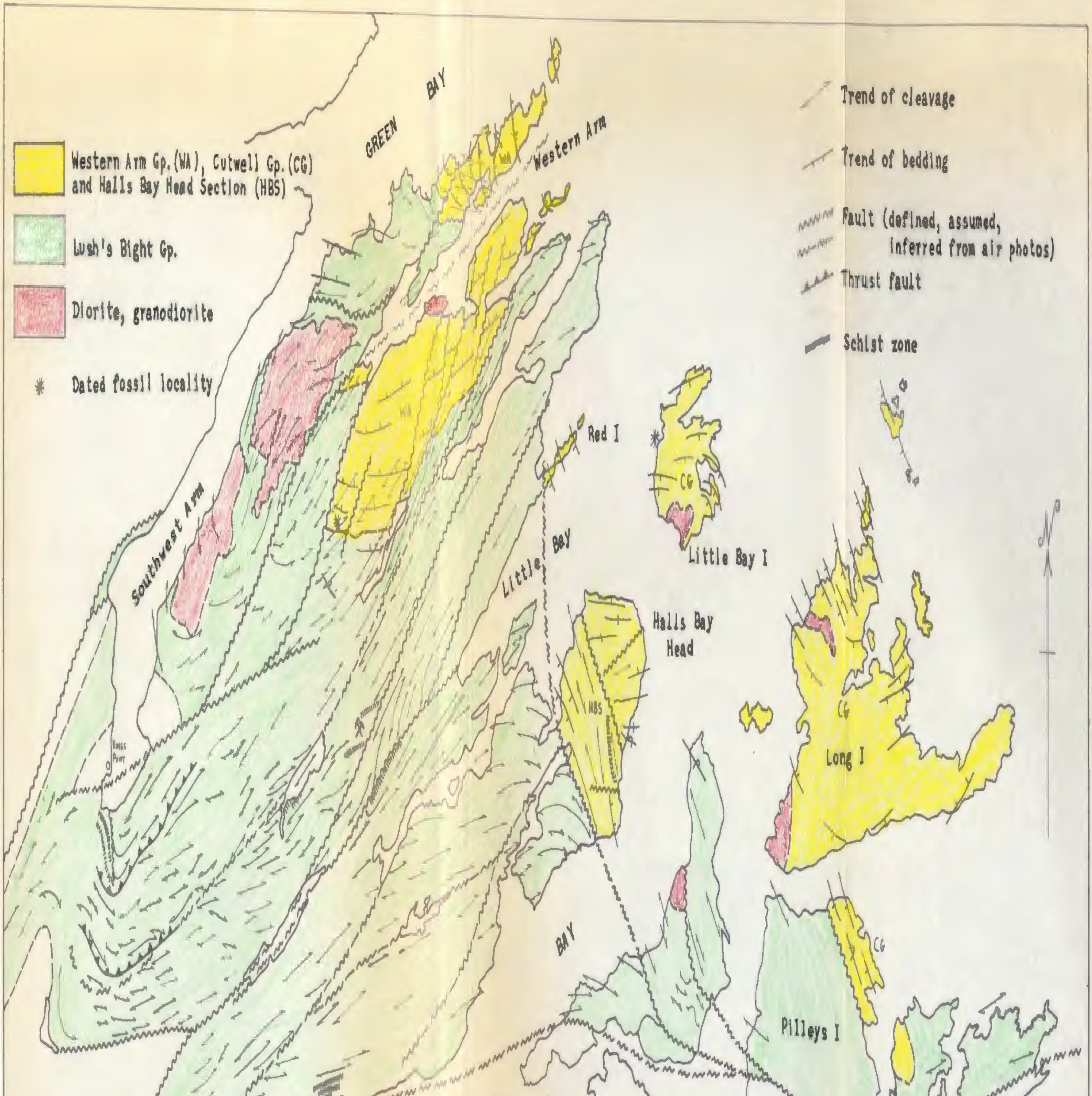

Figure 6: Structural trends in the Lush's Bight terrane, Halls Bay region.

In the Pilleys Island area Espenshade (1937) named the whole volcanic sequence the "Pilleys Series" which he subdivided into the dominantly pyroclastic Cutwell Group overlain by the Lush's Bight Group, chiefly pillow lavas. Williams (1962) reported fossils of probable lower Middle Ordovician (? Llanviren) age in the Cutwell Group and inferred that the Cutwell Group must be younger than the Lush's Bight Group dated as early Ordovician by MacLean (1947). Espenshade based his age grouping on the regional SW dip, apparently assuming the sequence to face SW also. Williams (1962) reports that the Lush's Bight - Cutwell Group contact is faulted on Pilleys Island (see Fig. 6), but the fault would have to be of very great magnitude to explain the present disposition. It appears more likely that an overturned, NE facing sequence is represented. Espenshade's map shows local overturning in NE Pilleys Island, but more regionally disposed data is required on this point.

The Western Arm Group has a broad lithological similarity with the Cutwell Group, but would appear to be slightly older. However, the fossil which dates the Western Arm Group comes from the very base of the sequence, whereas the stratigraphic position of the dated fossil locality (Limestone Island) in the Cutwell Group is unknown, but could be considerably higher in the succession. This is inferred from its position relative to the Halls Bay Head rocks (see Fig. 6). In addition, the dating of the Western Arm Group is certainly not precise, being based on only one brachiopod shell (MacLean, 1947). The writer therefore suggests a tentative correlation of the Western Arm and Cutwell Groups.

Structural Correlation

Structural information has been compiled in Fig. 6 from Espenshade (1937), MacLean (1947), Williams (1962), Fleming (1970), Sayeed (1970), DeGrace (in prep.), Neale (in prep.) and many unpublished BRINEX reports supplemented by air photo interpretation. It is apparent from Figure 6 that the penetrative fabric in the Western Arm area is equivalent to the regionally developed fabric in the "Little Bay Head Section". Near King's Point there is some uncertainty at present (DeGrace, personal communication) as to whether local schist zones pre-date or post-date the main fabric. This fabric, however, appears to post-date and fold an early ore-bearing chlorite schist zone in the Little Deer Mine, demonstrated to the writer by Mr. J. E. James, mine geologist. There is thus some evidence that the main deformation in the Lush's Bight Group may be a second-phase (D_2) event. Subsequent block faulting and thrusting in the King's Point - Yogi Pond area (DeGrace, in prep.) would appear from Figure 6 to be related to rejuvenation of earlier ? D_2 slide zones. Open flexures in the main fabric and faults occur in the same area (DeGrace, in prep.), and also in the fault-bounded Colchester block (Sayeed, 1970). This folding may be related to the large Green Bay and Western Arm wrench faults since the sense of 'drag' is correct for dextral movement on the faults.

A major structural discontinuity extends from Red Island peninsula to Pilleys Island (Fig. 6). East of the discontinuity structural trends lie athwart the NE trending fabric and slide zones in the "Little Bay Head Section". MacLean (1947) reported a schist zone exposed at two localities along the inferred position of the discontinuity, which appears to swing into the Lobster Cove Fault (equivalent to the Lukes Arm Fault). These structural complexities cannot be explained from the writer's work in the Western Arm area, but attention is drawn to them in the hope of stimulating further research. The problems involved do not appear to have been appreciated in the past. Thus, the "Notre Dame Bay orocline" proposed by Church (1965; 1969, Fig. 5) in order to explain the regional structure is a gross oversimplification.

The Western Arm Area in relation to Plate Tectonic Theory

The Pre-Carboniferous development of the Newfoundland Appalachians has been much discussed in the light of recent advances in the theory of lithosphere plate tectonics (e.g. Bird and Dewey, 1970). The Lush's Bight and Western Arm Groups play an important part in any such model because of their apparent oceanic and island arc affinities respectively. Unfortunately, the regional geology of the Central mobile belt is still imperfectly known. Consequently, current attempts to formulate a unifying plate tectonic model for the whole orogen tend to lead to unjustifiable assumptions being made where local details are not clear. As an example, some points in Bird's and Dewey's (1970) model which relate to the geology of the Springdale peninsula are discussed below.

Bird and Dewey (1970) postulate break up of a continuous North American/African continent in Late Precambrian times followed by oceanic expansion continuing to early Ordovician times. The Lush's Bight Group is interpreted as oceanic crust produced along a mid-Appalachian Atlantic accreting plate margin during this phase. Initiation of oceanic contraction in early Ordovician times led to the establishment of a westward-dipping Benioff zone and island arc system along the line of the Lukes Arm Fault. Penetrative deformation and uplift of the Lush's Bight Group is said to have taken place at this time as a direct consequence of the underthrusting of oceanic lithosphere along this zone. The deformation of the Lush's Bight Group is referred to the "Taconian/Humberian" orogeny, and the "Long Island volcanics" (Cutwell Group) and Catchers Pond sequence are stated to unconformably overlie the deformed Lush's Bight Group.

However, it has been argued in this report that the Western Arm Group, of early Ordovician age, conformably overlies the Lush's Bight Group, and the penetrative fabric in the Lush's Bight Group clearly passes into the Western Arm Group. Hence the "Taconian/Humberian" orogeny as defined by Bird and Dewey (1970) is invalid. Furthermore, there appears to be no evidence for the postulated island arc system along the line of the Lukes Arm Fault zone; as noted above the contrast in volcanic assemblages each side of the fault is due to juxtaposition of different structural and stratigraphic levels by considerable vertical movement on the fault.

These criticisms of a specific model do not deny the general relevance of plate tectonics to the Newfoundland Appalachians. It was pointed out above that the tholeiitic Lush's Bight Group may have been formed in a deep sea environment, and that the overlying Western Arm Group appears to represent a change to proximal island-arc conditions. Nevertheless, there is no concrete evidence that the "deep sea environment" referred to is directly analogous to present day oceanic conditions and that the Lush's Bight pillow lavas can be related to 'layer 2' of an ancient oceanic crust.

An oceanic-type basement in the Central mobile belt is generally postulated because of the non-recognition of a sialic type basement. The Bett's Cove sequence of the Snooks Arm Group has been interpreted by Upadhyay et al. (in press) as a conformable layered ophiolite sequence representing a profile through Ordovician oceanic crust. The difficulties in correlating the lower part of the sequence across the Green Bay Fault with the Lush's Bight Group have been mentioned above and imply that the Bett's Cove sequence may not be a conformable one.

The problem of relating the Lush's Bight Group to part of a true ophiolite sequence may perhaps be resolved geochemically by comparing trace elements in the rocks with the distinct proportions which characterize modern oceanic tholeiites (Cann, 1970; Hart et al., 1970).

CHAPTER VII

ECONOMIC GEOLOGY

No deposits of economic importance are known within the area mapped, but there are a number of minor mineral occurrences.

Sulphides

The Norris Prospect, a shallow abandoned shaft situated just above high water mark east of Dolland Arm Head was investigated for BRINEX by Papezik (1963). From the tip heap it was seen that minor amounts of pyrite, chalcopyrite and galena occur in quartz veins cutting gabbro. The prospect was believed to be of no economic significance. However, it is worth noting the comments of Howley (Murray and Howley, 1881, p. 497) who visited the site in 1878 at which time work on the shaft was progressing. He records that the owner's intention was to sink the shaft to a depth of 45 fathoms (sic.) and then drift out under the sea in order to intercept a band containing copper which had been observed on the surface at low tide. He learnt that the shaft was abandoned soon after inception, and the economic potential of the prospect must therefore be regarded as unknown.

The schist zone separating the base of the Harry's Harbour Section from the "Little Bay Head Section" contains pyrite mineralisation and weathers to a rusty brown colour. Traces of chalcopyrite disseminated in tuffs and basalt have been noted in the Harry's Harbour shore section west of the public wharf.

Asbestos

Thin quartz-asbestos veins have been found in basalt at two localities north of Clam Pond, in cherty tuff on the south shore of Welsh Cove, and in basalt near Harry's Harbour. The veins are from 1/2 inch to 2 inches thick and lens out over about 2 feet or less. The fibres have been kinked and only constitute 20% or less of the veins. The occurrences are of no economic significance, but may indicate that serpentine minerals occur among the secondary minerals in the volcanics.

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PLATE I

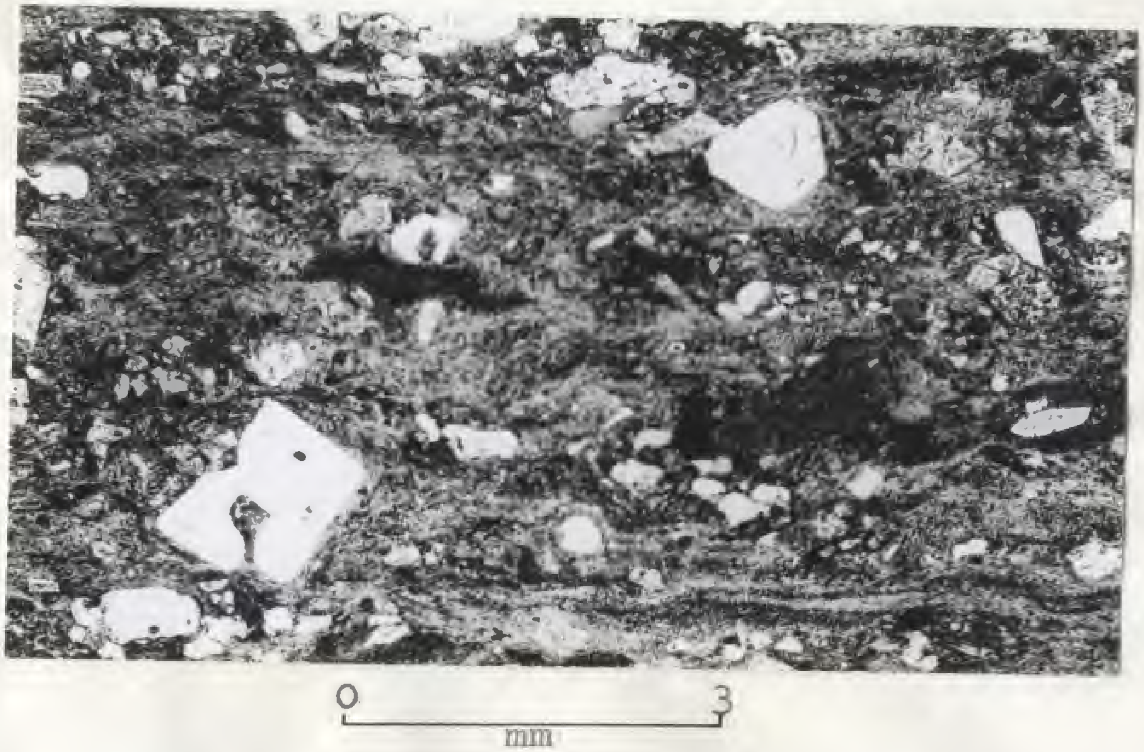

Fig. a: Cleaved coarse tuff, from the Lower Member, Sedimentary Formation. Note the large pyroxene crystals, and the pumice fragments around which the cleavage forms augen. East side of Small Skeleton Pond. Plane polarised light.

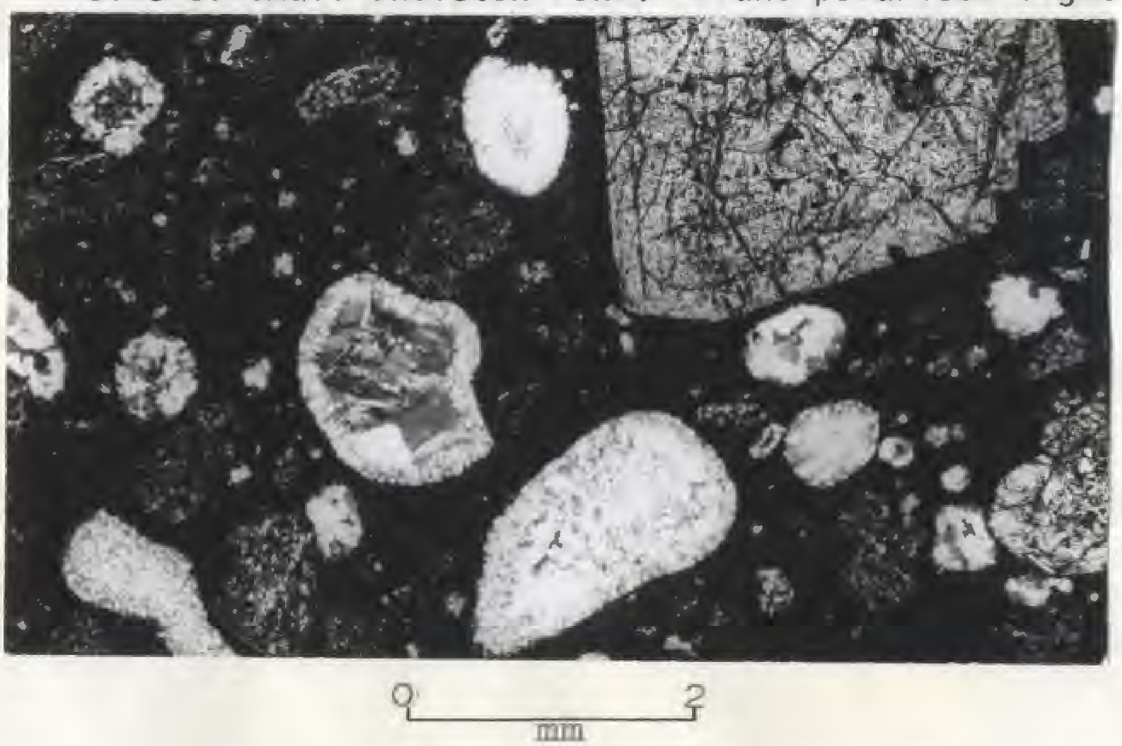

Fig. b: Porphyritic basalt, Black Basalt Formation. The phenocrysts are of labradorite-bytownite (An_{70}). 2000 ft. northwest of West Pond. Plane polarised light.

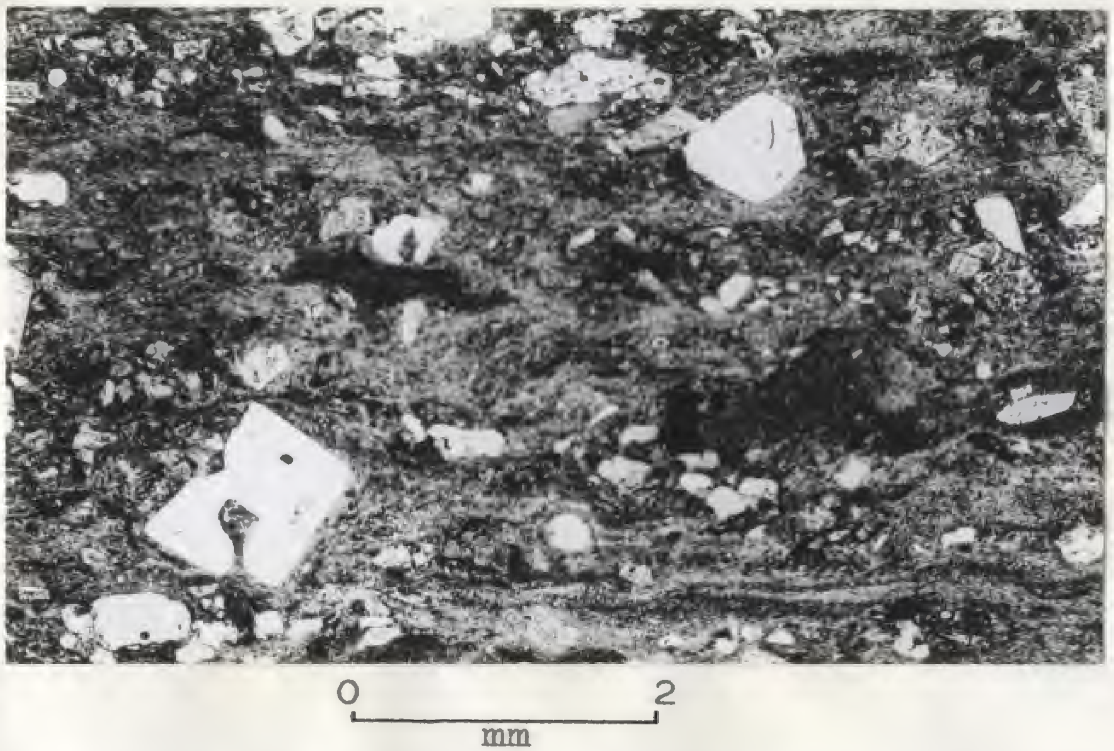

Fig. a: Ignimbrite dacite from Lower Member, Pyroclastic Formation. Note euhedral and deeply embayed quartz crystals (white) in foliated felsitic groundmass. 200 ft. north of west end of Middle Arm. Plane polarised light.

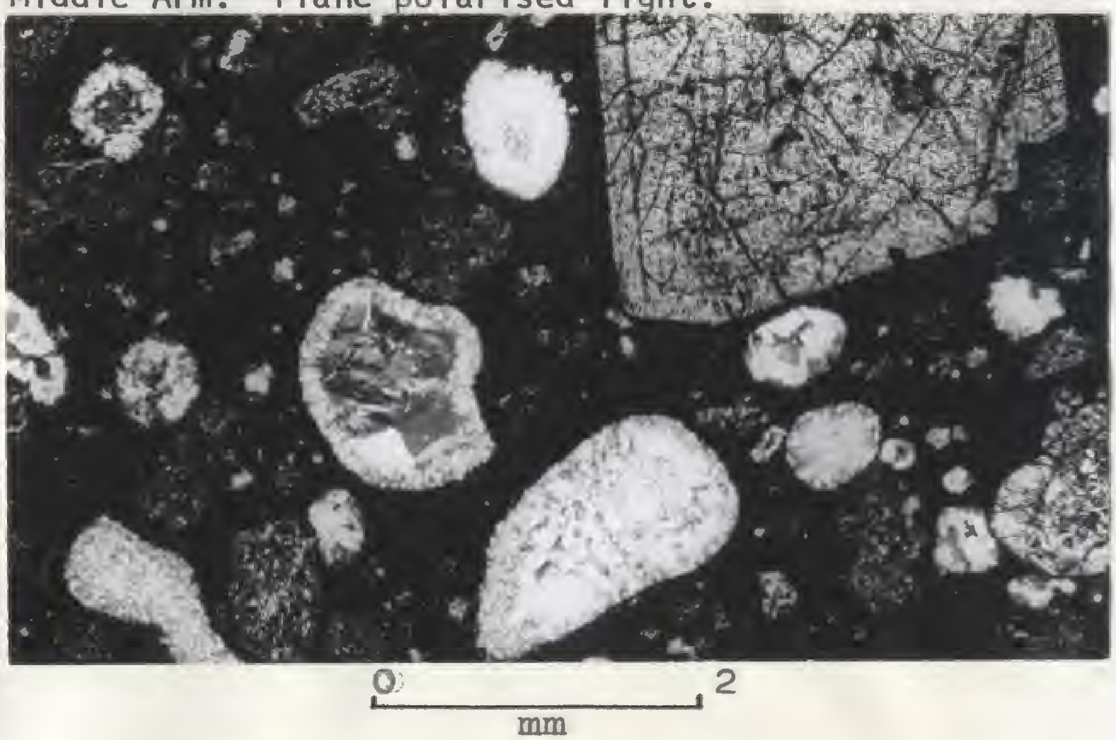

Fig. b: Amygdaloidal porphyritic basalt from block in Upper Member, Pyroclastic Formation. The amygdales are filled with zonally arranged chalcedony and quartz. The phenocrysts are of clinopyroxene. Shore due east of Harry's Harbour. Partially polarised light.

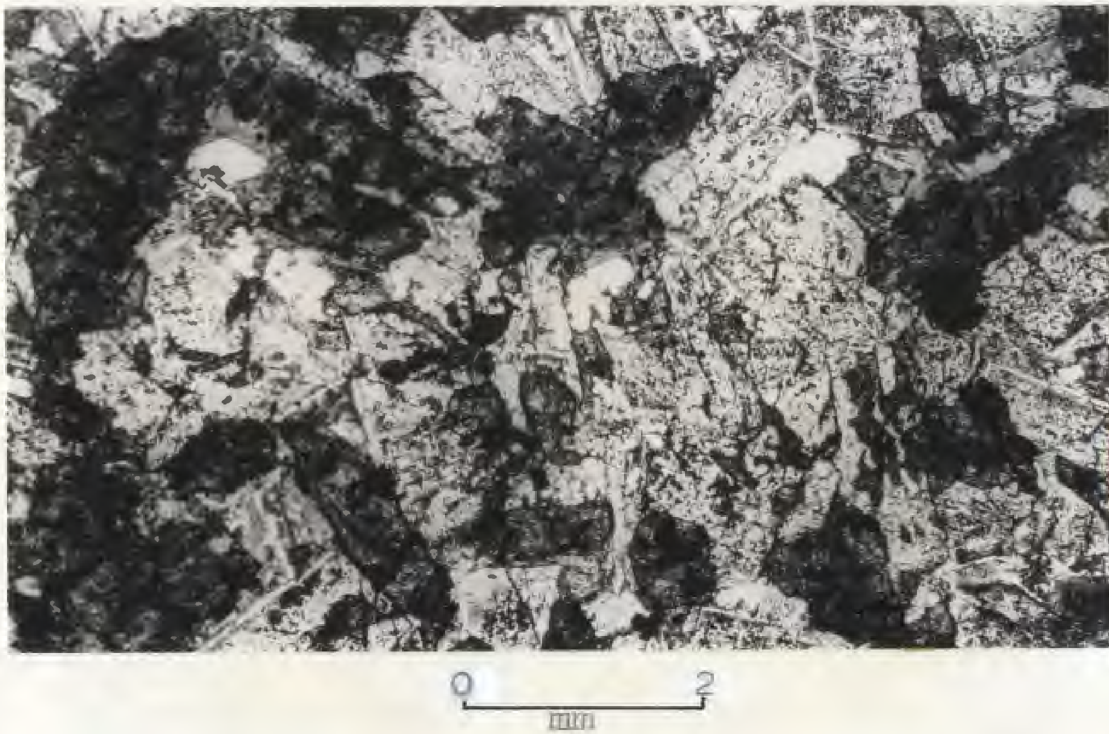

Fig. a: Gabbro. The euhedral plagioclase crystals (An_{35}) (grey) are bordered by thin rims of clear albite. Note the black skeletal plates of iron ore in the clinopyroxene crystals (dark grey) and the minor interstitial quartz. 3,800 ft. west of Langdown Cove. Plane polarized light.

Fig. b: Quartz diorite from the Dolland Quartz Diorite, showing turbid plagioclase grey, hornblende (dark grey) and interstitial quartz (white). Locality 1000 ft. west of Dolland Arm. 2000 ft. west of Dolland Arm. Plane polarised light.

Fig. a: Pillow breccia in the Little Bay Head Section. The subrounded clasts are of basalt in a basaltic tuff matrix, and have chilled margins. 800 feet north of west end of Clam Pond.

Fig. b: Concentric "onion skin" structure in pillows of the black facies, Little Bay Head Section. This may result from spheroidal weathering on a pre-Springdale Group or pre-Carboniferous erosion surface. 2000 ft. west of Clam Pond.

PLATE V

Fig. a: Banded, fine-grained tuff eroded and then overlain by coarse tuff. This may be due to channeling action of slump masses. Middle Tuff Member, Sedimentary Formation. East side of Small Skeleton Pond. Facing north and looking down dip.

Fig. b: Basalt flow-breccia. The blocks weather out more easily than the intervening siliceous-epidotic material. 200 ft. west of Small Skeleton Pond.

Fig. a: Chaotic slump-breccia in Upper Tuff Member, Sedimentary Formation. Rafts of banded fine tuffs show complex soft-sediment folds. South shore of Hennessey Is., looking west.

Fig. b: Detail of slump-breccia. Note flattening of tuff clasts parallel to bedding in overlying tuffs; this is attributed to plastic flowage of unconsolidated material. Note fragment of jasper. Locality and orientation: as in Fig. a.

Fig. a: Agglomerate, Upper Member of Pyroclastic Formation. Note the partly angular, and partly rounded blocks. A slightly calcitic matrix at this locality causes blocks to weather out. Shore, due east of Harry's Harbour.

Fig. b: Type II autobreccias in sharply defined dykes, Dolland Quartz Diorite. Looking east, 800 ft. west of Dolland Arm Head.

Fig. a: Pillow basalt of Black Basalt Formation, Harry's Harbour Section. Note vertical attitude and tops to right (east). 15,000 ft. west of public wharf, Harry's Harbour, looking north.

Fig. b: Autobreccia in Dolland Quartz Diorite. Note the angularity of the blocks, and how in places they may be fitted together. 1500 ft. west of Dolland Arm Head; looking east.

PLATE VIII

PLATE IX

Fig. a: Mineral layering interpreted as flow-banding, in Dolland Quartz Diorite. Note the folding of the bands. 2,700 ft. west of Dolland Arm, looking east.

Fig. b: Regular and flow-folded colour banding in dacitic facies of the Dolland Quartz Diorite. At Dolland Arm Head; looking southeast.

1 of

ORDOVICIAN

WESTERN ARM GROUP

- 6 COARSE AGGLOMERATE — 6a TUFF — UPPER MEMBER — PYROCLASTIC FORMATION
- 5 DACITIC TUFF & IGNIMBRITE, CHERT & ARGILLITE — LOWER MEMBER — PYROCLASTIC FORMATION
- 4 PILLOW BASALT — 4a TUFF — BLACK BASALT FORMATION
- 3 BASIC & INTERMEDIATE TUFF — 3b SLUMP BRECCIA — 3a PILLOW BASALT — SEDIMENTARY FORMATION

LUSH'S BIGHT GROUP

- 2 GRAY PILLOW BASALT — 2a TUFF — BLACK FACIES — LITTLE BAY HEAD SECTION
- metamorphic contact
- 1 GREEN PILLOW BASALT — 1b TRANSITIONAL FACIES — 1a PILLOW BRECCIA — MAIN FACIES — LITTLE BAY HEAD SECTION

INTRUSIVE ROCKS

ORDOVICIAN

- 9 DOLLAND QUARTZ DIORITE
- 8 PORPHYRITIC DIABASE
- 7 GABBRO

Ge
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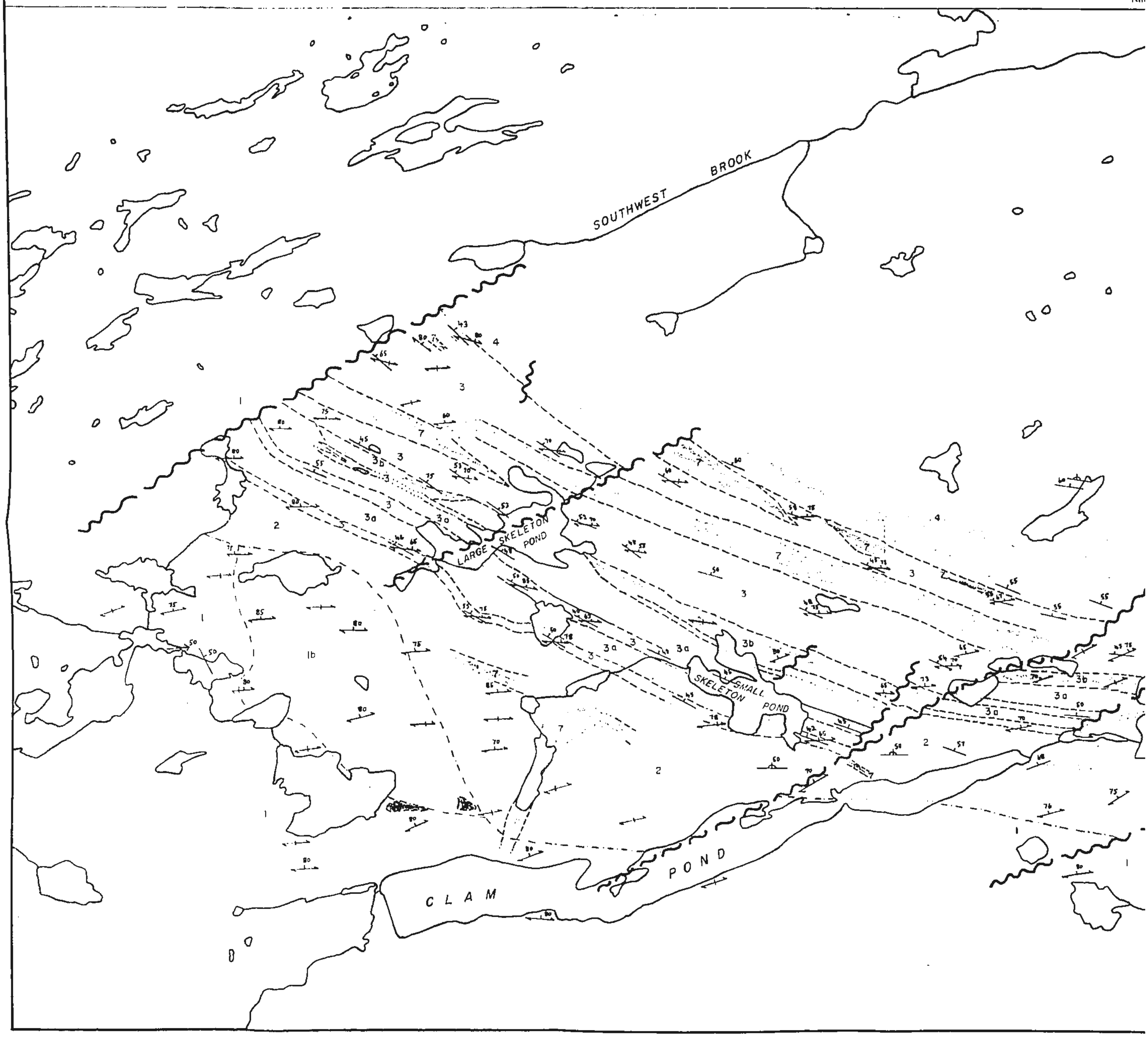
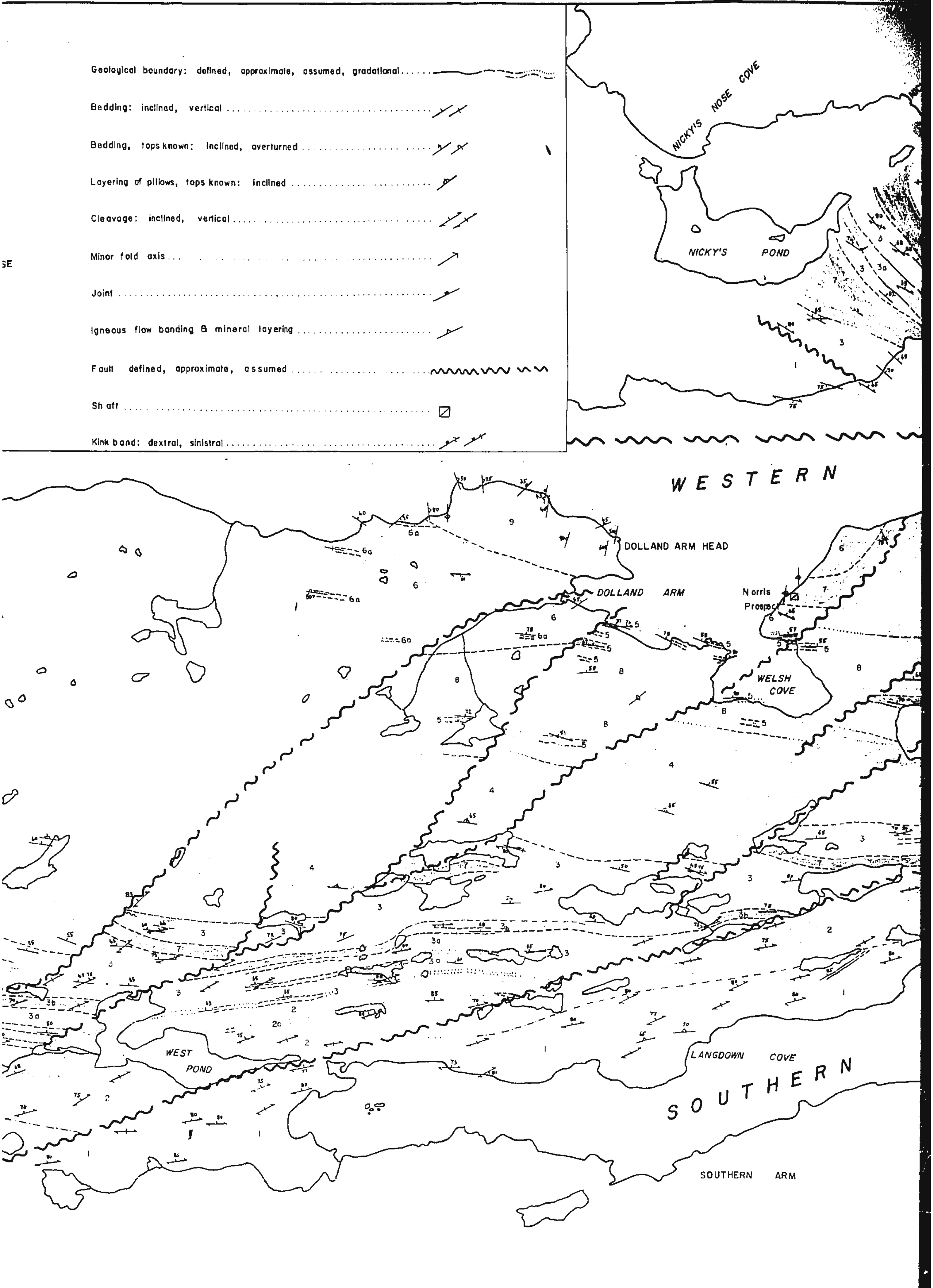
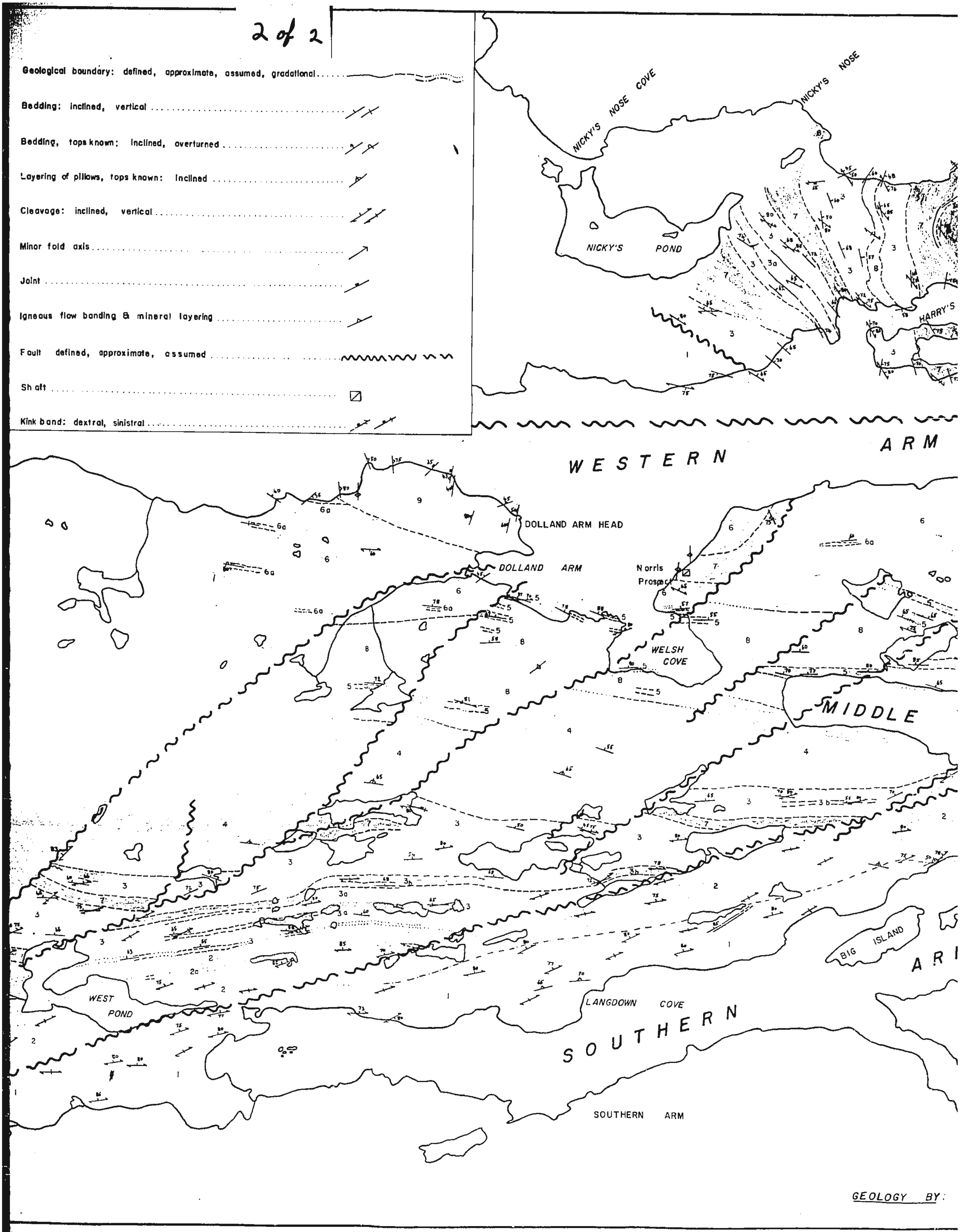
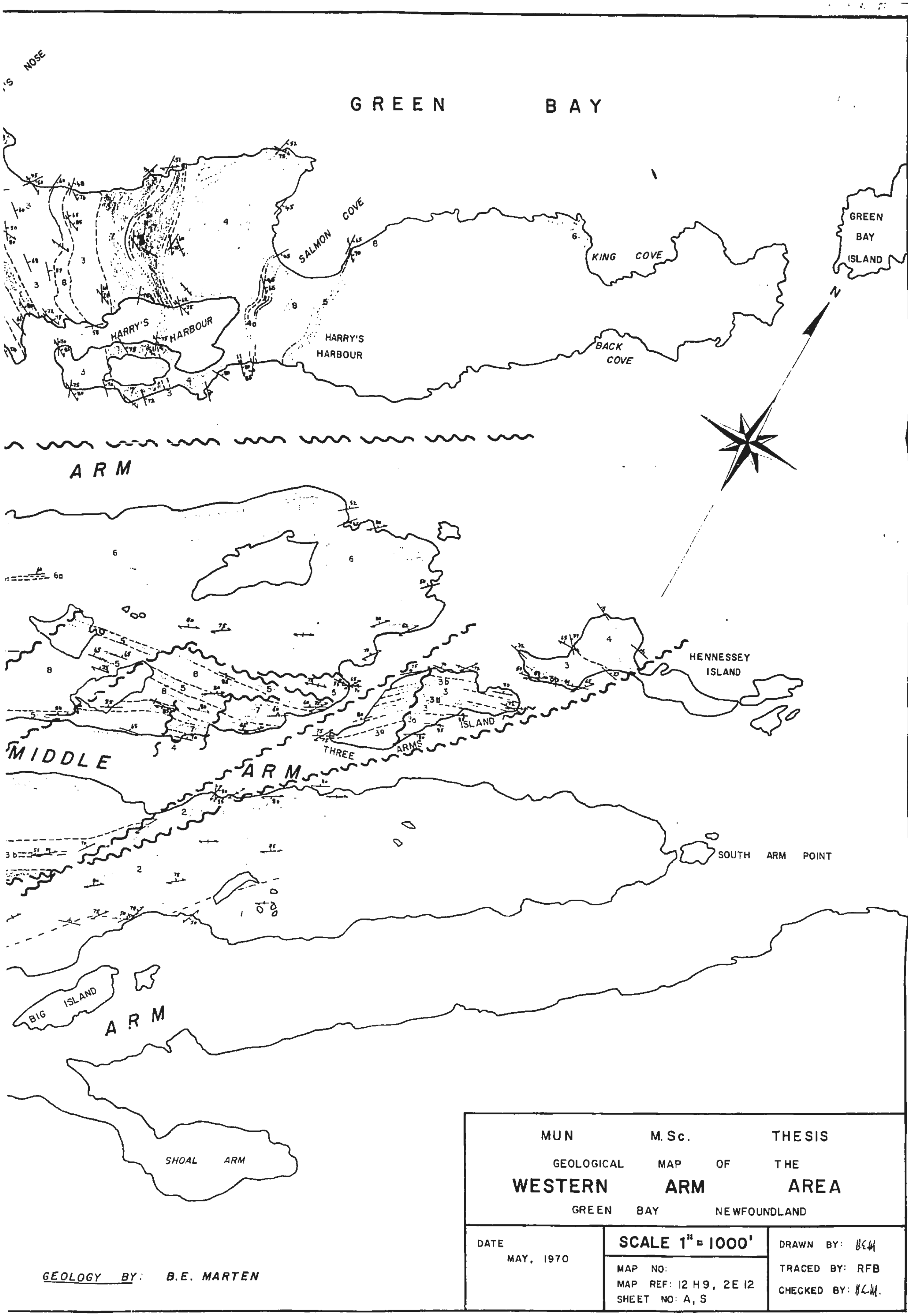



Geological boundary: defined, approximate, assumed, gradational
Bedding: inclined, vertical
Bedding, tops known: inclined, overturned
Layering of pillows, tops known: inclined
Cleavage: inclined, vertical
Minor fold axis
Joint
Igneous flow banding & mineral layering
Fault defined, approximate, assumed
Shaft
Kink band: dextral, sinistral
NICKY'S NOSE COVE
NICKY'S POND
WESTERN
DOLLAND ARM HEAD
DOLLAND ARM
Norris Prospect
WELSH COVE
WEST POND
LANGDOWN COVE
SOUTHERN
SOUTHERN ARM


Geological boundary: defined, approximate, assumed, gradational
Bedding: inclined, vertical
Bedding, tops known: inclined, overturned
Layering of pillows, tops known: inclined
Cleavage: inclined, vertical
Minor fold axis
Joint
Igneous flow banding & mineral layering
Fault defined, approximate, assumed
Shaft
Kink band: dextral, sinistral
NICKY'S NOSE COVE
NICKY'S NOSE
NICKY'S POND
HARRY'S
WESTERN ARM
DOLLAND ARM HEAD
DOLLAND ARM
Norris Prospect
WELSH COVE
MIDDLE ARM
BIG ISLAND
WEST POND
LANGDOWN COVE
SOUTHERN
SOUTHERN ARM
GEOLOGY BY:


GREEN BAY
SALMON COVE
KING COVE
GREEN BAY ISLAND
HARRY'S HARBOUR
HARRY'S HARBOUR
BACK COVE
N
ARM
HENNESSEY ISLAND
MIDDLE ARM
THREE ARMS ISLAND
SOUTH ARM POINT
BIG ISLAND
ARM
SHOAL ARM
MUN M.Sc. THESIS
GEOLOGICAL MAP OF THE
WESTERN ARM AREA
GREEN BAY NEWFOUNDLAND
DATE
MAY, 1970
SCALE 1" = 1000'
MAP NO:
MAP REF: 12 H 9, 2E 12
SHEET NO: A, S
DRAWN BY:
TRACED BY: RFB
CHECKED BY:
GEOLOGY BY: B.E. MARTEN