STRUCTURAL AND STRATIGRAPHIC RELATIONSHIPS IN SILURIAN ROCKS OF THE PORT ALBERT - HORWOOD AREA, TWILLINGATE - FOGO DISTRICTS, NEWFOUNDLAND

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by

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A THESIS

submitted in partial fulfilment of the

requirements for the degree of

MASTER OF SCIENCE

MEMORIAL UNIVERSITY OF NEWFOUNDLAND

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ABSTRACT

The Port Albert — Horwood area is situated in northeast Notre Dame Bay, Newfoundland. It is underlain by five stratigraphic units of probable Early Silurian age. In the southeast of the area the lower part of the stratigraphic succession differs from that of the northwest.

The lowermost unit in the southeast, the Lower Formation, comprises medium bedded slates and siltstones with some limestone beds. The overlying Stoneville Formation consists of a Lower, thin - medium bedded, sandy siltstone and slate Member, a Diamict Member mainly composed of thinly laminated beds containing outsize clasts, and an Upper, dominantly sandy siltstone Member.

In the northwest the Beaver Cove Formation comprises a Lower, thin bedded silt and mudstone Member, a Conglomerate Member containing graded polymict conglomerate and greywacke units, and an Upper, interbedded siltstone and greywacke Member.

Commonly andesitic, interbedded agglomerates, flows and tuffs of the Port Albert Formation conformably overlie the lower part of the succession in the northwest and southeast of the area. The overlying and uppermost unit, the Dog Bay Formation, comprises a Lower, thin bedded, siltstone Member, a Tuffaceous, massive bedded, sandy siltstone Member and an Upper, medium to fine sandstone Member which disconformably overlies the Port Albert Formation in the northwest.

Rhyolite and diabase dykes are sometimes composite and intrude rocks of the central part of the area. Rhyolite fragments in the Dog Bay Formation suggest that intrusion was in part contemporaneous with sandstone deposition, and except for a lamprophyre dyke, these intrusions

predate the regional deformation.

Three periods of deformation, of probable Mid-Devonian (Acadian) age, are recognised. The regional, first deformation produced a zonally developed, sub-vertical, penetrative cleavage in association with folding of differing styles. This zonal development may be controlled by a rigid, probably intrusive body close to the surface beneath the central parts of the area. The second and third deformations produced flat-lying and steep kink-bands and crenulations respectively, of the penetrative cleavage and bedding. The Reach Fault is a major, probable strike-slip displacement which parallels the regional structural trend. West trending tear faults have sinistral and dextral offsets.

The Diamict Member of the Stoneville Formation is of probable glacio-marine origin and may have been deposited in part by ice-rafting. The Member is compared to similar deposits of Late Ordovician - Early Silurian age which occur in Nova Scotia, Western Europe and Northwest Africa, and to which it may be indirectly related.

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. Support from Dr. Kennedy's N.R.C. Operating Grant No. A5246 is acknowledged. P. Browne and Lindo Hodder of Stoneville provided capable assistance in the field. Dr. L. Fahraeus kindly processed some limestone samples in a fruitless search for micro-organisms, and W. Marsh is acknowledged for preparation of the photographs. The following are acknowledged for many useful discussions of the area: B. E. Marten, W. R. Smyth, Dr. J. S. Sutton and Dr. H. Williams. Tenure of a Memorial University Fellowship while at M.U.N. is also acknowledged.

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Chapter I

INTRODUCTION

Location, Access and Topography

The Port Albert Peninsula — Horwood Bay area is situated in the northeastern part of Notre Dame Bay, Twillingate and Fogo Districts, Newfoundland. It is bounded on the west by the Reach Run and New World Island, and on the east by Gander Bay and Hamilton Sound. The area, consisting of approximately 35 square miles, was mapped on a scale of 4 inches to 1 mile, between June and the end of September, 1971.

The southern boundary of the map area is defined by the gravel road which links the district with Lewisporte, Boyd's Cove and New World Island to the west, and Gander (approximately 50 miles) to the east. Branch roads from the above link the settlements of Horwood on the east, Stoneville on the west side of Horwood Bay, and Port Albert on the northwest coast of the Peninsula. The Stoneville-Port Albert road affords easy access to the west and southwest shores of Horwood Bay and the immediate vicinity of Port Albert. The remaining parts of the Peninsula, some small islands in Horwood Bay, and the area from Dog Bay to Horwood, are accessible by small boat.

The region is one of undulating topography with low to moderate relief (max. elevation 276' above sea level), upon which both structure and lithology have exerted considerable control. The strong northeast-southwest grain of the country reflects the strike of both the major lithological units and the important faults.

Rock exposure is excellent on the coastline of the Peninsula, but is very poor inland. Much of the Peninsula is less than 50' above sea level, contains shallow lakes and is thinly covered by till which supports forest and bogland. The tops of the hills are generally 100 - 150' above the bog and lake level and provide the best inland exposure. Spruce, which are generally small and closely intergrown, form the vegetation between 50 and 150' above sea level.

Glaciation and differential erosion of underlying rocks have further influenced the topography of the region. The conglomerates and volcanic rocks in the northwest form prominent rounded ridges, while the low-lying central areas are underlain by sandstone. Rhyolite intrusion near Farewell Head makes the sandstone locally more resistant, resulting in higher relief. Some large granitic erratics, 3 - 4' in diameter, lie on the shore north of Stoneville and on Southern Dog Bay Island, and provide additional evidence of the last glacial period.

Previous Work

The earliest geological work in this region was that of Murray and Howley (1881). However, in this work, Ordovician and Silurian rocks were not differentiated, and both were grouped on Howley's map of insular Newfoundland (1919), under the heading 'Silurian.'

The first detailed examination of the rocks of the Port Albert Peninsula and Horwood Bay was undertaken by Twenhofel (1947). He followed the general practice of that time of assigning unfossiliferous, lower Palaeozoic rocks of northeast Newfoundland to the Ordovician System, especially where volcanic rocks were present. Consequently, a measured section of volcanic and sedimentary rocks at Port Albert was described as being representative of Ordovician strata. The rocks underlying Horwood Bay were interpreted as occupying a northeast trending syncline, bordered to the east and west by older strata. A Silurian age for these rocks was interpreted from the fossil content.

The area was subsequently included, in part, in regional studies on a scale of 1" to 1 mile by Patrick (1956) and Baird (1958). Patrick was the first to use the term, Indian Islands Group, to designate Silurian strata on both sides of Horwood Bay. This group name was also used by Baird when he mapped the northeast continuation of these beds across southern Dog Bay Islands and Indian Islands. Both Patrick and Baird interpreted the Indian Islands Group as occupying the northeast trending syncline at Horwood Bay.

West and east of Horwood Bay, Patrick (1956) assigned the strata to the undated Farewell Group. Baird (1958) similarly assigned strata west of Horwood Bay to the Ordovician Farewell Group (Table I).

Williams (1963; 1964*a*) indicated that the rocks of northwest and central Port Albert Peninsula can be correlated on lithology and age with the Silurian Botwood Group to the southwest. This term, the Botwood Group, was first used by Williams (1962) to designate Silurian sedimentary and volcanic rocks exposed at Exploits Bay. Williams (1967) later formally abandoned the use of the Farewell Group terminology of Patrick and Baird. Near Stoneville, on the southeast shoreline of the Peninsula, Williams (1964*a*) interpreted the contact between the Botwood Group and the Indian Islands Group, as probably faulted. His study indicated that the structural relationships at Horwood Bay were more complex than was previously considered. In particular, he showed (1964*a*) that lithological distribution and facing directions did not support previous structural

Table I. Summary of previous work

Age	Twenhofel 1947	Patrick 1956	Baird 1958	Williams 1963	Williams 1964*a*	Eastler 1969
SILURIAN	Conglomerate Quartzite Phyllite of Dog Bay Islands and Horwood Bay	Indian Islands Group of Horwood (Dog) Bay	Indian Islands Group of Horwood (Dog) Bay	Botwood Group of northwest Port Albert Peninsula	Botwood Group Map Units 20-22 of northwest - central Port Albert Peninsula	Botwood Group of Change Islands and northwest - central Port Albert Peninsula
					Indian Islands Group Map Units 17-19 of Horwood Bay	Indian Islands Group of Horwood Bay
SILURIAN —? ORDOVICIAN		Farewell Group of Port Albert Peninsula				
ORDOVICIAN —? ORDOVICIAN	Conglomerate Volcanic Rocks and Sandstone at Port Albert		Farewell Group of Port Albert Peninsula			

interpretations suggesting a synclinal axis at Horwood Bay.

More recently, Eastler (1969) mapped part of the Port Albert Peninsula, where he recognized the threefold stratigraphic subdivision of the Botwood Group of Williams (1964*a*). The area has also been briefly described by Kay (1969; 1970; 1972).

A summary of previous work and nomenclature is presented in Table I.

Regional Geological Setting

The map area lies in the Central Palaeozoic Mobile Belt of the Newfoundland Appalachians, one of three geological provinces (Fig. 1 inset), defined on the basis of distinct Pre-Cambrian and Early Palaeozoic geological histories (Williams, 1964). This central belt is bordered by two northeasterly trending orthotectonic belts of Pre-Cambrian to Cambrian metasedimentary rocks resting upon older gneissic basement. The northwest belt is represented on the Burlington Peninsula by the Fleur de Lys Supergroup (Kennedy, 1971), while the southeast belt is well exposed around Musgrave Harbour and Gander, where it has been referred to as the Gander Lake Group (Kennedy and McGonigal, 1972).

The wide paratectonic central zone of the mobile belt is characterized by thick, Pre-Silurian, mainly Ordovician mafic volcanic and clastic sequences which are locally underlain by ophiolite. These are overlain, in the northeast part of the zone, by a thick sequence of Silurian sedimentary and volcanic rocks.

The Silurian sequence in the Central Mobile Belt occurs in separated troughs or fault bounded belts, that generally trend northeastward (Williams, 1969). Williams (1967) termed the largest of these the Botwood Belt, part of which is included in the study area. This belt is dominated

Fig. 1. Geologic summary map of eastern Notre Dame Bay, adapted from Williams (1964*a*)

SILURIAN - DEVONIAN

12 Granite, granodiorite, quartz diorite

SILURIAN - BOTWOOD GROUP

11 Dog Bay Formation
Red and grey sandstone

10 Port Albert Formation
Agglomerate, lava, tuff

9 Beaver Cove (Goldson) Fm.
Conglomerate, greywacke, silt

8 Stoneville Formation
Diamict, greywacke, silt, slate

7 Lower Formation
Slate, silt, limestone

ORDOVICIAN - SILURIAN

6 Undifferentiated greywacke, conglomerate, silt, and mixed volcanic rocks

MIDDLE - ORDOVICIAN

5 Davidsville Group
Slate, silt, greywacke, mafic volcanic rocks

PRE-MIDDLE ORDOVICIAN

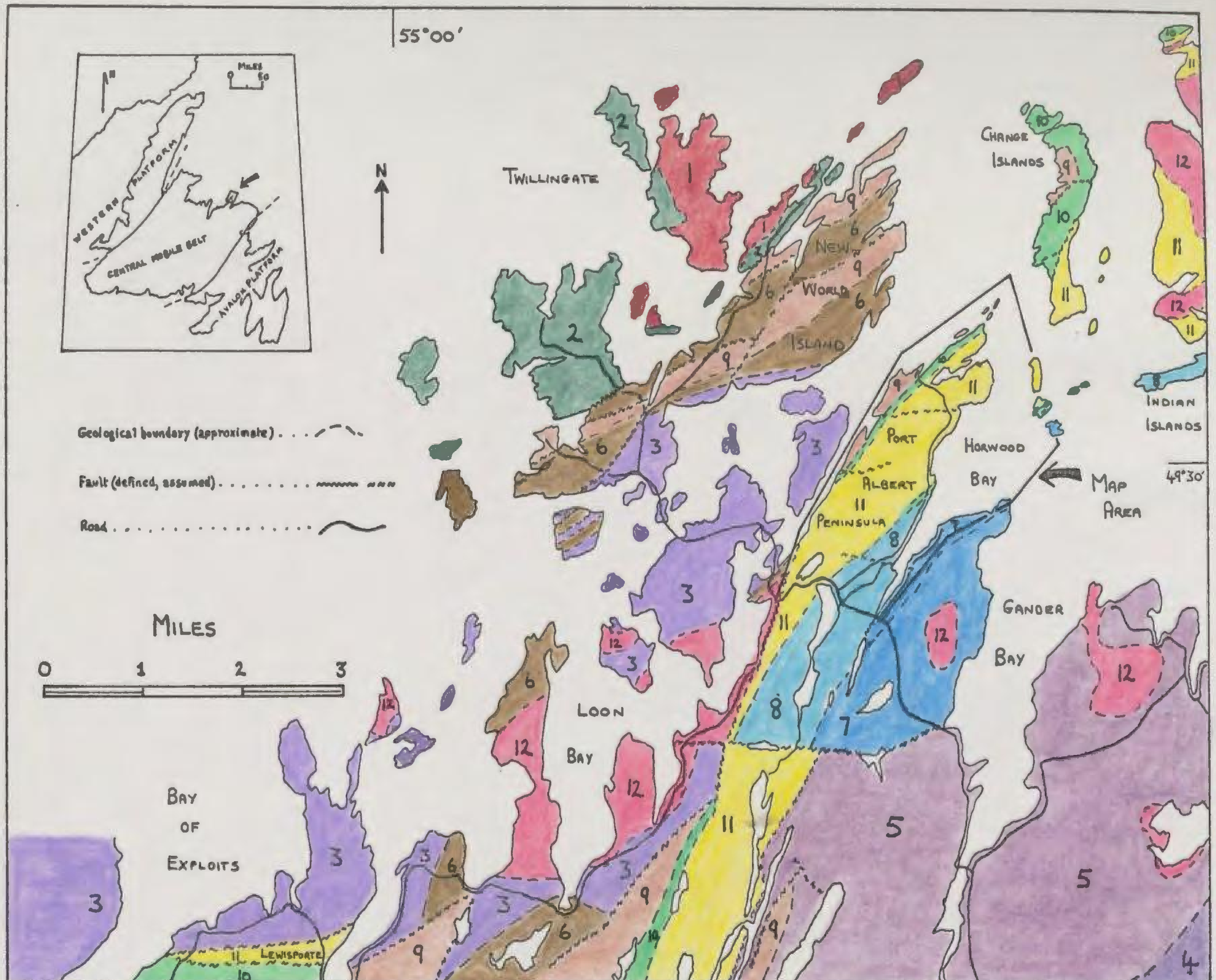
4 Gander Lake Group
Psammitic and semi-pelitic schists

PRE-MIDDLE ORDOVICIAN

3 Dunnage Complex
Chaotic assemblage of mafic volcanic and greywacke blocks in a shaly matrix

2 Lush's Bight Group
Mafic volcanic rocks, pyroclastic rocks, chert, greywacke, siltstone, amphibolite

1 Granodiorite, quartz diorite



55°00′
49°30′
N
Miles
0 50
Western Platform
Central Mobile Belt
Avalon Platform
Twillingate
New World Island
Change Islands
Indian Islands
Port Albert Peninsula
Horwood Bay
Map Area
Gander Bay
Loon Bay
Bay of Exploits
Lewisporte
Geological boundary (approximate)
Fault (defined, assumed)
Road
MILES
0 1 2 3

by three main lithologies, which from base upwards consist of conglomerates and greywackes, mixed volcanic rocks, and vari-coloured micaceous sandstones (Fig. 1). This facies division is everywhere distinctive of Silurian rocks in Newfoundland (Williams, 1969). Apart from the basal greywacke beds, the facies are markedly different from underlying Ordovician rocks, which show separate facies divisions from west to east across Newfoundland (Williams, 1964).

Both Ordovician and Silurian rocks of the Central Mobile Belt were intensely deformed by the Acadian Orogeny, which is dated as Mid-Devonian (Williams, 1969). This produced a steep, zonally penetrative foliation, commonly associated with tight folds, and which has suffered later kinking and crenulation. The zonal development of the main fabric, and the overall Acadian strain sequence, are well displayed in rocks of the Port Albert — Horwood area.

In terms of the tectonostratigraphic zones of the Appalachian Structural Province, the study area lies in the northwest corner of Zone F (Williams *et al.*, 1972). The study area and Zone F are bounded on the west by the Reach Fault (Kay, 1970; 1972). This fault places lower Silurian rocks of the Port Albert Peninsula in contact with pre-lower Ordovician rocks of the Dunnage Complex (Kay, 1970; 1972). To the south-east of the study area, the Indian Islands Group is interpreted as being in fault contact (Williams, 1964*a*) with Ordovician sediments of the Davidsville Group (Kennedy and McGonigal, 1972).

Purpose of Study and Summary of Results

This study was undertaken in order to elucidate the structure and stratigraphy of an area which has not received much attention in recent years. It was intended to show the distribution of the intense Acadian deformation in the area and to correlate the strain sequence with other Acadian strain sequences. In particular, very little was known about the structure and stratigraphy in southeast Horwood Bay, and the relationship of rocks exposed in this area to rocks of the Botwood Group farther to the west was largely unknown.

This study shows that the lower parts of the succession, outcropping at a similar stratigraphic position on opposite sides of a central syncline, differ in the northwest from those in the southeast. Thus, rocks previously assigned to the Indian Islands Group in the southeast are here considered probable facies equivalents of lower Botwood Group rocks in the northwest, and it is suggested that the term Indian Islands Group be discarded. Since the rocks contrast in lithology and environment of deposition they are described separately. The Diamict Member of the Stoneville Formation in the southeast of the area is shown to be of probable glacio-marine origin, and is compared to similar deposits in North America, Europe and Northwest Africa. The Acadian strain sequence of a horizontal uniaxial flattening with associated penetrative cleavage, a vertical shortening, and an axial shortening, is recognized and compared to Acadian and Caledonian strain sequences elsewhere. The Acadian deformation zonally affects rocks in the area and this is attributed to a shallow level intrusive body underlying the central parts of the Port Albert Peninsula.

Chapter II

STRATIGRAPHY OF THE BOTWOOD GROUP

INTRODUCTION

In this study lithologic sequences in the lower part of the stratigraphic succession differ in the northwest from those in the southeast of the map area. These are described separately (Table II). In the northwest the lithologic units in the lower part of the succession have been referred to the Botwood Group (Williams, 1963; 1964*a*), while those in the southeast were defined by Williams (1964*a*) as part of the Indian Islands Group. The study shows that rocks previously assigned to the Indian Islands Group in the southeast are probable facies equivalents of rocks assigned to the Botwood Group in the northwest (Fig. 2, sec. A-A^1). The term Indian Islands Group is discarded and all lithologic units of the map area are assigned to the Botwood Group. In the central parts of the map area volcanic rocks and shallow water sandstones, previously assigned to the Botwood Group (Williams, 1963; 1964*a*), are redefined in the light of more detailed knowledge.

LITHOLOGIC UNITS OF THE SOUTHEAST PART OF THE MAP AREA

Lower Formation

The name Lower Formation is proposed for the slates, siltstones and limestones which are well exposed along the eastern shoreline of Horwood Bay in the southeast of the map area.

The contact with overlying rocks, here assigned to the Stoneville Formation, is interpreted as faulted at the extreme south of Horwood Bay

Table II. Table of Formations

Age	Group	Formation	Member	Lithology			Member	Formation
				CENTRAL PART OF THE MAP AREA				
LOWER SILURIAN (LLANDOVERY)	BOTWOOD GROUP	DOG BAY FORMATION	Upper Member (c.138 m)	Cross-bedded, medium and fine grained sandstone, some mud cracks and containing metamorphic detritus.				
			Tuffaceous Member (c.160 m)	Massively bedded, poorly sorted, immature sandy siltstone, some slump structures, and containing abundant rhyolite fragments, some with crenulate outline.				
			Lower Member (c.385 m)	Thin bedded, coarse siltstone with ripple marks and much ripple-drift cross-lamination				
		PORT ALBERT FORMATION	(c.210 m)	Lenticularly interbedded agglomerate, crystal and lithic tuff and andesite-dacite flows.				
		NORTHWEST PART OF THE MAP AREA				*SOUTHEAST PART OF THE MAP AREA*		
		BEAVER COVE FORMATION	Upper Member (c.70 m)	Thin bedded siltstone and greywacke, some slate. Volcanic detritus near the top of the Member.	PROBABLE FACIES EQUIVALENTS	Thin - medium bedded greywacke and siltstone, some slate. Occasional thinly laminated beds containing outsize clasts	Upper Member (c.140 m)	STONEVILLE FORMATION
			Conglomerate Member (c.210 m)	Graded units of polymict conglomerate and greywacke, interbedded greywacke and siltstone units.	?	Thinly laminated beds containing outsize clasts with greywacke interbeds	Diamict Member (c.105 m)	
			Lower Member (c.210 m+)	Generally thin bedded siltstone and mudstone, some greywacke.	?	Thin - medium bedded sandy and fine siltstone and slate	Lower Member (c.350 m)	
		BASE NOT SEEN				CONTACT PROBABLY FAULTED		
						Grey, sometimes phyllitic, slate unit. (c.280 m)		LOWER FORMATION
						Limey siltstone unit, some limestone beds (c.225 m)		
						Contact probably faulted		
						Black siltstone-slate unit, some limestone beds (c.450 m+)		
						BASE NOT SEEN		

(Fig. 2). Only shoreline exposures were mapped in this part of the map area and units of the Lower Formation are considered as map units. The base of the lower unit was not seen and is outside of the map area.

The Formation is also exposed on the Indian Islands to the northeast (Williams, 1964*a*), some small islands in Horwood Bay and is faulted against sandstones of the Upper Botwood Group to the southwest (Williams, 1964*a*) (Fig. 1).

These rocks were earlier referred to the Indian Islands Group (Williams, 1964*a*). In the present study the Lower Formation underlies rocks of the Stoneville Formation (Fig. 2, sec. A-A^1), which are shown to be probable facies equivalents of the Beaver Cove Formation of the Botwood Group, in the northwest part of the map area (Fig. 2). Therefore it is suggested here that the term Indian Islands Group be discarded and that these rocks be included in the Botwood Group.

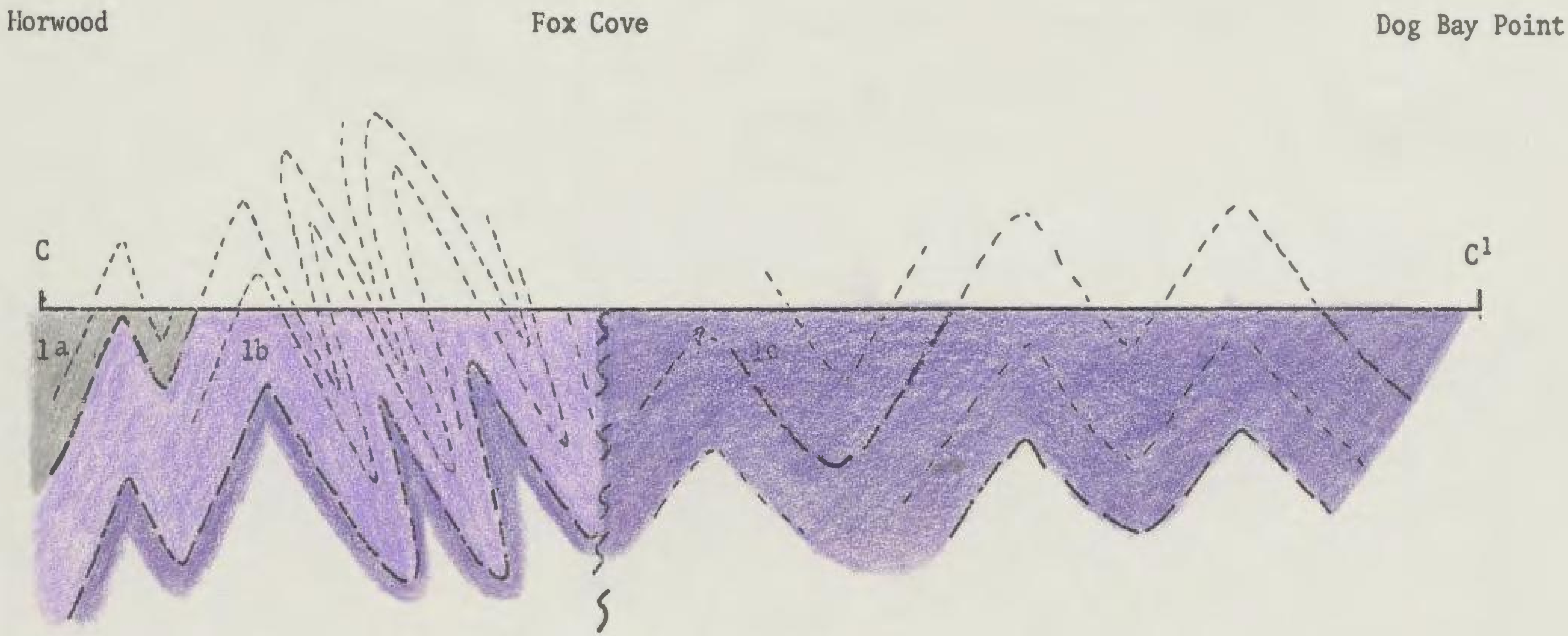
The effects of the regional deformation are well developed in the fine grained lithologies of the Lower Formation. Upright folding is developed in the slate and silt-slate units, while the limey silts and limestones contain tight folds slightly overturned to the northwest (Fig. 3).

The outcrop of the Lower Formation in the area is divided into three map units. These are (i) a lower black siltstone-slate unit with some limestone beds, (ii) a limey siltstone unit with some limestone beds, and (iii) an upper, grey, sometimes phyllitic, slate unit.

Lower Siltstone-Slate Unit (c. 280 m)

The Lower Unit of the Lower Formation outcrops between Dog Bay Point and Fox Cove on the northeastern shoreline of Horwood Bay.

Fig. 3. Diagrammatic geologic cross-section C-C[1] (Fig. 2.) Note differing fold styles in the Upper (1a), the Limey-Siltstone (1b) and the Lower (1c) Units.



The Unit consists of black silty slates, slates and some limestone beds. Bedding is generally difficult to recognize, and is defined by very thin silt or slate laminations in more thickly bedded units. The contact with overlying limey siltstones is interpreted as faulted (Fig. 3) and the base of the Unit is outside of the map area.

In thin section the finer grained rocks are almost opaque and comprise very fine grained, clay sized (Wentworth, 1922) sericite and saussurite rich sediment. The orientation of sericite and the long axes of quartz particles define the S_1 foliation. The siltstones are composed of medium-fine silt sized quartz and minor plagioclase particles and have a relatively low sericite content. Later crenulation cleavages are well developed, especially in the slates.

The Unit is probably also exposed on the eastern Dog Islands (Fig. 2). Here black silty slates are interbedded with bands of light brown weathering dolomitic slate (10 - 15 m. thick) and light grey limestone beds up to 1 metre thick. The limestone is strongly deformed and recrystallised. It consists of coral and crinoid fragments in a fine calcite mosaic with straight grain boundaries, meeting in triple points, and generally showing the effects of a strong annealing type recrystallisation (Spry, 1969).

Limey Siltstone Unit (c. 225 m)

This Unit outcrops to the west of Fox Cove on the northeastern shoreline of Horwood Bay (Fig. 2).

The Unit commonly comprises light grey, lime rich siltstones with interbedded sandy limestone, limestone, and rare greywacke and light brown weathering dolomitic siltstones. The Unit is generally thin to medium bedded and some sandy limestone beds are up to 3 metres thick.

In thin section the siltstones are composed of fine sand to medium silt size grains. Quartz is dominant, but some cloudy plagioclase is also present in a carbonate rich matrix which contains sericite and some saussurite. The sandy limestones contain quartz grains (15 - 20%), sericitised plagioclase (10 - 15%) and some clear sanidine (5%) is also present. The matrix (50 - 60%) consists of recrystallised calcite with some authigenic replacement by quartz, and subhedral to anhedral epidote probably replaces clay rich areas. The limestone interbeds contain large (2 - 3 mm) calcite crystals some of which show deformation twins, and recrystallised crinoid ossicles in a recrystallised groundmass of interlocking and elongate calcite crystals.

This Unit is probably also exposed on southern Dog Bay Island and on the western Dog Islands (Fig. 2). Southern Dog Bay Island is underlain by dolomitic silts and limestone beds, while limey siltstones and limestones are exposed on western Dog Islands. Rocks in both locations are tightly folded by northwest facing, slightly overturned folds. These structures are characteristically developed in the Limey Siltstone Unit on the shoreline at Horwood Bay.

Upper Phyllitic Slate Unit (c. 450 m+)

This Upper Unit of the Lower Formation is well exposed along the east and southeast shoreline of Horwood Bay at Horwood.

The Unit comprises thick, generally indistinctly bedded, grey slate and phyllitic slate, which commonly contain a well developed flat-lying kinking or crenulation cleavage. It overlies the Limey Siltstone Unit apparently conformably (Fig. 3) and is probably in fault contact with the overlying Stoneville Formation (Fig. 2).

In thin section the rocks are practically opaque and consist of very fine grained, clay sized, sericite and saussurite rich sediment.

Age of the Lower Formation

Previous workers (Twenhofel, 1947; Baird, 1958) have dated the rocks of the Lower Formation as Silurian, based on the coral fauna. However, most of the specimens are listed generically, and could possibly have ranged over a broad Upper Ordovician — Lower Silurian period. More recently Boucot, McKerrow and Ziegler (Berry and Boucot, 1970) have collected *Pentamerus sp.* at an unidentified locality. This suggests a late Llandovery age for the beds from which it came (Berry and Boucot, 1970).

In the present study 'Favosites type' corals were collected mainly from limestone beds and lenses on the Dog Islands. Further identification was not possible due to the effects of deformation and recrystallisation in the limestone.

Depositional Environment of the Lower Formation

While reliable indicators of environment are lacking, the fine grained lithological association of slatey-silty sediments would suggest deposition from turbidity currents in a distal environment.

Stoneville Formation

The name Stoneville Formation is proposed for the sandy siltstones, greywackes, slates, and thinly laminated beds containing outsize clasts (2 mm to 30 cm across), which are typically exposed on the southwest shoreline of Horwood Bay, near Stoneville.

These sediments have previously been included in the Indian Islands Group (Williams, 1964*a*). In the present study, stratigraphic, structural and some lithologic evidence indicates that the Formation is a probable facies equivalent of the Beaver Cove Formation in the northwest part of the map area. The Stoneville Formation is therefore a probable facies equivalent of the lower Botwood Group in Central Notre Dame Bay, and it is suggested here that the term Indian Islands Group be discarded.

The Stoneville Formation comformably underlies volcanic rocks here considered equivalent to the Port Albert Formation. This contact is clearly exposed near Squashberry Island, approximately one mile north of Stoneville. The Stoneville Formation is probably in fault contact with slates and siltstones of the Lower Formation. This contact, not exposed, is at the extreme south of Horwood Bay.

The Formation is exposed on the southern shore of middle Dog Bay Island, where it is much condensed (30 - 40 m). This part of the map area was not mapped in detail, but volcanic rocks, here considered equivalent to the Port Albert Formation, overlie this condensed sequence apparently conformably. The Formation is also exposed on the Indian Islands to the north (Williams, 1964*a*). To the south of the map area the Formation is in fault contact with shallow water sandstones of the Botwood Group (Williams, 1964*a*) (Fig. 1).

The three members are defined on the basis of separate lithologic associations — the Lower, the Diamict and the Upper.

Lower Member (c. 350 m)

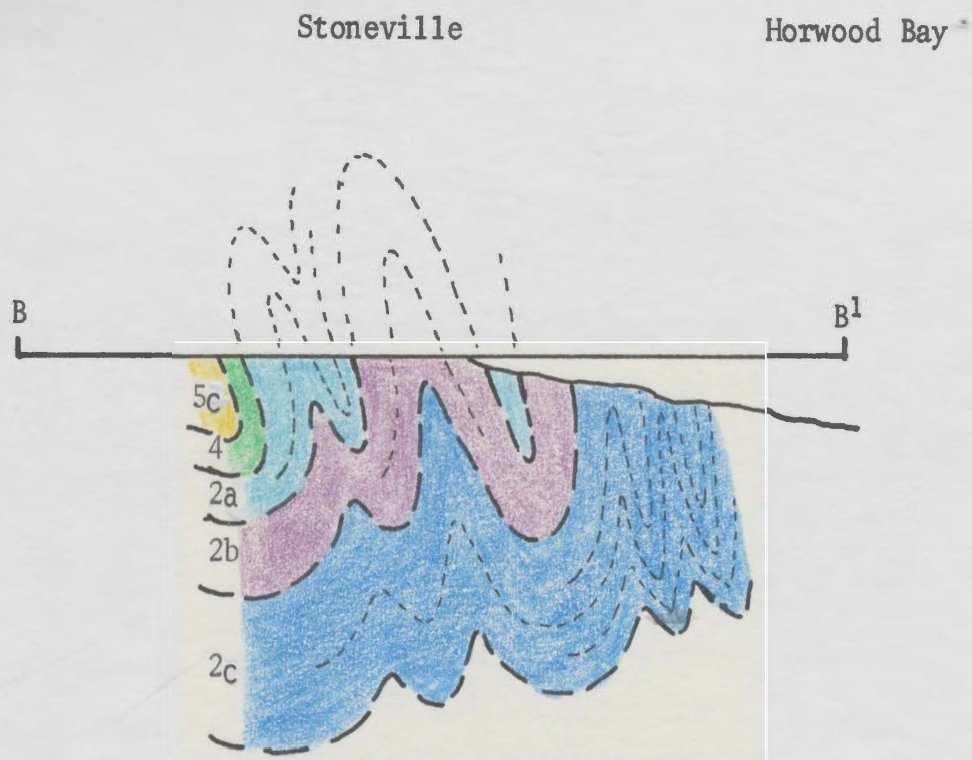
The Lower Member of the Stoneville Formation outcrops along the shoreline of southwest Horwood Bay at Stoneville, and it extends in a broad belt inland to the road which forms the boundary of the map area (Fig. 2).

The Member consists of interbedded slates and sometimes granular, sandy to fine siltstones. Bed thickness ranges from 25 cm to 1 - 2 m. The coarser beds generally show indistinct grading and, rarely, tabular cross-bedding and some ripple-drift cross-lamination.

The Member is very tightly folded on the shoreline at Stoneville, and almost isoclinal folds are generally slightly overturned to the northwest (Fig. 4). These structures complicate estimation of thickness but the Member is approximately 350 m thick at Stoneville.

In thin section the coarser beds are poorly sorted, immature and typically composed of approximately 35 - 40% very coarse sand size grains (1 - 2 mm diam.). Less commonly granules and small pebbles range up to 5 mm in diameter. Quartz grains comprise 20 - 25% of the sediments, are generally elongate and angular, and some show internal sutured crystal boundaries. Granitic fragments (5 - 10%) are chiefly of quartz-microcline, some of which show a micrographic intergrowth, and quartz-oligoclase grains are also present. Plagioclase (5%) is generally fine grained (0.3 - 0.5 mm), sericitised or replaced by calcite. Rhyolite and more rarely basic fragments (3 - 5%) are generally highly elongated and contained in the plane of flattening. The matrix 50 - 60% is

Fig. 4. Diagrammatic geologic cross-section B-B[1] (Fig. 2.)



chiefly composed of sericite, calcite and fine silt size quartz and some plagioclase grains. The S_1 foliation is defined by the orientation of sericite and elongate quartz grains. Calcite, although widespread in the matrix, tends to be concentrated in strain shadows against the larger grains.

Interbedded fine silt to slate beds sometimes contain up to coarser silt size quartz grains and rare plagioclase in a groundmass largely composed of authigenic calcite (replacing and etching quartz), sericite and chlorite.

Diamict Member (c. 105 m)

The Diamict Member of the Stoneville Formation occurs in a relatively narrow band which is well exposed on the shoreline to the north, and in road cuts to the southwest of Stoneville.

This Member is mainly composed of thinly laminated beds containing dispersed outsize clasts, hereafter termed diamict beds (Harland *et al.*, 1966). These diamict beds are interbedded and roughly alternate with feldspathic and lithic sandstones, siltstones and some slate. Bed thickness varies from 30 cm to approximately 5 m. On weathered outcrops the rock is a light buff colour and relationships between the laminations and contained clasts are clearly shown (Plate 1a). The diamict beds generally show an indistinct grading; otherwise sedimentary structures indicative of strong current action or mass flow phenomena are absent.

The local tight, slightly overturned fold style, associated with the first deformation is developed in the Member (Fig. 4) which is approximately 105 m thick.

Clasts supported in the matrix range in size from very coarse sand to cobbles and boulders up to 30 cm in diameter, and constitute between 5 and 40% of the rock. Sorting is generally poor with granules and cobbles (boulders more rarely) distributed randomly throughout each bed. The less ductile, igneous clasts have not been much affected by the deformation and are generally well rounded with clast form showing a variation from cylindrical to commonly discoidal and spherical types. Some pebbles and cobbles are facetted, and vary from roughly triangular, with rounded smooth edges to pentagonal "flat-iron" shapes (Plate 1b). Cobbles tend to lie with long axes aligned with the stratification (Plate 2a); however, some are aligned with long axes at or near to 90° to the stratification and S_1 foliation (Plate 2b). The diameter of these cobbles exceeds by many times the thickness of the bedding laminations. There is also a tendency for clasts to occur in clusters of twos and threes. In contrast with igneous clasts, the sedimentary clasts are generally highly flattened by the first deformation, resulting in thin discoidal shapes (Plate 3a) and similar relationships with bedding are not discernible.

The dispersed clasts consist on an average of: rhyolite-dacite (up to 20%); quartz-feldspar porphyry (up to 15%); mafic volcanic rock (up to 10%); granodiorite and quartz diorite (up to 10%); jasper (1 - 2%); greywacke (up to 8%); quartz and quartzite (up to 20%) and feldspar (oligoclase dominant, up to 10%). The clasts constitute up to 45% of the rock mass.

Porphyritic rhyolite and dacite clasts are most abundant. The former are more common and contain phenocrysts of quartz and sanidine in a recrystallised microcrystalline mosaic. The dacite clasts commonly contain phenocrysts of plagioclase (An 34).

Quartz-feldspar porphyry clasts are dominantly rhyolitic in composition. They consist of euhedral quartz and sometimes sanidine, microcline or heavily sericitised plagioclase phenocrysts in a devitrified finely granophyric and spherulitic groundmass (Plate 3b). The groundmass of these clasts consists of radiating aggregates of quartz and alkali feldspar, which are generally clustered around the phenocrysts. Tiny spherulitic crystallites of epidote and/or chlorite and larger masses of radiating epidote are also present, and probably replace amphibole or pyroxene.

Mafic lava clasts are commonly composed of heavily sericitised and saussuritised plagioclase laths in a dark brown glassy groundmass.

As in the Beaver Cove Formation, some granodiorite clasts have undergone a cold working type deformation before inclusion in the diamict. These contain plagioclase porphyroclasts in an elongate sutured quartz mosaic.

Greywacke clasts range from immature to submature, medium to fine sandstones. They contain some volcanic fragments and vary from subarkosic to arkosic in composition.

Over 50% of the diamict beds consist of irregular and discontinuous alternations of silt and finely siliceous laminae (Plate 4a). The lamination thickness generally averages between 1 - 2 mm but varies from 0.4 mm to 1.5 cm. The silt-finely siliceous couplets, then, are mainly less than 5 mm but may be up to 2 cm thick.

In general there appears to be an association of pebbles, etc., under 10 mm in diameter with the silty layers. Larger clasts tend to disrupt the laminae. Both silty layers and especially the finer grained finely siliceous laminae are rich in sericite, saussurite and chlorite. This implies an original high clay mineral content, and the finely siliceous laminae may result from recrystallisation (silicification) of clay layers.

The silt is composed of angular fragments of quartz and some plagioclase, is poorly to unsorted, and is an immature sub-arkose which is generally saussurite or chlorite rich. Grain size varies from fine to medium sandy silt to coarse silt. The finely siliceous laminae commonly comprise crypto-crystalline quartz mosaics, with infrequent fine silt size quartz fragments, and are generally rich in sericite, saussurite and chlorite. However, the laminae may also be composed of coarser microcrystalline varieties containing up to medium-fine silt size quartz particles.

The primary irregularity of the laminae (especially finely siliceous) has been enhanced by the regional deformation which produced the slaty cleavage (S_1) in finer grained beds. This enhancement has taken place in two ways: (i) disruption of laminae around 'augen' clasts in the plane of the S_1 foliation, and (ii) boudinage of laminae, also in the plane of S_1.

Grey to buff coloured sandstones, silts and sometimes slate are interbedded with the diamict beds. Primary structures, apart from poorly developed graded bedding and rare traces of cross-lamination, are absent. Bedding planes are sharply defined and dispersed clasts are absent (Plate 4b).

In thin section these sediments range from medium grained sandstones and poorly sorted sandy silts to slate. Angular and some elongate grains (especially quartz) are common and the rocks are generally texturally immature. Quartz (including grains with internal sutured boundaries) varies from 25 - 30%; plagioclase (oligoclase-andesine) 10 - 15%;

k-feldspar (sanidine dominant) 10 - 15%; quartz-plagioclase grains 5%; quartz-microcline grains with some micrographic intergrowth 3%; and rhyolite fragments up to 3% are present. The matrix (20 - 30%) is composed of very fine silt and clay, and is rich in chlorite, sericite and saussurite.

Upper Member (c. 140 m)

The Upper Member of the Stoneville Formation is well exposed on the shoreline south of Squashberry Island in southwest Horwood Bay. Inland to the southwest the exposure is very poor and is restricted to a small number of isolated moss covered outcrops.

The Member comprises some 140 m of interbedded feldspathic and lithic sandstones, silts and some slates. Diamict beds are relatively infrequent and form only a very small percentage of this Member. Bed thickness ranges from approximately 20 cm to 1 - 2 m and the sediments are similar in composition to those described in the underlying Member.

Depositional Environment of the Stoneville Formation

Lower Member

The lower 350 m of the Formation reflects a marked change in environment from the underlying relatively quiet water conditions of the Lower Formation of the Botwood Group. This change is represented by the influx of coarser sandy material, which results in the thick flysch-like sequence of interbedded sandy silts and slate. Sedimentary structures indicate that higher energy scouring type mechanisms were apparently inoperative during deposition. It is suggested that deposition took place from turbidity currents and that these rocks are intermediate to distal turbidities.

Diamict Member

The occurrence in this Member of diamict beds, composed of poorly sorted clasts in a matrix of thin, roughly alternating finely siliceous and silty laminae, is of especial significance, and forms the basis for discussion of the depositional environment of the entire Stoneville Formation. It will be demonstrated that this type of sediment was probably deposited in a glacio-marine environment largely by a process of iceberg-rafting.

The recognition of ancient glacial and glacio-marine deposits has long been a source of controversy (see Harland *et al.*, 1966 for a review). Briefly, many early claims for such environments (*circa* 1880-1930) were later discredited (1950-1960), and more recently a careful re-examination of these deposits is being carried out (Harland, 1972).

The identification of glacial environments is dependent on the presence of a number of criteria (Harland *et al.*, 1966). In the present study the relevant criteria will be considered under a number of headings, as follows:

1. *Clast Characteristics*

a) The larger clasts occur sporadically, although there is a tendency in places for concentrations or clusters to occur (Ovenshine, 1970). The Pre-Devonian age of the deposit rules out the possibility of biological rafting, and the extent and thickness of the Member appears too great for transport and deposition from seaweed (Harland *et al.*, 1966; Schenk, 1972).

b) Variability in clast shape. Clasts displaying facets and pentagonal 'flat-iron' shapes are possibly indicative of glacial abrasion (Plate 1b) (Schenk, 1972).

c) Clasts generally lie with long axes parallel to the stratification. Some clasts characteristically have long axes normal to bedding, possibly indicating rafted deposition (Plate 5a) (Crowell, 1964; Harland *et al.*, 1966). However, ice-rafted stones may display both orientations (Spjeldnaes, 1965).

2. *Stratification Characteristics*

a) Stratification containing the clasts: Roughly rhythmically alternating finely siliceous and silty laminae suggest periodic varve-like deposition in a standing body of water, possibly lacustrine or estuarine (Crowell and Frakes, 1972). Association of pebbles, etc., under 10 mm in diameter with the silty layers appears to point to a mechanism whereby the silty layers were deposited rapidly, while the finer grained finely siliceous laminae took longer. Such a mechanism could be related to vertical density currents (Bradley, 1965), caused by the tilting of icebergs, with a sudden discharge of their load (Ovenshine, 1970).

b) Clast/Stratification relationship: Both the clasts with long axes parallel to bedding and especially those with long axes normal to bedding distort and penetrate the varve-like laminae. Where the underlying layers are clearly disrupted and penetrated — this criterion is regarded as decisive evidence for rafting (Harland *et al.*, 1966). This relationship, although sometimes observed in the Diamict Member, has tended to be obscured by the regional deformation (D_1). In any case, penetration and deformation of the strata below an iceberg rafted clast may be very slight, absent, or indistinguishable from the later effects of compaction (Ovenshine, 1970). In addition, clasts are randomly distributed with respect to bedding and there is no indication of penecontemporaneous erosion of the laminae about the clasts. If present, this would suggest that they were lag clasts (Crowell and Frakes, 1972).

3. Effects of Deformation (D_1) *on Clasts*

The member has undergone the regional flattening associated with the first deformation (see Ch. IV) and criteria for identification of glacial deposits tend to be obscured as follows:

a) Apart from a tendency to brittle failure, the less ductile igneous clasts show little evidence of deformation. However, sedimentary clasts are strongly deformed into thin discoidal shapes, and glacial surface textures, if any, were destroyed.

b) During deformation, only clasts with long axes near to vertical to the plane of flattening (at Stoneville = plane of stratification) would retain their original orientation. All others rotate towards the plane of flattening.

c) Small pellets of poorly sorted sediment (Ovenshine, 1970) are probably flattened so that their significance is obscured.

4. Effects of Deformation (D_1) *on Stratification*

a) Finely siliceous laminae: The unpersistent irregular nature of the finely siliceous laminae has been enhanced by the effects of deformation. This has taken place by a process of boudinage or flattening around clasts.

b) Clast/Stratification relationship: The deformation has generally caused the finely siliceous and silty laminae to be broken and depressed around both top and bottom of the clasts (Plate 5b).

5. Sedimentary Structures

Apart from an imperfect grading in some diamict beds, sedimentary structures are absent. Submarine mass flow processes which would have associated slump type structures are therefore unlikely as a mechanism of formation for these beds (Aalto, 1971; Schenk, 1972).

6. Interbedded Sediments

Deposition most likely took place from turbidity currents. These may have originated from slumping of glacially derived material, possibly of a seasonal or periodic nature. The association of turbidities with glacial deposits has been noted by several authors (Heezen and Hollister, 1964; Harland *et al.*, 1966; Binda and Van Eden, 1972; Reid and Tucker, 1972).

7. Conclusion

The evidence indicates possible iceberg rafting of the larger clasts in the Diamict Member and deposition in varve-like sediments. The formation of these varve-like sediments may be related to (i) deposition from debris laden icebergs by vertical density currents, or (ii) deposition mainly from low density suspension currents (Keunen, 1951; Heezen and Hollister, 1964), or possibly some combination of both. The interbedded sandstones result from periodic turbidity currents, and material remaining in suspension after deposition may contribute to the varve-like sedimentation. The lack of dispersed clasts in the interbedded sandstones possibly denotes direct interplay between turbidity current and ice rafting mechanisms of deposition. It is suggested that such interplay would most likely occur in a relatively restricted environment, possibly lacustrine or estuarine.

Upper Member

The infrequent occurrence of diamict beds in this Member with an increasing proportion of flysch-like sediments would suggest the waning influence of the glacio-marine environment, and return to deposition mainly from turbidity currents.

Regional Significance of the Stoneville Formation

The evidence for a glacio-marine derivation of diamict beds in the Stoneville Formation has been presented. This evidence is strengthened if similar sedimentation can be demonstrated elsewhere in the Upper Ordovician — Lower Silurian times.

The existence, centered in Northwest Africa, of a major Late Ordovician ice age (Harland, 1972) may then be very important in palaeoenvironment interpretation of the Stoneville Formation. The sedimentologic and stratigraphic evidence for this glaciation (Beuf *et al.*, 1971; Fairbridge, 1971; Reid and Tucker, 1972) indicates that a major ice sheet lay over the continental area of Northwest Africa during Late Ordovician — Early Silurian times. Palaeomagnetic evidence (McElhinny *et al.*, 1968; McElhinny and Luck, 1970; McElhinny and Briden, 1971) plots the Palaeozoic mean poles (south) for Gondwanaland in the region of Northwest Africa (Fig. 5). However, North American palaeomagnetic results (Creer, 1970; Hicken *et al.*, 1972) show Palaeozoic poles (south) to the southwest of West Africa, near Sierra Leona (Fig. 5). These palaeomagnetic results are difficult to evaluate because of the problem of reconstructing palaeocontinental positions during the Palaeozoic era and are not therefore very useful. However, deposits showing strikingly similar stratigraphic and sedimentologic characteristics to the Diamict Member of the Stoneville Formation have been described in the White Rock Formation in Nova Scotia (Schenk,

Fig. 5. Regional significance of the Diamict Member of the Stoneville Formation*

*1 - Diamict Member, Stoneville Formation

*2 - Schenk, 1972

*3 - Reid and Tucker, 1972

*4 - Temain, 1971

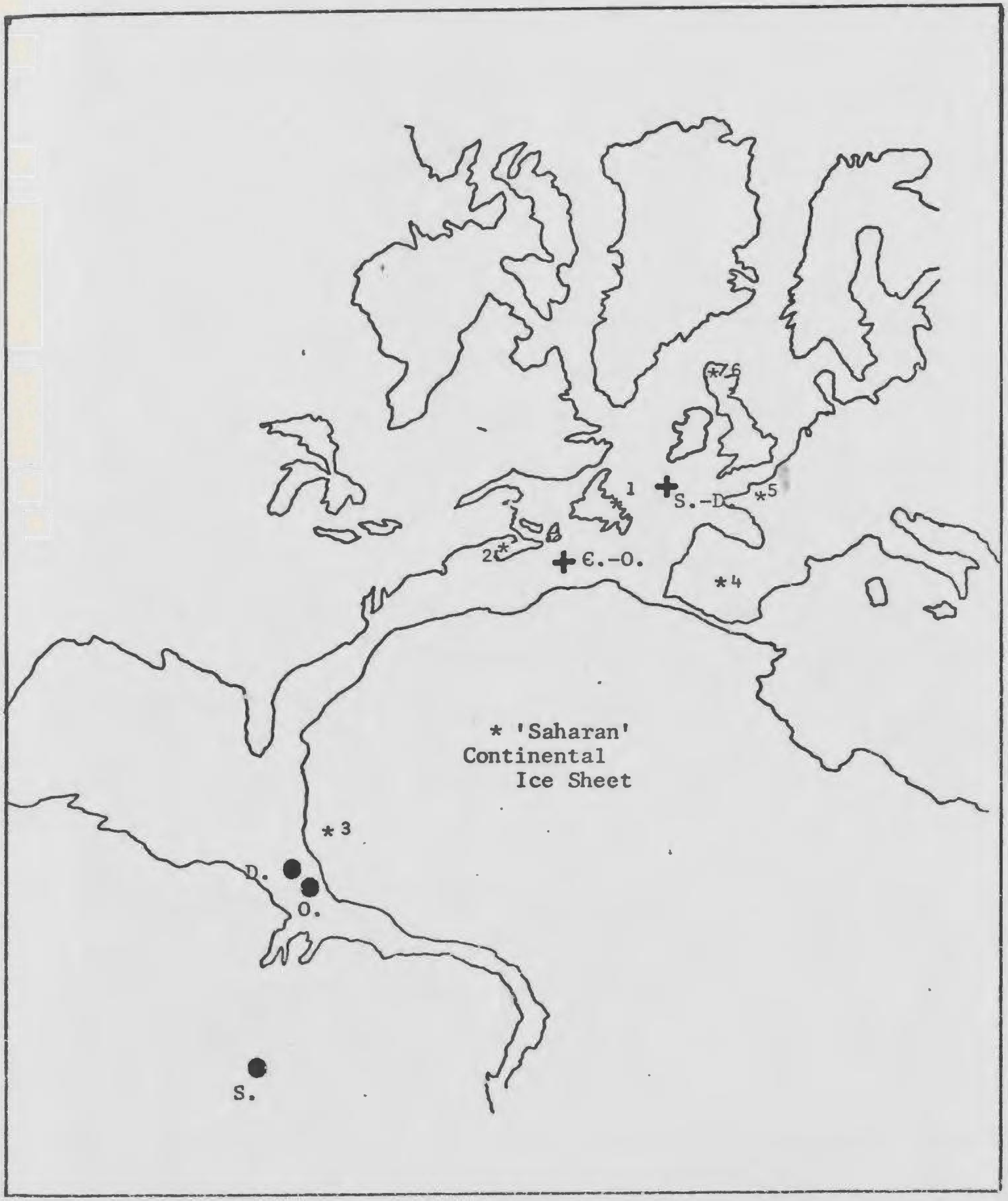
*5 - Dangeard and Doré, 1971

*6 - Sutton and Watson, 1954; Harland, 1972

● North American Palaeozoic Palaeomagnetic Poles (South)

+ Gondwanaland Palaeozoic Palaeomagnetic Poles (South)

*Fit of continents from Bullard *et al.*, 1965.



*7
6
1
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Continental
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1972), and the Waterfall Formation in Northern Sierra Leone (Reid and Tucker, 1972) (see Table III for a summary of characteristics). In Scotland, ice rafted sediments in the Macduff Group (Sutton and Watson, 1954) may be of Late Ordovician age (Harland, 1972). Late Ordovician glacio-marine sediments have also been interpreted in Normandy (Dangeard and Doré, 1971), and evidence of glaciation of a similar age has been described in Spain (Temain, 1971) (Fig. 5).

The Diamict Member of the Stoneville Formation thus appears to be related to other similar deposits over a widespread area, and its glacio-marine origin appears evident. It now follows that the sudden influx of flysch-like sediments, i.e. the Lower Member of the Stoneville Formation, may be indirectly related to the Diamict Member. These sediments may possibly relate to a glacio-eustatic lowering of sea level such as described by Burke and Waterhouse (1973). However, block faulting and plutonism (Helwig and Sarpi, 1969) were likely other influences in the general region.

LITHOLOGIC UNITS OF THE NORTHWESTERN PART OF THE MAP AREA

Beaver Cove Formation

The name Beaver Cove Formation is proposed for the conglomerate, greywacke, silt unit of the Botwood Group which is conformably overlain by the Port Albert Formation. The Formation outcrops in a relatively narrow zone in the northwest of the map area from the Farewell Duck Islands in the north to Lower Indian Brook in the south (Fig. 2). Rock exposure is very good along the northwest shore of the Peninsula, but inland is very poor.

The conformable contact between the Beaver Cove Formation and the

Table III. Comparison of Upper-Ordovician — Lower Silurian glacio-marine deposits and other glacio-marine deposits of different ages.

			Diamict Member Stoneville Formation Newfoundland (This study)	White Rock Formation Nova Scotia (Schenk, 1972)	Waterfall Formation North Sierra Leone (Reid and Tucker, 1972)	Macduff Group Scotland (Sutton and Watson, 1954)	Great Conglomerate (Kundelungu Tillite) Zambia (Ice-rafted beds) (Binda and Van Eden, 1972)	Dwyka Tillite Karoo Basin, South Africa (Crowell and Frakes, 1972)
Upper Ordovician — Lower Silurian Age			*	*	*	Possible	Pre-Cambrian	Upper Carboniferous
Thickness of Deposit			c. 105 m	1 m	150 m	5 m	Variable	5 m
Variable Clast Composition			*	*	*	*	*	*
Size Range of Clasts			Up to 30 cm	Up to 10 cm	Up to 30 cm	5 cm - 1 m	1 mm - 2-3 cm	Up to 40 cm
Patchy Clast Distribution			* (+ some clustering)	*	*	*	*	* (+ clusters)
Variable Clast Morphology			* (+ some facets)	* (+ facets and 'flat-irons')	*	*	*	
Clast Long Axes both In and Normal to the Plane of Stratification			*	*	*	*		*
Stratification Containing the Clasts	Alternating coarse-fine laminae		*	Poorly thinly stratified	*	Graded greywacke beds	*	*
	Couplet thickness		Up to 2 cm Gen. < 5 mm		3-4 mm	15-70 cm	1-8 mm	Up to 10 cm
Clast to Stratification Relationship	Deformed		*	*	*	*	*	
	Larger clast diameter >> Stratification thickness		*	*	*	*	*	*
	Disruption of stratification beneath clast		Some	*	*	*	*	*
Effects of Deformation	On clasts	Igneous	Brittle					
		Sedimentary	Flattening (k ≈ o)					
	Disruption of stratification around clasts		Common	*			*	
	Boudinage of finely siliceous laminae		Common					
Common Sedimentary Structures			Imperfect grading in greywackes	Grading	Grading, scouring, slumping	Grading, small-scale current-bedding		
Interbedded Sediments			Turbidites		Channel turbidites		Pebbly mudstone, graded sands	Massive diamictite
Suggested Mechanisms for Deposition	Ice-rafting		*	*	*	*	*	*
	Turbidity Currents		*		*	*	*	

overlying Port Albert Formation is well exposed at the base of the cliffs along the northwestern shoreline of the Peninsula. It is also exposed at Lower Indian Brook and at Farewell Duck Islands (Fig. 2). The base of the Formation is not seen.

The Beaver Cove Formation is divided into three members: (i) a Lower Member comprising generally thin-bedded siltstone and mudstone with some greywacke, (ii) a Conglomerate Member composed of graded units of polymict conglomerate and greywacke, with interbedded greywacke and siltstone units, and (iii) an Upper Member consisting of thin-, inter-bedded siltstone and greywacke and some slate, with volcanic detritus common near the top of the member.

The Formation is also exposed to the north on Change Islands, where it has been referred to as the Change Islands Formation (new) (Eastler, 1969). Here the Conglomerate Member is absent and the Formation consists of approx. 1,000 m of greywackes and silts. To the south the Formation outcrops as far as Lewisporte (Fig. 1) and at West and Southwest Arms of New Bay (Williams, 1964*a*).

Lower Member (210 m +)

This Member, the base of which is not seen, conformably underlies the Conglomerate Member. It is well exposed around the shoreline at Beaver Head on the extreme northwest of the Peninsula. Here relatively thin-bedded (< 60 cm thick) medium to fine silts and some greywackes alternate with very thin mudstone layers (5 - 10 cm thick). Some of these layers show ripple laminations.

In thin section the silts are similar to those in the overlying Member, i.e. immature, sericite and saussurite rich, and subarkosic to arkosic in composition. The mudstones are almost opaque, saussurite and sericite rich clays, which generally contain scattered fine silt sized quartz fragments. Greywackes chiefly occur near the top of the Member and are similar in composition to those in the overlying Member.

Conglomerate Member (c. 210 m)

This Member is best exposed on the west shore of Little Beaver Cove and also on Hare Island, farther to the north. To the southwest, it extends in a relatively narrow zone to Little Beaver Cove and Lower Indian Brook (Fig. 2). The Member is composed of graded polymict conglomerate and greywacke units with interbedded greywacke and siltstone. Conglomerates are not exposed on Change Islands, north of the map area (Fig. 1), and here the sequence comprises some 1000 m of interbedded greywacke and silt (Eastler, 1969).

Beds range in thickness from 50 cm to 3 - 4 cm, and are commonly well graded (Plate 6a). Shallow channels occur at the base of some conglomerate beds at Little Beaver Cove and south Hare Island. These range in width from 3 - 5 m across and are approx. 50 cm to 1 m deep.

The conglomerates are composed of chert, silt, greywacke, jasper, quartz, acid to intermediate volcanic clasts, granitic fragments and and some fossiliferous limestone clasts.

Clast diameter ranges up to a maximum of approx. 30 cm. However, the average maximum diameter is approx. 3 - 5 cm or medium to large pebble size (Plate 6b). Most igneous clasts are well rounded and show a high degree of sphericity, whereas most chert and sedimentary clasts tend to be angular or subangular and of low sphericity. These chert and sedimentary clasts are commonly flattened in the plane of the S_1 foliation.

Conglomerate clasts constitute 70 - 90% of the rock mass and consist of an average of: chert and jasper (35%), rhyolite and dacite (15%), mafic lava (13%), granophyric clasts (10%), greywacke and siltstone (10%), granitic clasts (8%), limestone and lime silt (4%), quartz and feldspar grains (5%). Clast descriptions are as follows:

Chert and jasper. These clasts comprise micro- and cypto-crystalline quartz mosaics with varying amounts of finely dispersed haemititic iron oxide. Many of the crypto-crystalline varieties are rich in sericite, and some are dark brown, saussurite rich, and contain tiny quartz grains (approx. .01 mm diam.). The latter were possibly originally fine muds or clays that were later silicified.

Rhyolite and dacite. Porphyritic rhyolite is most abundant and comprises approx. 75% of this grouping. The phenocrysts are commonly composed of embayed and euhedral quartz and euhedral sanidine in a microcrystalline mosaic. Some clasts contain phenocrysts aligned by flow. Dacite clasts are sometimes prophyritic and contain phenocrysts of plagioclase (An_{34}).

Mafic lava. Clasts are composed of heavily sericitised and/or saussuritised plagioclase laths in a dark brown glassy groundmass. They may be andesitic in composition. Some of the plagioclase laths show a flow alignment.

Granophyric clasts. Clasts showing a micrographic intergrowth of quartz and alkali feldspar are grouped under this heading. Composition is commonly granodioritic in the coarser grained varieties. Here isolated blebs and patches of quartz occur in alkali feldspar in the groundmass.

Quartz-feldspar porphyries also show this texture. They contain finely granophyric, commonly spherulitic intergrowths of quartz and alkali feldspar, which tend to cluster around the phenocrysts.

Greywacke and siltstone. Sedimentary clasts vary in grain size from medium to fine sandstone to fine siltstone. The greywackes are commonly immature to submature, subarkosic to arkosic and some are chert or volcanic bearing. The siltstones are subarkosic in composition.

Granitic clasts. The most abundant plutonic clasts are granodioritic in composition. They commonly contain quartz (20 - 30%), oligoclase and andesine (30 - 40%), k-feldspar (15 - 20%), chlorite and saussurite (5 - 10%), and minor calcite. Albitic rims on the plagioclase are common. Other plutonic clasts include quartz diorite, some trondhjemite and rare granite.

Some granodiorite clasts contain fabrics probably produced by a strong cold working type of deformation. The fabrics are defined by partially recrystallised elongated quartz mosaics which contain sutured grain boundaries. This fabric contains augens of heavily sericitised plagioclase porphyroclasts. A later crenulation of the fabric was seen in one clast. Other clasts show effects of cataclasis. Corroded quartz and sericitised plagioclase phenocrysts are set in a fine grained partially recrystallised quartz aggregate. Plagioclase commonly shows kinked twins and quartz a strong undulose extinction.

Limestone-limey silt. A minor quantity of limestone, limey silt and buff weathering dolomitic clasts are present. Some clasts are fossiliferous. They consist of a recrystallised elongated and interlocking groundmass of calcite with varying amounts of silt sized quartz grains and some authigenic quartz.

Quartz and feldspar. Quartz and quartzite grains range in size up to 4 mm. Clear quartz is most common but some grains show a strong undulose extinction. Many of the larger clasts consist of elongate quartz crystals with suture grain boundaries. The feldspar mainly consists of unaltered sanidine. Sericitised and saussuritised oligoclase and andesine and rare monomineralic plagioclase (An_{34}) rock are also present.

The conglomerate matrix ranges from 10 - 30% of the rock, is poorly sorted and texturally immature. Grain size ranges from medium to fine sandy silt composed of quartz, sanidine plagioclase, epidote and rock fragments. The grains are surrounded by a greenish mixture of chlorite and saussurite.

Greywacke and siltstone occur in both graded conglomerate units and as interbedded sequences between conglomeratic horizons. These sequences are up to 70 m thick and make up approx. 50% of the Member at Little Beaver Cove.

Grain size varies from pebble (4.5 mm) to fine sand and silt (0.1 mm diam.). The grains are sub-angular to sub-rounded and these sediments are poorly sorted and texturally immature.

Rock fragments (40 - 45%) of similar composition to the conglomerate clasts are most abundant in the coarser grained greywackes. These consist of micro- and crypto-crystalline chert (max. 25%) rhyolite and dacite (max. 20%) and mafic lava (max. 10%). Some of the finer grained acid volcanic grains show a spherulitic, finely micrographic intergrowth of quartz and alkali feldspar. Quartz (up to 25%) is chiefly composed of sericitised oligoclase-andesine, sanidine, and lesser microcline, orthoclase and some myrmekite. The matrix (up to 15%) comprises fine silt size quartz and feldspar in a groundmass rich in calcite, chlorite, sericite and some saussurite.

The silts are generally immature, sericite and saussurite rich and are subarkosic to arkosic in composition.

Upper Member (c. 70 m)

This Member is best exposed on the northwest shoreline of the Peninsula near Little Beaver Cove, and it extends in a narrow zone southwest to Lower Indian Brook (Fig. 2). It is composed of thin-bedded, dark grey silts with greywacke and slate interbeds. Bed thickness ranges from 15 - 60 cm. Slump structures, e.g. convolute bedding and slump brecciation, are evident on the northwest shore of the Peninsula near Hare Island, close to the contact with the overlying Port Albert Formation.

In thin section, grain size ranges from 0.02 to 0.12 mm, i.e. coarse silt to very fine sand. The grains vary from angular to sub-rounded and sorting is poor. The silts are composed of quartz and chert (25 - 30%), sericitised plagioclase (olig.-and.) (20 - 25%), sanidine (10 - 15%), orthoclase (5 - 10%), myrmekite (0.5 - 1%), mafic lava fragments (1 - 2%), and muscovite (1 - 2%). The matrix (15 - 20%) is composed of chlorite, saussurite and some calcite.

Interbedded greywacke ranges in grain size 0.04 mm to 0.5 mm, or fine to medium sand. The grains vary from sub-angular to sub-rounded and the rocks are texturally immature. The rocks are composed of: quartz (10 - 15%), chalcedony (sometimes slightly spherulitic) (5 - 10%), sericitised and saussuritised plagioclase (olig.-and.) (15 - 20%), sanidine (10 - 15%), orthoclase (3 - 5%), and rock fragments consist of: vitrophyric lava with relic plagioclase laths outlined by sericite (10 - 15%), and rhyolite

(2 - 5%). The matrix of sericite, saussurite and chlorite ranges from 10 - 15%.

This Member appears very similar to volcanic bearing thin-bedded siltstones which outcrop on Change Islands to the north (Eastler, 1969). There the siltstones occur at the top of a greywacke sequence and conformably underlie volcanic rocks, as does the Upper Member on the Port Albert Peninsula.

Depositional Environment of the Beaver Cove Formation

The well developed graded bedding and shallow channels, especially in the Conglomerate Member, indicate deposition from turbidity currents. In local context the coarse grained nature of the Conglomerate Member suggests that these currents were of a proximal nature. The apparent lenticularity of the Formation to the southeast (Fig. 2, sec. $A\text{-}A^1$), and the non-deposition of the Conglomerate Member to the north, on Change Islands, possibly indicates proximity of the Port Albert area to the boundary of the Beaver Cove Formation's basin of deposition.

The slump structures near the contact with the overlying Port Albert Formation, and the volcanic content in the Upper Member, are attributed to the nearby volcanism.

Age of the Beaver Cove Formation

Fossiliferous limestone fragments, contained in the Conglomerate Member at Beaver Cove, have been described by Williams (1963). The fossils (coral and crinoidal debris) are poorly preserved and exact identification is impossible. Similar limestone fragments occurring in known Silurian conglomerates, elsewhere in northeast Newfoundland, suggested to Williams

(1963) a Silurian age for these rocks. In the present study, a fossiliferous limestone clast was found in the Conglomerate Member, on a small island between Hare Island and Farewell Duck Islands (off the northwest extremity of the Peninsula). This yielded a Syringophyllid tabulate coral (possibly Saffordophyllum) of Middle or possibly Upper Ordovician aspect (R.K. Jull, 1972 pers. comm.). The effects of recrystallisation and deformation make a more precise identification impossible. However, this find indicates that the conglomerate postdates accumulation of limestones of Mid.-Upp. Ordovician age.

Eastler (1969) has identified Silurian favositid corals contained in thin bedded siltstones on Change Islands. These rocks are probably similar to those of the Upper Member of the Beaver Cove Formation, on the Port Albert Peninsula.

Relationship of the Beaver Cove Formation to the Goldson Formation

Palaeocurrent indicators were not seen in the Beaver Cove Formation, but shallow channels at the base of some conglomerate beds show an approximate northwest-southeast orientation. Sole markings from the northerly continuation of the Beaver Cove Formation on Change Islands show a northwest source area (Eastler, 1969). So that, indirectly, the Beaver Cove Formation is probably derived from the northwest.

Silurian conglomerates occur on New World Island to the northwest of the area. These have been referred to the Goldson Formation (Twenhofel and Shrock, 1937) which locally attains a thickness exceeding 2,000 feet (Williams, 1967). This Formation has been considered equivalent to the basal conglomerate unit of the Botwood Group (Williams, 1964*a*, 1967), similar to that exposed on the northwest Port Albert Peninsula.

This interpretation is supported by many striking similarities between the Goldson Formation and the Conglomerate Member of the Beaver Cove Formation. In particular, the plutonic and volcanic clast associations and clast morphology are very similar (see Helwig and Sarpi, 1969 for Goldson Formation description). Sedimentary clasts are approximately similar, with ubiquitous chert, jasper, greywacke and less frequently limestone. The sedimentary clast morphology contrasts with igneous clast morphology in both deposits. So, dominantly angular to sub-angular sedimentary clasts with low sphericity imply a nearby source area, whereas the relatively well rounded nature of the igneous clasts with accompanying high sphericity suggests considerable transport and/or the influence of a littoral environment.

However, in contrast with the Beaver Cove Formation, the Goldson Formation is very much thicker, contains larger clasts (diameters > 50 cm are common), and shows abundant evidence of mass flow phenomena. These features suggest the comparatively proximal deposition of the Goldson Formation, and contrast with the more distal nature of deposition of the Beaver Cove Formation.

It is stressed, however, that widespread faulting (Fig. 1), generally of unknown displacement, and possibly of a strike-slip nature, greatly complicates palaeogeographic restorations in the area. In particular only more general comparisons can be made between New World Island and the Port Albert Peninsula since these areas are separated by a major fault zone, i.e. the Reach Fault, which forms the boundary between tectonostratigraphic Zone E and Zone F (Williams *et al.*, 1972) in Central Newfoundland.

Provenance of the Beaver Cove Formation

The source of the igneous clasts in the Conglomerate Member of the Beaver Cove Formation appears most likely to have been from a terrane similar to the Loon Bay and/or Twillingate plutons and volcanic rocks of the Lush's Bight Group (Fig. 1). The Loon Bay and Twillingate (Williams, 1963, 1964*a*; Williams *et al.*, 1972) plutons are chiefly composed of granodiorite with lesser quartz diorite. The Twillingate pluton has undergone strong zonally developed deformations (J. Payne, 1973, pers. comm.). This may be reflected by the association of non-deformed with strongly deformed granodiorite clasts in the Conglomerate Member at Little Beaver Cove. The Lush's Bight Group dominantly composed of mafic volcanic rocks most probably supplied the volcanic clast assemblage in the Conglomerate Member. Similar provenance interpretations have been made for igneous clasts in the Goldson Formation on New World Island by Kay (1967; 1969), and Helwig and Sarpi (1969). Source lithologies for the sedimentary clasts are widespread in Ordovician rocks on New World Island terrane, and the chert and jasper may relate to volcanic associations which are also common in the regional stratigraphic column.

Relationship of the Beaver Cove Formation to the Stoneville Formation

The Beaver Cove and Stoneville Formations outcrop on opposite sides of a broadly synclinal structure which underlies the central parts of the Port Albert Peninsula. Both form part of similar Lower Silurian sequences which resemble Botwood Group stratigraphy. However, due to lack of continuous exposure and indigenous fossils, correlation between the Formations must remain speculative (Fig. 2, sec. $A\text{-}A^1$).

The Conglomerate Member of the Beaver Cove Formation has been deposited from turbidity currents and may have a distal relationship to conglomerates of the Goldson Formation, presently exposed on New World Island. The distal nature of this Formation is possibly also suggested by the absence of conglomerates deposited from turbidity currents in the Stoneville Formation, indicating lenticularity of the Beaver Cove Formation to the southeast.

Deposition of the Diamict Member of the Stoneville Formation most probably took place by ice rafting with periodic deposition of finer beds from turbidity currents. The igneous clast morphology and assemblage of the diamict beds is generally similar to that of the Conglomerate Member of the Beaver Cove Formation. In particular both members contain granodiorite clasts with fabrics produced by cold working deformation. It has been suggested that terranes similar to Loon Bay, Twillingate and Lush's Bight may have provided the igneous clast assemblage of the Beaver Cove Formation. The generally similar igneous clast assemblage in the Diamict Member of the Stoneville Formation may have been derived by resedimentation via floating ice from shorelines associated with the above terranes. However, good palaeocurrent indicators were not seen in the Stoneville Formation and the site of the source terranes is therefore unknown.

LITHOLOGIC UNITS OF THE CENTRAL PART OF THE MAP AREA

Port Albert Formation

The name Port Albert Formation is proposed for the volcanic unit of the Botwood Group, which conformably overlies the Beaver Cove Formation.

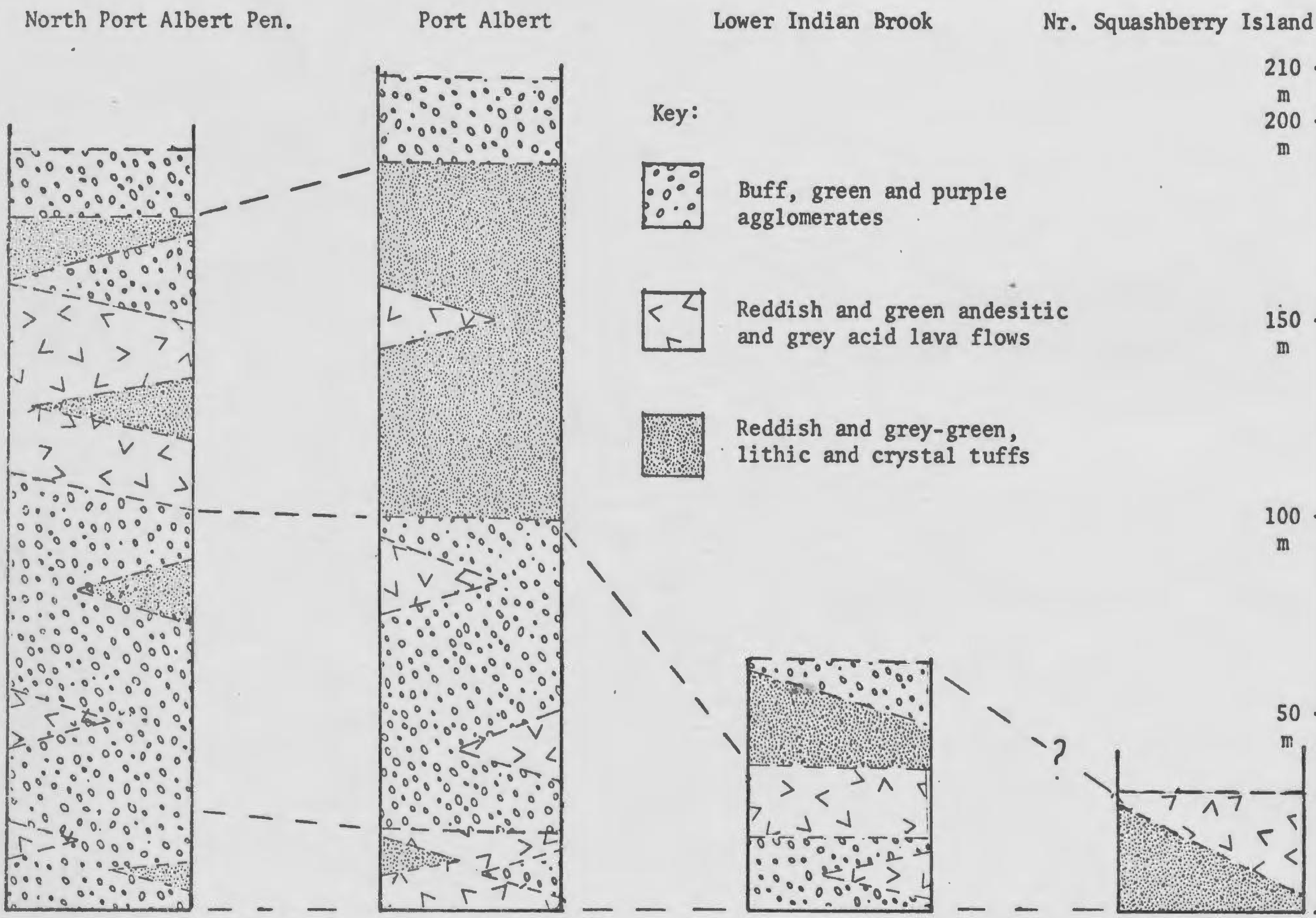
These volcanic rocks are almost continuously exposed from Change Islands in the northeast to the Bay of Exploits in the southwest (Williams, 1964*a*) (Fig. 1). The type area is chosen at Port Albert, where locally the section is thickest, and the conformable contact with underlying sediments clearly exposed. This relationship is also seen at Lower Indian Brook and on the eastern Farewell Duck Islands.

The Port Albert Formation is at least 210 m thick in its type area, but appears to thin to the southwest. At Lower Indian Brook a narrow band (50 - 70 m thick) of volcanic rocks, here assigned to the Port Albert Formation, is exposed on the shoreline (Fig. 6). Elsewhere, the Formation has been estimated at 1,700 m. approx. (Williams, 1967) and approx. 1,000 m at Change Islands (Eastler, 1969).

Near Squashberry Island on the southeastern shoreline of the Peninsula, volcanic rocks (approx. 30 m thick) of similar composition, here correlated with the Port Albert Formation, are exposed (Figs. 2 and 6). These rocks are northwest facing, dip southeast, and display a conformable contact with the underlying Stoneville Formation. Volcanic rocks with similar relationships are exposed on the southern shore of middle Dog Bay Island. These are also correlated with the Port Albert Formation.

The Formation consists of undivided: buff green and purple agglomerates, reddish and green intermediate and grey acid flows, and a variety of reddish to grey-green tuffs. Agglomerates are prominent at the base and upper part of the Formation, especially near Port Albert (Fig. 6). Here coarse agglomerates form up to 50% of the lithologic units. The mid-parts of the section are largely composed of fine grained, sometimes vesicular andesitic flows on the northern shoreline of the Peninsula. Near Port Albert lithic and crystal tuffs are dominant (Fig. 6). The thickness of the lithologic units (Fig. 6) are approximate since many are

Fig. 6. Columnar sections in the Port Albert Formation



lenticular and bedding is commonly difficult to recognise.

Agglomerate

Coarse agglomerates consist of a variety of poorly sorted angular and sub-rounded volcanic fragments (Plate 7a). Clast size varies from approx. 2 cm in diameter to large blocks 60 cm or more across. Most of the fragments are reddish brown, amygdaloidal and sometimes porphyritic andesite. Others are reddish porphyritic and of rhyolite to dacitic composition. Clasts of lithic and crystal tuff were also noted.

In places the agglomerates contain fragments that appear to be water worn. Some lenses of coarse tuffaceous feldspathic silt contain small shreds of andesitic flow rocks. Near the contact with overlying sandstones on the northern shoreline of the Peninsula discontinuous silt lenses define bedding. This is at a shallow angle to steeply oriented agglomerate clasts (Plate 7b). The orientation appears a primary depositional feature and is not related to the regional penetrative cleavage (S_1) which has a similar trend.

In thin section, the fragments are similar in composition to the interbedded flow rocks and tuffs. The coarse tuffaceous silt matrix is dominantly composed of angular quartz grains. Some sanidine, sericitised plagioclase and muscovite are also present. The groundmass is rich in saussurite and calcite and also contains sericite and chlorite. The commonly red appearance of the matrix and fragments results from the abundance of finely dispersed haematite.

Lithic and Crystal Tuffs

The tuffs are commonly thickly bedded (1 - 5 m) and range in composition from coarse lithic lapilli tuffs with some crystals to more crystal rich and lithic varieties.

In thin section the more lithic tuffs consist dominantly of angular to sub-angular vitrophyric intermediate lava fragments. These range in diameter from 0.4 mm to 5 mm across. The fragments contain heavily sericitised plagioclase laths which range up to 1.5 mm across and sometimes show a tachylitic texture. Amygdaloidal varieties with chert filled amygdules are also present. Rhyodacitic, dacitic, and sometimes trachytic rhyolite clasts are also common. These range in size from 1 mm to 8 mm across and vary from sub-angular to sub-rounded. The larger clasts are enclosed in augen of the cleavage. Plagioclase phenocrysts (An_{30-34}) in these clasts are generally replaced by sericite or calcite, and the glassy groundmass is partially altered to saussurite and calcite. Broken and abraded crystals are also present in varying amounts. These are commonly plagioclase (An_{34}) which is generally sericitised or replaced by calcite. Some tuffs are rich in microcline and sanidine crystals.

The matrix of the tuffs is a very fine grained recrystallised quartz feldspar aggregate. It is commonly altered by sericite and calcite and some chlorite. Varying amounts of haemetite are present.

Lithic and crystal tuffs, near Squashberry Island, are strongly deformed. Very fine grained laminated tuff clasts are locally common. These clasts and vitrophyric intermediate lava fragments are flattened in the plane of the foliation. Dacitic clasts are resistant to the deformation and are enclosed by augen of the cleavage. Flattened lenses of silt are also present in the matrix, which is similar to that described at Port Albert. Agglomerates, however, were not seen in this section, and this lithology is also absent in volcanic rocks on Middle Dog Bay Island.

Flows

Non-pillowed andesitic lava flows are massive and commonly amygdaloidal. They occur in a variety of red, green and purplish green to purple shades. Diffuse epidote veining is locally common.

In thin section some of these flows are porphoritic and contain lath shaped phenocrysts of saussuritised or sericitised plagioclase (An_{32-34}). This saussuritisation has commonly taken place along crystal cleavage directions in phenocrysts which range from 2 to 5 mm in length. The groundmass is composed of relic plagioclase laths outlined by sericite or calcite, with intersertal pools of chlorite and dark brown glass.

Some of the flows are both porphyritic and amygdaloidal, but amygdaloidal varieties are most common. Amygdules vary from spherical to elongate and have straight or amoeboid outlines. They are infilled with either calcite, chlorite, radiating epidote, or spherulitic chalcedony.

Much of the basal and northerly mid-parts of the Formation contain very fine grained non-pillowed andesitic or basaltic flows. In hand specimen this lithology has a characteristic green-red colouration due to abundant jasper and epidote in the groundmass. In thin section, plagioclase has been almost completely altered to saussurite and epidote, and crystal outlines are obscured. Jasper is associated with haematite grains and chlorite probably results from alteration of pyroxene and/or olivine.

Acid flows are less common and are dacitic in composition. These generally contain phenocrysts of plagioclase (An_{30-33}) and some quartz in a glassy groundmass, altered by calcite and sericite.

Near Squashberry Island flow rocks consist of both the fine grained jasper and epidote rich, non-pillowed andesite-basalt, and porphyritic and amygdaloidal andesite. Here the flows are up to 10 m thick.

Age of the Port Albert Formation

Early workers either assigned these volcanic rocks to the Ordovician or else reasoned indirectly that the rocks were more probably Ordovician than Silurian (Twenhofel, 1947; Patrick, 1956; Baird, 1958). This was in keeping with the early belief that volcanic rocks in central Newfoundland were all of Ordovician age. Williams (1962) was the first to recognise that the volcanic rocks conformably underlay Silurian sediments and were Silurian in age.

No fossils were found in the Port Albert Formation. However, the continuation of the Formation on Change Islands has yielded an Early Silurian (Llandoverian) mixed fauna (Eastler, 1969).

Depositional Environment of the Port Albert Formation

The following features suggest a nearby explosive volcanic source and contemporaneous volcanism and sandstone deposition in shallow water to sub-aerial environments.

1) The abundance of coarse pyroclastic rocks, especially in more northwesterly exposure of the Formation.
2) Discontinuous silt lenses in agglomerate units, and volcanic shreds in some of these lenses. Some tuff units also contain silt lenses.
3) Some agglomerate clasts appear water-worn.
4) The lack of pillow structures in the flows.

The absence of agglomerates in the southeast exposures of the Formation may indicate that these units were farther from the volcanic centre.

Dog Bay Formation

The name Dog Bay Formation is proposed for the sandstone unit of the Botwood Group which overlies the Port Albert Formation.

These rocks were earlier referred to the Farewell Group where mapped by Patrick (1956) and Baird (1958). Williams (1964*a*; 1967) abandoned the Farewell Group terminology and assigned the unit to the Botwood Group. More recently, Eastler (1969) mapped similar rocks outcropping on Change Islands, where he referred them to the South End Formation.

The sandstones are the most extensive rock type both of the map area and the Botwood Group. To the north they are exposed on Change Islands and other small islands north of Horwood Bay (Eastler, 1969). In the map area, they occur in a broad central belt, two to three miles wide (Fig. 2). To the southeast, the rocks can be followed in a broad belt up to 10 miles wide, as far as Exploits River and beyond (Williams, 1964*a*) (Fig. 1).

The outcrop of the Dog Bay Formation in the area is divided into three members (Table II). These are defined on separate sedimentologic and lithologic characteristics. Briefly, these are (i) a Lower, thin bedded, coarse siltstone Member with ripple marks and much ripple-drift cross-lamination, (ii) a Tuffaceous, massively bedded, poorly sorted sandy siltstone Member with abundant rhyolite fragments, and (iii) an Upper cross-bedded, medium to fine sandstone Member containing metamorphic detritus.

The Lower Member overlies apparently conformably, to the southeast of the Peninsula, hitherto unrecognised volcanic rocks, here considered equivalent to the Port Albert Formation. This contact is only exposed on the shoreline near Squashberry Island (Fig. 2). Both Williams (1964*a*) and Eastler (1969) interpreted the contact between the sandstones and rocks assigned to the Indian Islands Group, as faulted.

The sequence of Lower through Tuffaceous to Upper Members is apparently conformable, i.e. east of the synclinal axis at Farewell Harbour (Fig. 2). However, the Lower and Tuffaceous Members are not exposed on the western limb of the syncline. Here sandstones of the Upper Member overlie the Port Albert Formation, and the contact is apparently one of disconformity. This is indicated by conglomerate beds (50 - 70 cm thick) in the sandstones close to the contact. These beds contain pebbles similar in lithology to the underlying volcanic rocks. This contact relationship is clearly seen northwest of Farewell Harbour, and south of Lower Indian Brook (Fig. 2).

Lower Member (c. 385 m)

This Member is well exposed on the shoreline northwest of Squashberry Island, and also on the northern Dog Bay Islands in Horwood Bay (Fig. 2).

The Member consists of commonly thin-bedded (15 - 30 cm) light grey siltstones. Some of the beds contain lime rich nodules which tend to weather rapidly (Plate 8a). Ripple-drift cross-lamination is ubiquitous, and current and oscillatory ripple marks are also common. On and near Squashberry Island many of the beds face northwest and are overturned, and the rocks contain the penetrative cleavage (S_1) associated with the main deformation (D_1). However, further northwest, and in the rest of the Formation, the beds are right way up, and a coarse fracture cleavage (S_1) is generally present (Plate 8a).

In thin section the rocks are commonly composed of medium to coarse grained silt size grains, i.e. 0.01 - 0.05 mm size range. The grains range from angular to sub-rounded, are moderately sorted and the rocks are texturally sub-mature. The silts commonly contain quartz (55 - 60%), feldspar (15%), muscovite (up to 3%), saussurite (up to 10%), cement (5 - 18%), and are sub-arkosic in composition.

Quartz is generally clear and may be volcanic in origin. The feldspar dominantly consists of fresh and altered plagioclase (olig-and.). Some sanidine and albite are also present. Saussurite probably replaces plagioclase. The cement is composed of authigenic calcite, sericite and some quartz. Sericite is more abundant in the penetratively cleaved silts close to the base of the member, where it defines the S_1 cleavage.

Tuffaceous Member (c. 160 m)

This Member is well exposed on the north shore of Indian Pond, near Hunts Cove, and around Farewell Head (Fig. 2).

Williams (1964*a*) previously assigned part of this Member, outcropping near Indian Pond, to the volcanic unit of the Botwood Group.

The Member consists of massively bedded, dark grey and fine grained tuffaceous sandstones, which contain a variety of fine grained intrusive igneous and tuffaceous fragments. Some beds show slump structures (Plate 8b).

In thin section, grain size ranges from 0.01 mm to 0.2 mm, i.e. sandy siltstone, but fragments range from 1 mm to max. 12 cm across. Grains range from commonly angular to sub-rounded, and are poorly sorted. These rocks are texturally immature. Average composition is as follows: quartz (40 - 45%), feldspar (up to 15%), igneous and tuffaceous fragments (10 - 15%), muscovite (1 - 2%), matrix (20 - 30%). The quartz and feldspar are similar to that of the underlying Member, and some albite is also present.

Igneous clasts are dominantly rhyolitic in composition. Several varieties are present, but they are commonly very fine grained, glassy and generally contain quartz and sanidine phenocrysts. The fragments generally show a crenulate or pumaceous outline (Plate 9a), and are slightly vesicular. These especially indicate a very local origin. Some of the glassy fragments contain a perlitic structure. Other fragments are flow banded, some with a later spherulitic texture. Very fine grained tuff clasts are also common and, in thin section, are largely replaced by calcite or sericite and may be devitrified glass. Many of these clasts weather to a light buff colour on weathered outcrop. Some diabasic fragments are also present.

The matrix consists of varying amounts of authigenic calcite (dominant), saussurite, and fine sericite/chlorite aggregates. Saussurite generally replaces plagioclase. Detrital grains are commonly etched by the matrix so that grain boundaries are indistinct.

Upper Member (c. 138 m)

This Member is best exposed at Farewell Harbour (Fig. 2). It consists of thin to medium bedded, light grey micaceous sandstones, which are commonly of medium grain size. Bed thickness ranges from 15 cm to more usually 1 m. Tabular and trough cross bedding are well developed (Plate 9b). Mud-cracks (Plate 10a) and some ripple-drift cross-lamination and ripple marks are also present. Rare flute marks (Plate 10b) are seen in the lower parts of the Member.

Microscopically the sandstones are medium to fine sands. Grain size ranges from 0.2 to 0.5 mm and some finer grained beds average 0.04 mm and

1 mm. The grains range from angular to sub-rounded, are moderately sorted, and the rocks are texturally sub-mature. The sandstones comprise: quartz (50 - 55%), chert (5 - 10%), feldspar (15 - 20%), muscovite (1 - 2%), volcanic fragments (1 - 2%), haematite and pyrite (1%), cement (15 - 20%). Quartz is commonly clear and inclusion free and may be volcanic in origin. Some quartz grains have internal partially re-crystallised sutured grain boundaries, and others show strong undulose extinction. These may imply a deformed source terrane. Plagioclase (olig.-and.) comprises some 50% of the total feldspar and is a mixture of both fresh and altered varieties. Some grains show kinked twin planes. Albite (up to 5%) is fresh, and commonly contains both straight and curved inclusion trails. These inclusion trails are composed of epidote or rutile needles and/or highly elongate quartz crystals. Sometimes the epidote/rutile needles contain augen of quartz, and the grains generally show a post inclusion trail overgrowth of clear albite (Plate 11a). These inclusions in the albite are a common metamorphic texture in albite porphyroblasts especially in albite schists (Spry, 1969). Sanidine, and microcline sometimes containing blebs of quartz, are also present. Muscovite flakes up to 0.5 mm in length are sometimes kinked. Volcanic fragments are andesitic and comprise felted lathlike plagioclase crystals in an altered glassy groundmass.

The cement is composed of authigenic calcite, chlorite and sericite. Calcite commonly etches adjacent grains and sometimes 'ophitically' encloses small quartz and feldspar grains. Fibrous chlorite and sericite tend to destroy the original grain boundary of detrital grains.

Age of the Dog Bay Formation

No fossils were found in the Dog Bay Formation. However, in the continuation of the Formation to the south, at Salmon Pond, 14 miles west of Gander, a graptolite fauna indicates an Early Ludlow age for beds from which it came (Berry and Boucot, 1970).

Depositional Environment of the Dog Bay Formation

The Lower Member is characterised by ripple-drift cross-lamination, and current and oscillatory ripple marks. The cross-lamination generally shows erosion of laminae on the up-current side and consists of Types 1 and 2 (Walker, 1963). These types may suggest parent fluvial or shallow water traction currents (Walker, 1963). It appears that deposition of the Member took place on a shallow sub-littoral basin floor, washed by weak bottom currents and occasionally stirred by storm waves. Current measurements from ripple marks at 10 locations show a derivation from the southeast (Fig. 7a).

Shallow water structures are generally absent in the Tuffaceous Member. Slump structures indicate a relatively unstable environment. This instability was apparently related to contemporaneous rhyolite/diabase intrusion and sandstone deposition. The dominantly rhyolitic clast composition, and delicately preserved crenulate outline (Plate 9a) of many clasts, supports this conclusion.

The deposition of the Upper Member evidently took place in a relatively shallower water, stable environment. The lower parts of the Member contain flute marks, and some ripple marks. They may indicate deposition in a shallow basin. However, trough and tabular cross-bedding and mud cracks, evident at Farewell Harbour, characterise the upper parts. These

Fig. 7a. Palaeocurrent directions from ten locations in the Lower Member of the Dog Bay Formation

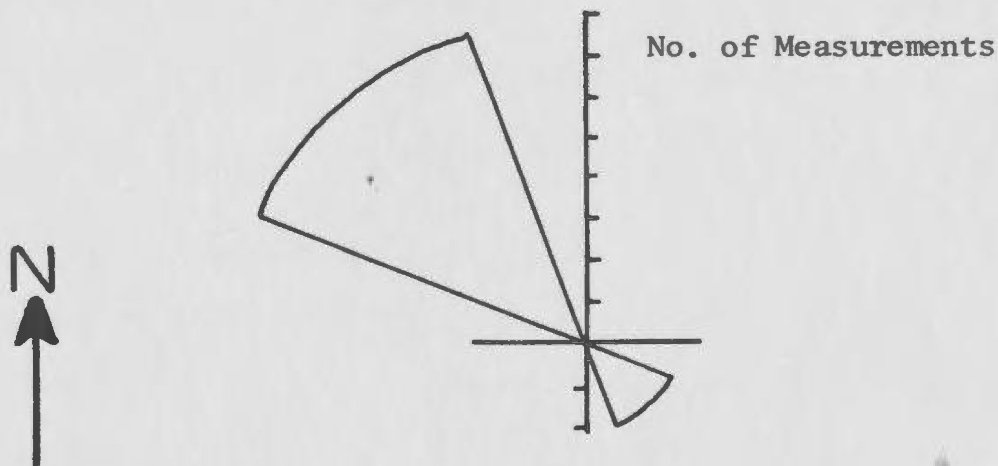
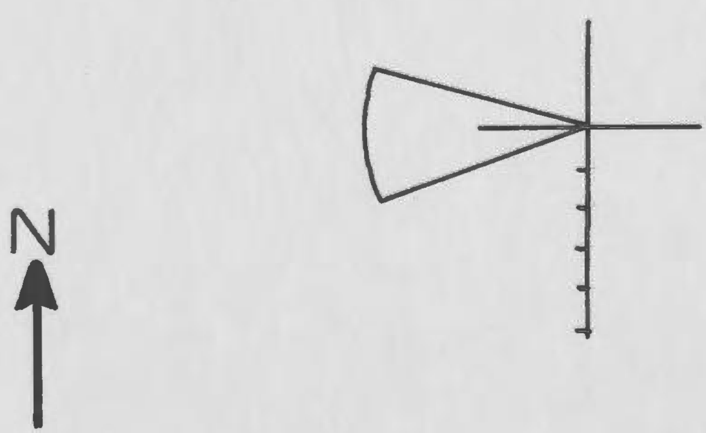


Fig. 7b. Palaeocurrent directions from five locations in the Upper Member of the Dog Bay Formation



structures probably indicate a terrestrial fluviatile or deltaic environment, with periodic exposure to the atmosphere.

Current measurements from the Upper Member were taken at 5 locations, from trough cross-bedding, flute marks and ripple marks. These indicate derivation from the east/northeast (Fig. 7b).

Provenance of the Dog Bay Formation

The source terrane for these sediments was apparently one of high relief, which was capable of providing a relatively large volume of quartz rich sediment. This terrane was apparently undergoing a comparatively deep weathering, since the original silicate minerals did not survive transport in the form of large fragments. The presence of albite grains containing inclusion trails, in the Upper Member, suggests a metamorphic source terrane of moderate grade. Grains of similar composition may be present in the Lower and Tuffaceous Members. However, conclusive identification was not possible due to fine grain size and relatively infrequent nature of occurrence or preservation.

The current directions indicate an easterly source area. The Gander Lake Group and/or the basement to this Group, which presently outcrop to the east of the map area (Fig. 1), thus present a likely source terrane for sediments of the Dog Bay Formation.

Chapter III

INTRUSIVE IGNEOUS ROCKS

Rhyolite and Diabase Dykes

Rhyolite and diabase dykes in the area occur in a broad zone between Farewell Harbour and Squashberry Island, and inland to the southwest (Fig. 2). The dykes commonly show a central acid component contained between two layers of basic rock. However, other intrusions lacking one or both basic layers, or the acid component, were also noted. The basic margins of composite intrusions are approximately 1 m thick, whereas the acid component is generally greater than 2 m. The other intrusions are commonly 1 - 2 m thick, but are locally up to 30 m thick (e.g. north Dog Bay Island).

Usually an initial injection of basic magma was followed by later injection of acidic or silicic material along the same fissure. This is apparently indicated by inclusions of diabase in the rhyolite. However, some diabase dykes contain inclusions of rhyolite.

Rhyolite is generally very fine grained and either porphyritic or non-porphyritic, while the diabase dykes show a textural variation from fine to medium and porphyritic to non-porphyritic.

Porphyritic rhyolite generally contains euhedral phenocrysts of quartz, sanidine and rarely plagioclase (An_{30-32}). The groundmass is a devitrified, sometimes spherulitic, glassy aggregate of quartz, feldspar and secondary chlorite.

Porphyritic diabase contains relic plagioclase phenocrysts (5 mm long) outlined by sericite and saussurite. The groundmass consists of randomly oriented, cloudy plagioclase (An_{34-36}) laths which are commonly sericitised and saussuritised. Interstitial minerals are pyroxene (augite and titanaugite), chlorite, opaque oxide (probably ilmenite), and minor hornblende. Pyroxene and plagioclase generally show a sub-ophitic relationship, and the pyroxene is commonly altered to chlorite, epidote and possibly uralite. Some finer grained varieties contain amygdules infilled by quartz and calcite.

Some diabase intrusion breccia are also present in this zone. These contain angular fragments of diabase in a very fine diabasic groundmass.

Fine grained, sometimes prophyritic diabase and coarser diabase/gabbro dykes intrude sandstones and slates to the northwest and southeast respectively, of the central zone. The dykes in the northwest are relatively little deformed and are similar to those occurring in the central zone. However, coarse gabbroic intrusions, near the mouth of Horwood River (Fig. 2) show effects of a strong cold working type deformation. Plagioclase is completely broken down and sericitised, although the outline of some smaller plagioclase crystals is preserved by albite. Augite and titanaugite phenocrysts (3 - 5 mm across) are somewhat fragmented and replaced by chlorite, epidote and possibly uralite, and some show an ophitic relationship with sericitised plagioclase. A prominent opaque oxide, probably ilmenite, is developed in intergranular and skeletal forms. Minor hornblende is also present. The S_1 foliation is defined by the orientation of the chlorite, saussurite and pyroxene phenocrysts.

Dacite Breccia

This intrusion is spatially associated with the Reach Fault and is exposed at the southwest near Boyd's Cove, and along the western shoreline of the area (Fig.2). The rock consists of angular to sub-angular fragments in a much altered matrix. Some of the fragments are porphyritic and contain plagioclase (An_{30-33}) phenocrysts in a devitrified groundmass. The matrix is a carbonate rich and saussuritised quartz-feldspar aggregate.

The rock may be an intrusive breccia, but the brecciated texture could also be associated with movement on the Reach Fault.

Lamprophyre

Northeast of Horwood, a dark brown dyke rock with finer grained margins is lamprophyric in composition. The rock contains generally elongate pyroxene phenocrysts (up to 1 mm long) and carbonate pseudomorphs, possibly after olivine. The finer groundmass consists of pyroxene, hornblende, some biotite, chlorite, carbonate, minor opaque haematite or ilmenite, and radiating laths probably composed of albite. The pyroxenes consist dominantly of augite with some titanaugite, and tend to occur in patches or clots in the matrix. The augite is commonly zoned and contains hour-glass stiuctures.

The dyke cross-cuts the S_1 foliation and is a post-tectonic lamprophyre.

Age of Intrusions

The igneous rocks in the area, except for the lamprophyre, apparently pre-date the regional Acadian deformation. This is indicated in the southeast by the presence of the penetrative foliation associated with the first deformation in gabbroic rocks. Intrusive rocks in the central and northwest parts of the area are little deformed. They generally contain a weak fracturing or joint pattern associated with the S_1 regional foliation, and in some cases they are displaced by minor faulting.

The mutual occurrence of diabase inclusions in rhyolite, and vice versa, may indicate what was essentially a single intrusive episode (Walker and Skelhorn, 1966). The intrusion of rhyolite and diabase dykes took place over a wide period. This is indicated by apparently contemporaneous intrusion and sedimentation in the Tuffaceous Member and the post-depositional intrusion in the Upper Member of the Dog Bay Formation.

Relationship to Regional Deformation

The parent body of the intrusions is interpreted as being at a relatively shallow level beneath central and northwesterly parts of the Peninsula. This may have acted as a buttress during the regional deformation. The relatively weak structures developed in rocks of the central area contrast with the penetrative deformation to the southeast and apparently support this conclusion, suggesting that the central part of the map area was protected from deformation by a rigid, probably intrusive body close to the surface.

Chapter IV

STRUCTURE

INTRODUCTION

Rocks of the Port Albert-Horwood area have been affected by three phases of deformation (Table 4). The first and main deformation produced open and tight folding associated with an incipient fracture cleavage and a penetrative slaty cleavage, respectively. The tight folding occurs especially in the southeast margins, while the open folding is restricted to the central and more northwesterly parts of the area. The fabric associated with this first deformation has been kinked and/or crenulated by two later deformations. Large scale folding is interpreted from cleavage/bedding intersections and stratigraphic facing directions. Some smaller scale structures are visible. The description of these structures follows that of Fleuty (1964).

The First and Main Deformation, D_1

Fabric, S_1

A single penetrative slaty cleavage (S_1) is strongly developed chiefly in rocks of the Stoneville and Lower Formations, to the southeast of the Peninsula (Fig. 2). In rocks of the Dog Bay and Beaver Cove Formations to the northwest, the fabric is generally a coarse fracture cleavage. Locally within this area more penetratively cleaved zones are usually associated with finer grained lithologies.

The cleavage generally dips steeply to the southeast, and is roughly axial planar to tight to isoclinal and to more open folds. In hand specimen, the slaty cleavage shows smooth and non-lineated surfaces

Table IV. Summary of the structural history of the Port Albert — Horwood Area

Deformation	Strain Regime	Structures	Age
Strike-slip faulting?	Brittle fracture	Major steep northeast faults parallel to regional strike, e.g. the Reach Fault	
D_3	Brittle, horizontal northeast-southwest axial shortening	Vertical joint-drag kink-bands (S_3), rarely developed crenulation cleavage	
D_2	Dominantly brittle, vertical shortening	Flat-lying, sometimes conjugate, joint-drag kink-bands and weak crenulation cleavage (S_2). Minor open folding of S_1 and bedding	MIDDLE DEVONIAN (ACADIAN)
D_1	Ductile, horizontal northwest-southeast uniaxial flattening and rare sub-vertical extension $(o \lessgtr k \gtrless 1)$	Major north-northeast — south-southwest upright and slightly overturned F_1 folds, generally steep S_1 slaty and fracture cleavage	

(possibly indicative of a uniaxial flattening type strain — Dewey, 1969). The cleavage in thin section is defined by fine-grained sericite and chlorite.

The origin of slaty cleavage is controversial, and various theories of mechanical rotation and recrystallisation have been proposed (Sorby, 1853; Ramsay, 1967; Dieterich, 1969). The latest of these involves a tectonic dewatering process. By this process, platy particles are mechanically rotated into the direction of flow of the escaping pore fluids, to form a slaty cleavage (Maxwell, 1962; Powell, 1972). Examples of this mechanism, i.e. intrusive clastic dykes parallel to slaty cleavage, are apparently lacking in the Port Albert-Horwood area. Evidently the clayey sediments had compacted to a shale or mudstone, prior to deformation. The slaty cleavage in the area was most probably formed by alignment of the platy particles by flattening, coupled with some recrystallisation in a preferred orientation parallel to the foliation.

The first fabric is the product of a near-horizontal northwest-southeast shortening strain. This is indicated by flattened limey nodules (Plate 11b) and deformed clasts (Plate 3a) which are contained in the plane of the S_1 foliation. However, good strain guages are absent, i.e. the original shape of deformed objects is unknown, and estimation of strain value (Flinn, 1962) is approximate.

A large ductility contrast between sedimentary and igneous clasts is evident in the Diamict Member at Stoneville. The less ductile igneous clasts occur in a variety of shapes, and generally retain their original clastic form during deformation. However, some of those clasts with Z and Y in the plane of the foliation show brittle failure (Plate 12a, Fig. 8a), resulting in elongation parallel to Z. Sedimentary clasts occur

Fig. 8a. Sketch of Granodiorite Clast which has undergone brittle failure, resulting in elongation parallel to Z. Diamict Member, Stoneville Formation

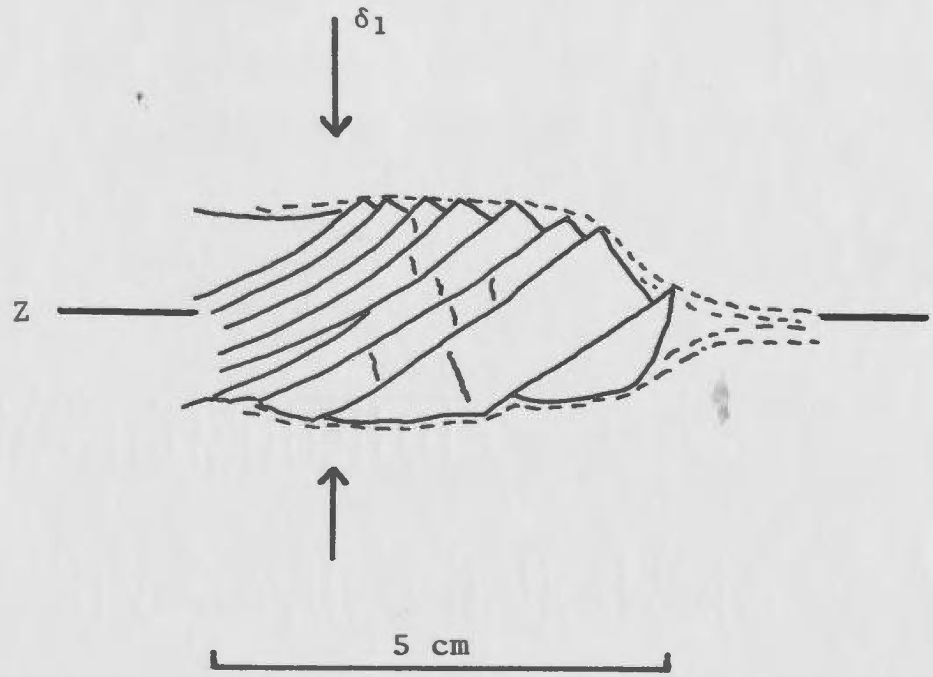
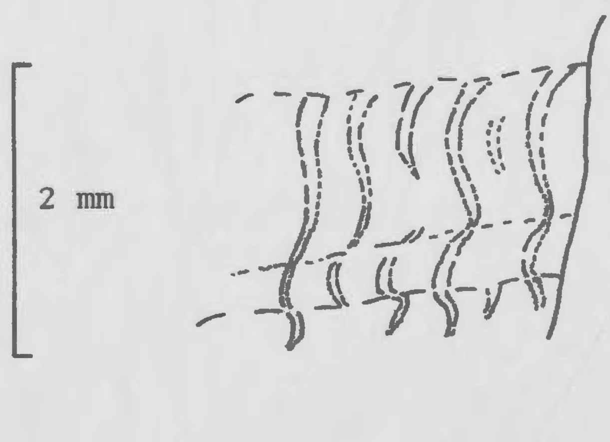


Fig. 8b. Sketch of shear type kink-bands. Lower Unit, Lower Formation



as strongly oblate ellipsoids and discs (Plate 3a). Such shapes result from strain with k value approximately equal to o, i.e. uniaxial flattening (Flinn, 1962). The thin very fine grained finely siliceous laminae containing these clasts are parallel to the S_1 foliation. They commonly form augen around the igneous clasts, and this usually results in disruption of the layers (Plate 5b). The laminae have also been disrupted by 'chocolate tablet' type boudinage, i.e. from relatively equidimensional stretching on the Z and Y axes.

Bulk D_1 strain throughout the area is not exclusively uniaxial flattening. Some examples of a sub-vertical extension strain ($k \approx 1$) are also present (Plate 12b). This is shown by a stretching lineation plunging 45 - 50° southwest in the plane of the foliation, and here defines the orientation of the Z axis of the deformation ellipsoid. The bulk strain over the area is therefore more correctly expressed as $o \lessapprox k \gtrapprox 1$.

Minor F_1 *Folds*

Minor folds are well displayed on Hare Island and along the northwest shore of the Peninsula. They are also common in the Dog Bay Formation on the north central parts of the Peninsula, and on northern Dog Bay Islands. The folds are upright, rounded, and are generally of similar style showing thickening in the hinge, and plunge gently (0 - 20°) to both the northeast and southwest. On Hare Island (Plate 13a) the folds are close (i.e. inter-limb angle), the half-wavelength $\lambda/2$ is 2 - 3 m, and the plunge is gentle (5 - 20°) to the northeast. On North Dog Bay Island, thin-bedded sandstones contain a fairly open asymmetrical fold, plunging gently (approx. 15°) to the southwest, and with axial plane steeply inclined to the southeast. This fold is probably of somewhat similar style to the large scale folds as interpreted at Stoneville (Fig. 2).

Soft sediment slump folds (Plate 8b) occur in the Tuffaceous Member of the Dog Bay Formation. However, these are easily distinguished from tectonic folding as the cleavage is either not axial-planar or more usually absent, and the fold axes are widely divergent.

Major F_1 *Folds*

The D_1 deformation produced the major F_1 folds with associated cleavage throughout the area. These folds show the regional northeast-southwest Acadian trend.

The F_1 major structure consists of two differing fold styles (Fig. 2, sec. A-A^1). West of Squashberry Island, the folds are upright, gentle to open and probably concentric. Plunge, from the intersection of S_1 and bedding, varies from sub-horizontal at Farewell Harbour to approx. 25° southwest at Indian Pond. Between Squashberry Island and Fox Cove, and also locally on Farewell Duck Islands, the folding is tight to isoclinal, probably similar and apparently the folds plunge both northeast and southwest. One limb of these isoclines is shown by cleavage-bedding intersections and sedimentary 'tops' commonly to be overturned. However, the bedding faces upwards on the cleavage, so that the folds are upward facing (Shackelton, 1958). Axial planes are therefore inclined 60 - 90° southeast and the folds are slightly overturned to the northwest. These overturned folds are characteristically produced in areas where a large ductility contrast exists between beds, while the upright more open folding is restricted to the more homogeneous lithologies.

The parent body of the intrusive rocks in the area probably acted as a shield or buttress for the overlying rocks during deformation. This influence therefore may have enabled the development of open folding in the central parts of the map area in contrast to the tight to isoclinal folding especially in the southeast margin.

The Second Deformation, D_2

D_2 structural features comprise generally gently dipping sometimes conjugate kink-bands and weak crenulation cleavage of the S_1 slaty cleavage. The kink-bands are generally of the joint-drag type, but some are shown microscopically to resemble shear-kink bands (Dewey, 1965).

Joint-drag type kink-bands show well developed kink-planes (15 cm - 1 m in width) which are surfaces of total strain discontinuity (Plate 13b). The rotation of the kink-bands is such that the external foliation makes an obtuse angle with the kink-plane. This results in a shortening parallel to the foliation. Kink-bands showing similar geometric relationships have been termed reverse or negative (Dewey, 1965; 1969*a*). These are believed to result from continuous simple shear or flexural-slip deformation mechanisms (Dewey, 1965). Conjugate kink-bands, where developed, show an orthorhombic symmetry (Dewey, 1965; Ramsay, 1967). The principal stress axis (δ_1) is contained in or very close to the plane of foliation, and the dihedral angle is less than 90° (Plate 14a).

Shear type kink-bands (Dewey, 1965) occurring in very fine grained sericite rich slate have been identified in thin section (Fig. 8b). Here quartz and sericite platy foliae define the S_1 foliation and show a similar style folding with median fracture or incipient median fracture planes. These structures are only developed in the slate and terminate against nearby less ductile silt lenses. In more homogeneous units, e.g. slate bands in the Lower Formation, the kink-planes are closely spaced and tend to form a weak crenulation cleavage (Plate 14b). In these areas more intensely deformed by D_1, this crenulation cleavage is probably associated with very open, large scale folding of the first foliation, S_1 (Plate 15a). In some instances local reversals of dip (S_1 and bedding) have been interpreted as being the results of this deformation.

The Third Deformation, D_3

D_3 structures comprise steeply to vertical dipping kink-bands, with axial surfaces normal to the S_1 foliation. The kink-bands are common in finer grained lithologies throughout the area. Sometimes they become a crenulation cleavage (Plate 15b).

These kink-bands are negative joint-drags (Dewey, 1965; 1969*a*) and are generally similar to those developed during D_2. However, kink-band width is commonly less than 10 cm and although a conjugate set apparently has developed, they are rarely exposed in any one outcrop. The orientation of the kink-planes, normal to the S_1 foliation, indicates that they are the product of a northeast-southwest bulk shortening strain. This strain is contained in or close to the regional S_1 foliation trend, and has an associated horizontal extension normal to the foliation.

Where D_2 and D_3 kink-bands are developed together they form interference patterns on the S_1 foliation (Plate 16). There is little experimental evidence of rekinking already kink-banded surfaces, but the evidence in the area suggests that the vertical kink-bands were produced by the last deformation to affect the area. Thus on the shoreline north of Stoneville flat-lying D_2 kink-bands and the S_1 foliation are apparently folded by near-vertical D_3 kink-bands. These D_3 structures most probably had little effect on the major F_1 structure.

Elsewhere in the Central Mobile Belt, steeply inclined kink-bands fold flat-lying crenulations and kinking of the penetrative fabric (Kennedy and DeGrace, 1972; Williams *et al.*, 1972).

Faults

The absence of clear dating criteria, e.g. the folding of fault planes by later structures, and the generally poor exposure of the fault planes makes interpretation of age and the type of faulting in the area very subjective.

The major faults are northeast trending and reflect the structural trend of the region. Other faults trend to the north-northwest and west-southwest approximately and cross-cut the regional structural trend. These are apparently tear faults.

Faults Trending Parallel to S_1

These faults appear genetically related to the regionally developed cleavage (S_1), which is parallel to them. Dominantly strike-slip movements are assumed on account of the apparently large horizontal components, straightness and lateral continuity, e.g. the Reach Fault. However, fault planes are commonly not exposed, or are obscured by later intrusion and the actual displacements are unknown.

The Reach Fault

The Reach Fault forms the boundary between Zones E and F of the Appalachian Structural Province (Williams *et al.*, 1972), and truncates the outcrop of the Botwood Group west and southwest of the map area.

It forms a strong lineament and can be traced for many miles to the southwest of the area (Williams, 1964*a*). Across the fault zone rocks of the Botwood Group on the east are in contact with pre-Middle Ordovician rocks of the Dunnage Complex to the west (Kay, 1968; 1970; 1972). In the map area the fault zone is obscured by a brecciated dacite intrusion and brecciation may be due in part to rejuvenate fault movement. However, because of the intrusion the sense of displacement of the fault could not be determined in the area.

Faulting at Horwood Bay

A fault has been assumed at the extreme south of Horwood Bay (Fig. 2). This fault is not exposed; however, a prominent northeast trending lineation extends to the southwest of Horwood Bay and the structural trends on the west side of Horwood Bay strike into those on the east side (Fig. 2). A zone of brecciation (5 m thick) on the shoreline at Stoneville may be associated with the above fault. Slate fragments containing the penetrative cleavage (S_1) are randomly oriented in the breccia, so that brecciation evidently took place post-first deformation.

Faults Trending North-northwest and West-southwest

These faults are best displayed on the north and west coastline of the Peninsula, and where visible the fault planes are either steeply dipping, generally to the northeast, or are vertical.

To the northwest of the Peninsula a number of north-northwest trending tear faults displace rocks of the Port Albert and Beaver Cove Formations (Fig. 2). The fault planes with 1 - 2 m brecciated zones dip steeply to the northeast and contain slickensliding plunging at 30° to the northwest. Sinistral displacements of up to 30 m are associated with these faults.

At Lower Indian Brook an unexposed fault, associated with a strong west-southwest lineament, apparently dextrally displaces rocks of the Port Albert, Beaver Cove, Dog Bay Formations and the dacite intrusion which is spatially associated with the Reach Fault (Fig. 2).

Conclusions

Faults in the area in general appear to be of a strike-slip nature and post-date the Acadian deformation. However, the widely differing zones on either side of the Reach Fault (Williams *et al.*, 1972) may indicate that this fault has been active over a long period, and the possibility that it is a Pre-Silurian fault should be considered.

Metamorphism

The Acadian regional metamorphism has generally only produced chlorite and sericite in the more deformed rocks of the map area, while the relatively undeformed rocks in the central parts of the Peninsula were very little metamorphosed. The area may thus be classified as sub-greenschist to non-metamorphic.

SUMMARY AND CONCLUSIONS — STRUCTURE

The successive sequence of strain regimes associated with the Acadian deformation, i.e. horizontal northwest-southeast uniaxial flattening, vertical shortening and horizontal axial shortening, have been recognised in the map area. In contrast with most other areas affected by the Acadian deformation (Williams *et al.*, 1972), the effects of all the strain regimes are frequently superimposed especially in finer grained sediments outcropping in the southeast of the map area. The strain regimes in addition to similarity with the regional Acadian strain history (Williams *et al.*, 1972), also show similarity to the strain history of the Caledonian orogenic belt (Dewey, 1969). However, the axial extension regime of Dewey (1969) cannot be placed in the Port Albert-Horwood strain sequence due to the lack of clear dating criteria for strike-slip faulting in the area.

Chapter V

SUMMARY AND CONCLUSIONS

It has been shown that the lower part of the stratigraphic succession in the area differs in the southeast from that in the northwest. In the southeast slates and limestones of the Lower Formation were probably slowly deposited in a relatively quiet environment. This environment contrasts with the sudden influx of flysch in the lower part of the Stoneville Formation. The contact between the Lower and Stoneville Formations, although not exposed, thus represents an abrupt depositional change in the area. The probable deposition of the Diamict Member of the Stoneville Formation in a glacio-marine environment, partly by a process of ice-rafting, has been suggested. This mechanism of deposition appears most likely because of: (i) the evidence from the Member, i.e. the thinly laminated beds containing outsize clasts, and (ii) the general similarity of the Diamict Member with glacio-marine deposits (Table III) of Late Ordovician - Early Silurian age in Nova Scotia, Europe and Northwest Africa (Fig. 5). These deposits have been linked with a 'Saharan' glaciation (Harland, 1972; Schenk, 1972), i.e. a major ice sheet with continental and marine, glacial deposits in Northwest Africa. The interbedded relationship of diamict and greywacke beds in the Diamict Member suggests deposition in a relatively restricted environment such as an arm of the sea or possibly an estuarine environment. The igneous clasts in the Member are broadly similar in composition and morphology to clasts in the Conglomerate Member of the Beaver Cove Formation, outcropping in the northwest of the area. It is suggested that the diamict clasts were possibly derived via floating ice from a shoreline similar to that producing the clasts in the Conglomerate Member of the Beaver Cove Formation. This interpretation, if valid, suggests that the Diamict Member, while glacial in origin, was not directly linked with a major ice sheet and may be of relatively local significance. Deposition of the upper parts of Stoneville Formation were dominantly from turbidity currents. In the northwest of the area, siltstones, greywackes and conglomerates of the Beaver Cove Formation were most likely deposited from turbidity currents of an intermediate or distal nature and the Formation is apparently lenticular to the southeast. The contact between the Port Albert Formation and the lower part of the stratigraphic succession in the northwest and the southeast is also a depositional break in the area, and the Port Albert and Dog Bay Formations show evidence of both shallow water and sub-aerial environments. Furthermore, deposition of the Tuffaceous Member of the Dog Bay Formation was apparently contemporaneous with a period of rhyolite and diabase dyke intrusion. Dyke intrusion was apparently episodic since similar dykes also post-depositionally intrude shallow water sandstones of the Upper Member of the Dog Bay Formation. Metamorphic detritus in the Upper Member suggests a rising metamorphic terrane of moderate grade to the east. The Member also displays a disconformable contact with the Port Albert Formation in the northwest of the area which suggests uplift of the easterly basin margins.

The study has indicated that rocks of the Stoneville Formation are probable facies equivalents of the Beaver Cove Formation, thus, rocks previously assigned to the upper Indian Islands Group are probable facies equivalents of the lower Botwood Group. Since rocks similar to those of the Stoneville Formation are probably exposed on the Indian Islands, northeast of the map area, the term Indian Islands Group should be reconsidered. This term has been discarded for the purposes of this thesis; however, whether the term should be formally abandoned, or included in a redefined 'Botwood Supergroup' must await further work on the lateral extent of the Stoneville and Lower Formations.

Lithologic units of the Botwood Group in the map area are broadly similar to units of this Group outcropping elsewhere in northeast Newfoundland. In particular, the Conglomerate Member of the Beaver Cove Formation has been related to the Goldson Formation of the Botwood Group outcropping on New World Island. However, the presence of a major fault zone, i.e. the Reach Fault separating the areas, makes palaeogeographic conclusions difficult. Nevertheless, the Beaver Cove Formation is considered here to be a more distal equivalent of the Goldson Formation. The resedimented littoral material, widespread in northeast Notre Dame Bay and especially in both the Beaver Cove and Goldson Formations has been noted. It is suggested here that in addition to tectonic influences (Helwig and Sarpi, 1969), these shorelines might also be related to a glacio-eustatic sea level lowering, possibly associated with the major ice sheet in Northwest Africa.

Rocks similar to the Lower Formation are apparently not exposed elsewhere in the Botwood Belt and the contact of this Formation with the Stoneville Formation is an abrupt depositional change. The relatively small amount of the Lower Formation mapped in the area makes relationships difficult to establish. However, the possibility that this Formation may represent the upper part of the Davidsville Group and, as such, may be transitional with the Botwood Group in the map area should be considered.

The successive sequence of strain regimes associated with the Acadian deformation has been demonstrated in the area. These comprise a penetrative first fabric resulting from a horizontal northwest-southeast uniaxial flattening and vertical extension. A later vertical shortening produced flat-lying kink-bands and some crenulations associated with a large scale very open folding of the first fabric. These regimes were succeeded by vertically oriented kink-bands produced by a horizontal axial shortening. Faulting in the area is of probable strike-slip nature, but due to lack of clear dating criteria, their age relation to strains described above is unknown. This strain sequence is similar to Acadian strain sequences in Northeast Newfoundland (Williams *et al.*, 1972) and also closely resembles the strain history of the paratectonic British Caledonides (Dewey, 1969).

The study area overlies, to the east, a thick sequence of sedimentary and volcanic rocks with underlying metasediments and gneissic basement (Kennedy and McGonigal, 1972). These metasediments and possibly basement had been uplifted and were probably supplying material, e.g. the metamorphic albite, to the Upper Member of the Dog Bay Formation in Lower to Middle Silurian times. The Dunnage Complex, to the west of the area, possibly represents the site of an oceanic trench and subduction zone within an Early Ordovician ocean (Dewey, 1969*b*; Bird and Dewey, 1970; Kay, 1970; 1972). Whether the study area overlies continental or oceanic crust is unknown, especially since the Reach Fault intervenes between the study area and the present outcrop of the Dunnage Complex.

However, whatever the basement, the shallowing upward sequence demonstrated in the map area possibly represents the last stages of infill of this ancient ocean.

This work, it is hoped, represents a solid contribution to the geology of Newfoundland, and will aid the further studies which are warranted of Silurian rocks and their provenance.

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Plate 1a. *Diamict Member, Stoneville Formation*

Weathered outcrop showing a thinly laminated diamict bed containing an outsize clast. Note lack of clasts in interbedded greywacke. Looking northeast, southwest of Stoneville.

Plate 1b. *Diamict Member, Stoneville Formation*

Granodiorite pebble showing pentagonal or "flat-iron" shape.


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Plate 2a. *Diamict Member, Stoneville Formation*

Dacite cobble with long axis parallel to the thinly laminated stratification. Bedding dips steeply away to the southeast. Shoreline north of Stoneville.

Plate 2b. *Diamict Member, Stoneville Formation*

Granodiorite cobbles with long axes at approximately 90° to the stratification and S_1 foliation. Note the apparent disruption of the stratification beneath the lower cobble on the left of the photograph. Bedding dips steeply away to the southeast. Shoreline north of Stoneville.

Plate 3a. *Diamict Member, Stoneville Formation*

Flattened greywacke clast, with strongly oblate ellipsoidal (discoidal) shape, contained in the S_1 foliation and suggesting $k \rightarrow o$ (uniaxial flattening type strain). Shoreline at Stoneville.

Plate 3b. *Diamict Member, Stoneville Formation*

Quartz-feldspar porphyry clast showing finely spherulitic groundmass. Cross-nicols, shoreline at Stoneville.

0.5 mm

Plate 4a. *Diamict Member, Stoneville Formation*

Hand specimen showing irregular and discontinuous, alternating silt and finely siliceous (light coloured) laminae and contained clasts.

Plate 4b. *Diamict Member, Stoneville Formation*

Hand specimen showing interbedded greywacke and diamict. Note the lack of clasts in the greywacke bed and the relatively sharp contact between greywacke and diamict.


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Plate 5a. *Diamict Member, Stoneville Formation*

Quartz-diorite cobble with long axis at approximately 90° to the stratification. Bedding faces downwards, and dips steeply away to the southeast. Note disruption of stratification 'beneath' the clast. Shoreline north of Stoneville.

Plate 5b. *Diamict Member, Stoneville Formation*

Hand specimen showing disruption of the stratification around a granodiorite pebble.

Plate 6a. *Conglomerate Member, Beaver Cove Formation*

Graded polymict conglomerate and greywacke unit.

Looking north, near Port Albert.

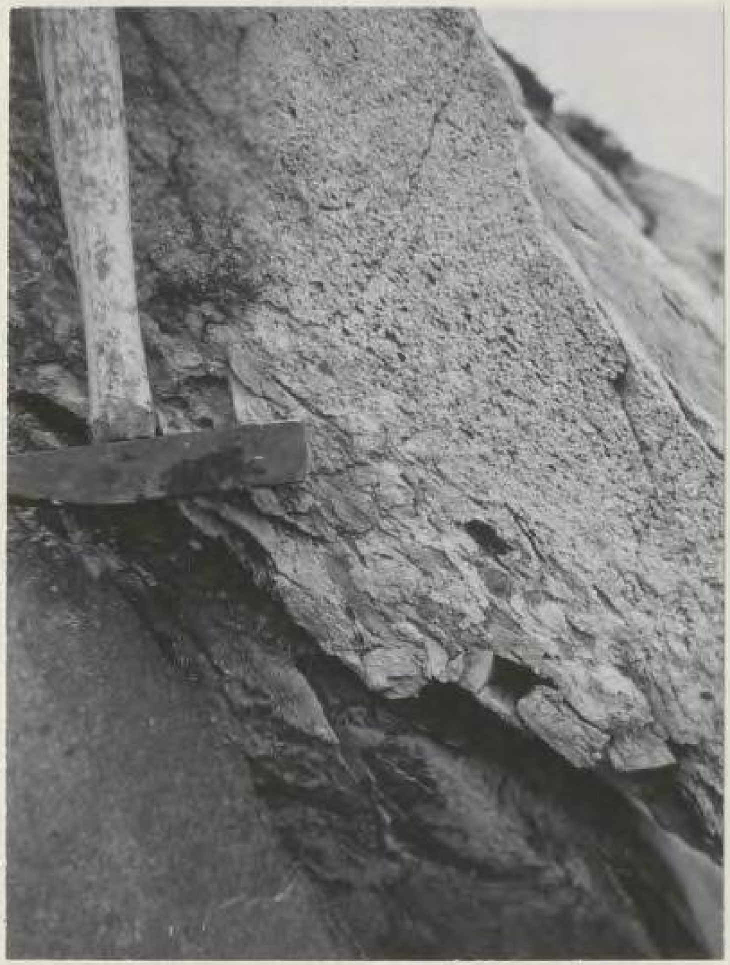


Plate 6b. *Conglomerate Member, Beaver Cove Formation*

Polymict, medium to large pebble conglomerate near Port Albert. Igneous clasts are rounded. Note the contrast with the Diamict Member of the Stoneville Formation.

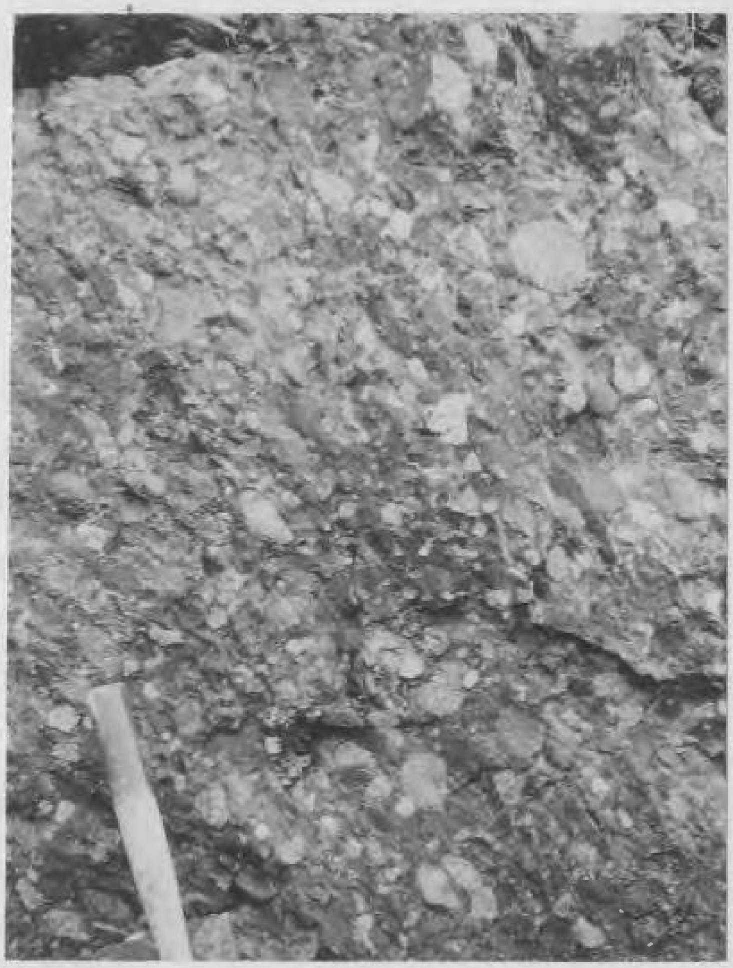


Plate 7a. *Agglomerate, Port Albert Formation*

Coarse, poorly sorted agglomerate with angular and sub-rounded volcanic fragments showing primary near-vertical clast alignment. Looking southwest, northwest of Farewell Harbour.

Plate 7b. *Agglomerate, Port Albert Formation*

Silt lens defining bedding in agglomerate at a shallow angle to steeply oriented volcanic fragments. Looking southeast, northwest of Farewell Harbour.

Plate 8a. *Lower Member, Dog Bay Formation*

Lime-rich nodules in siltstones, with an imperfectly developed fracture cleavage. Looking northwest, shoreline northwest of Squashberry Island.

50 cm

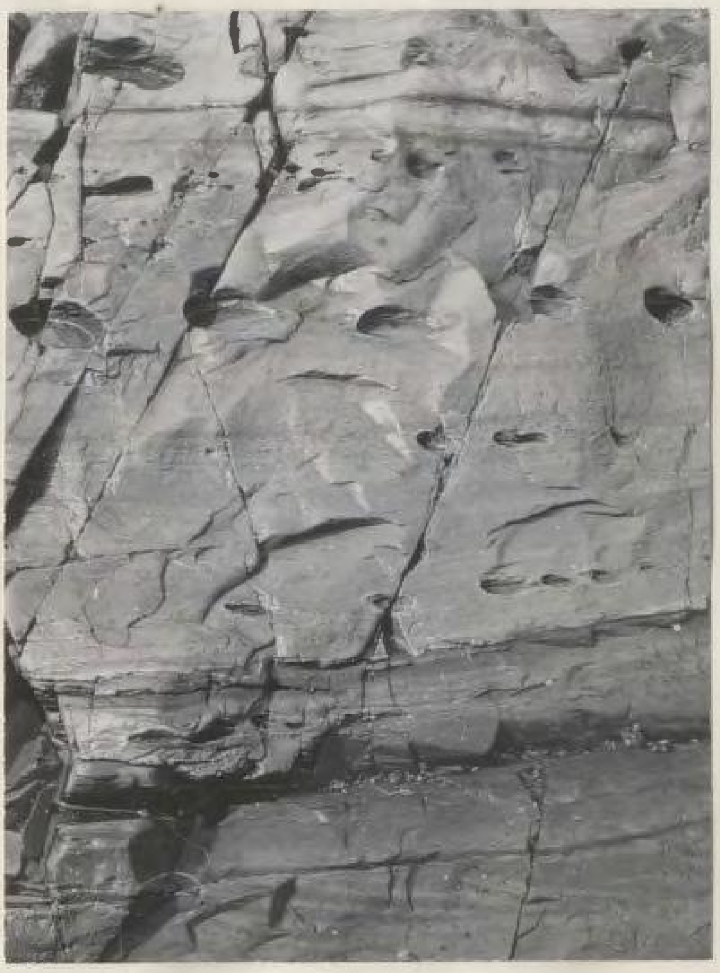


Plate 8b. *Tuffaceous Member, Dog Bay Formation*

Soft sediment slump folds. Note lack of axial-planar cleavage. Looking southwest, near Farewell Head.

Plate 9a. *Tuffaceous Member, Dog Bay Formation*

Rhyolite fragment in tuffaceous silt. Note the well preserved crenulate or pumaceous margin of the fragment. Plain polarised light, shoreline southwest of Hunts Cove.

4 mm

Plate 9b. *Upper Member, Dog Bay Formation*

Large scale trough cross-bedding, looking southeast, northwest of Farewell Harbour.

Plate 10a. *Upper Member, Dog Bay Formation*

Mud cracks in light grey, medium grain, micaceous sandstone at Farewell Harbour.

Plate 10b. *Upper Member, Dog Bay Formation*

Flute marks in medium grain, micaceous sandstone. Looking east, near Farewell Head.

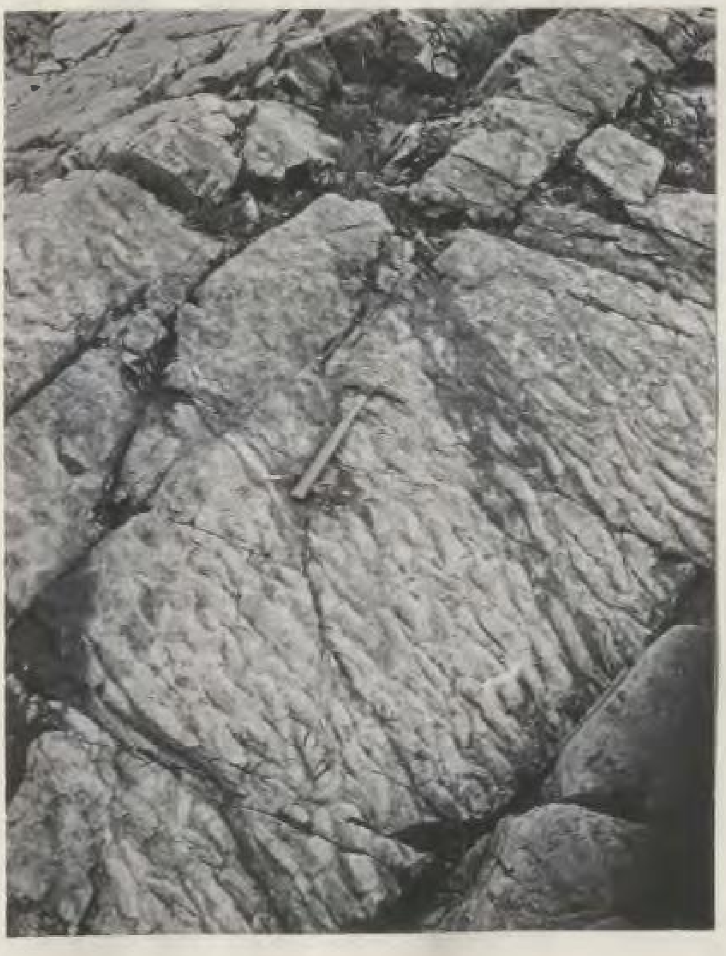


Plate 11a. *Upper Member, Dog Bay Formation*

Albite grain containing an inclusion trail defined by epidote and/or rutile needles and elongate quartz crystals, with a post-inclusion trail overgrowth of clear albite. Cross-nicols, northwest of Farewell Harbour.

0.35 mm

Plate 11b. *Upper Member, Beaver Cove Formation*

Flattened lime rich nodules in cleaved silts indicating a near horizontal northwest-southeast shortening strain. Looking northeast, northwest shoreline of the Port Albert Peninsula.

Plate 12a. *Diamict Member, Stoneville Formation*

Granodiorite clasts with Z and Y axes in the plane of the foliation and the thinly laminated stratification. Upper clast has undergone brittle failure, resulting in elongation parallel to Z. Bedding dips steeply away to the southeast, shoreline north of Stoneville.

Plate 12b. *Diamict Member, Stoneville Formation*

Stretching lineation plunging 45 - 50° southwest, defined by the elongation of sedimentary clasts and alignment of igneous clasts, here indicates the orientation of the Z axis of the deformation ellipsoid and is the product of a sub-vertical extension strain ($k \simeq 1$). Looking northwest, shoreline at Stoneville.

Plate 13a. *Conglomerate Member, Beaver Cove Formation*

Minor folding of similar style in cleaved silt with gentle plunge to the northeast. Note thickening in hinge zones. Looking northeast, northwest shore of Hare Island.

3 m

Plate 13b. *Lower Unit, Lower Formation*

Joint-drag type kink-band (1 m wide). Note kink-planes are surfaces of total strain discontinuity. Looking northeast, eastern Dog Island.

Plate 14a. *Lower Unit, Lower Formation*

Conjugate kink-band, in steep, northwest dipping slates, showing orthorhombic symmetry and produced by a near vertical shortening strain (δ_1) which is close to or in the plane of the S_1 foliation. Note the dihedral angle (facing hammer) is less than 90°. Looking northeast, eastern Dog Island.

Plate 14b. *Upper Unit, Lower Formation*

Weak crenulation type cleavage (S_2) in slate resulting from closely spaced D_2 kink-planes. Looking northeast, shoreline north of Horwood.

Plate 15a. *Upper Unit, Lower Formation*

F_2 minor open folding of S_1 slaty cleavage with a weak, axial-planar flat-lying, S_2 crenulation cleavage. Plunge is gentle to the southwest. Looking southwest, roadside south of Horwood.

Plate 15b. *Upper Member, Stoneville Formation*

Near vertical S_3 crenulation cleavage of the penetrative S_1 slaty cleavage which dips steeply away to the southeast. Shoreline north of Stoneville.

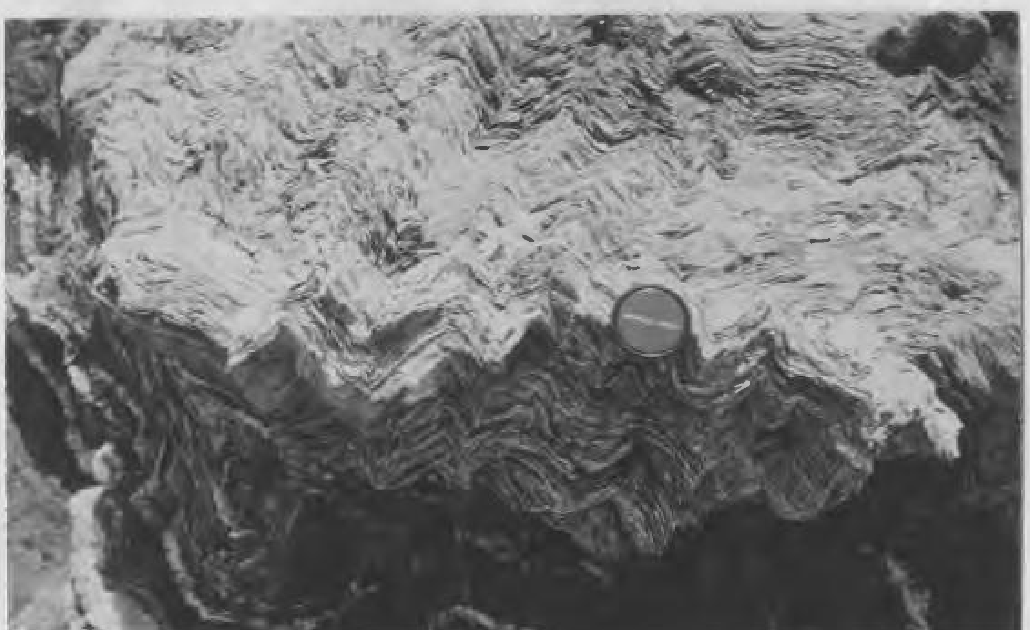
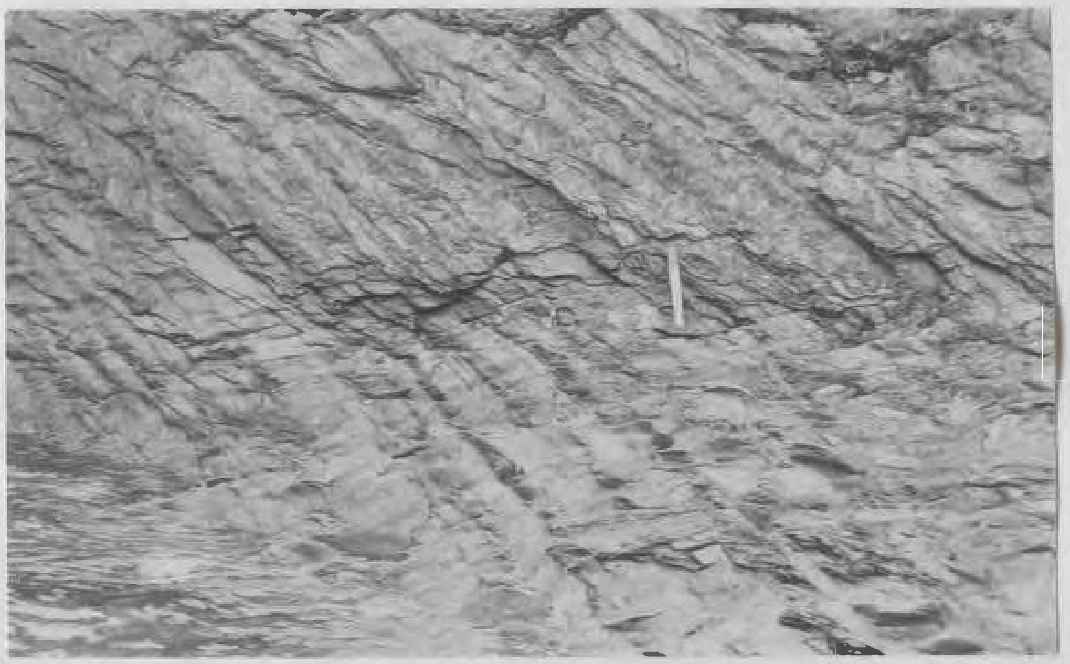


Plate 16. *Lower Unit, Lower Formation*

D_2 (flat-lying) and D_3 (steep) kink-band interference on S_1 foliation in dolomitic slate. Looking east, eastern Dog Island.



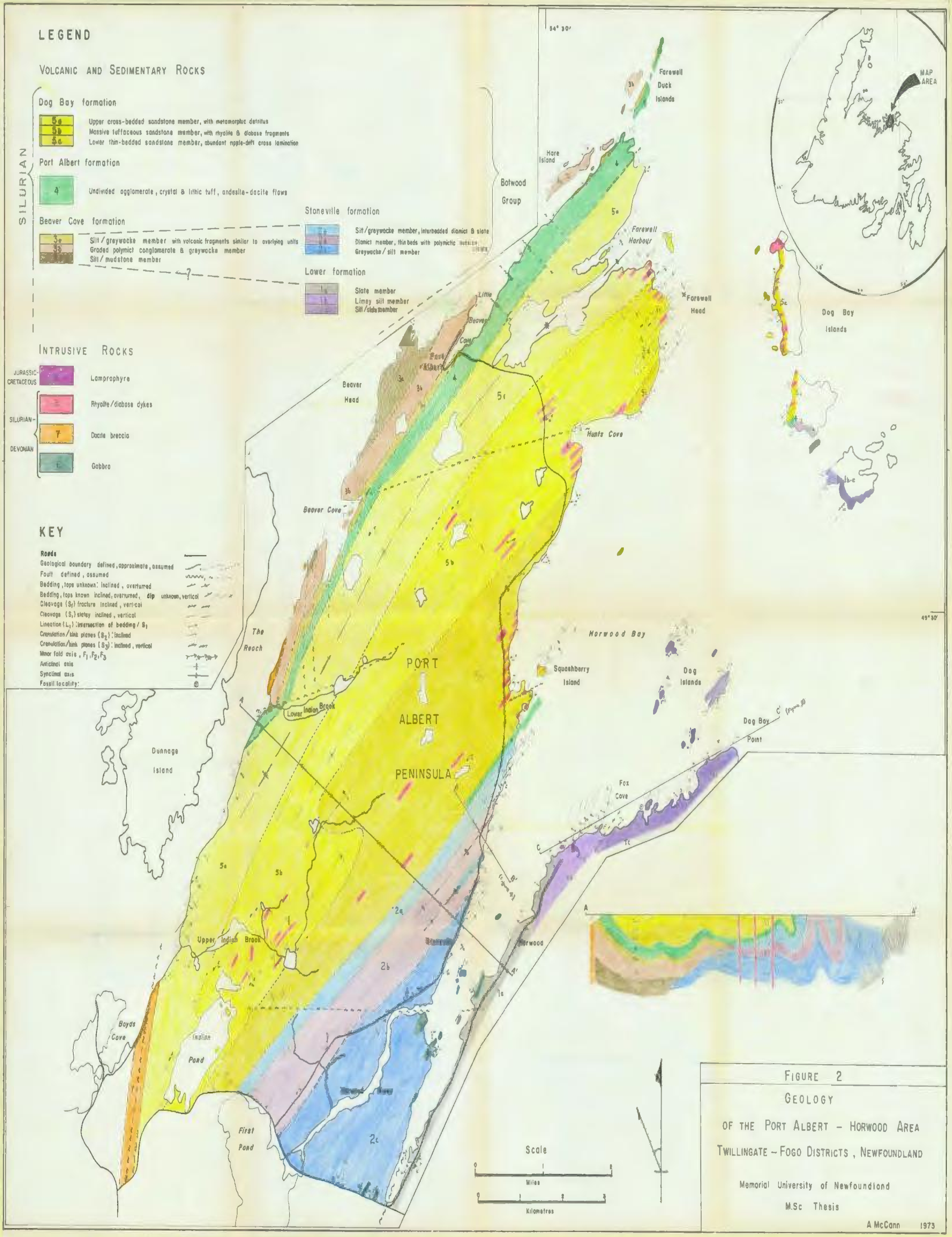


FIGURE 2

GEOLOGY

OF THE PORT ALBERT - HORWOOD AREA

TWILLINGATE - FOGO DISTRICTS, NEWFOUNDLAND

Memorial University of Newfoundland

M.Sc Thesis

A McCann 1973