THE STRATIGRAPHY AND SEDIMENTOLOGY OF THE LATE PRECAMBRIAN ST. JOHN'S AND GIBBET HILL FORMATIONS AND THE UPPER PART OF THE CONCEPTION GROUP IN THE TORBAY MAP-AREA, AVALON PENINSULA, NEWFOUNDLAND

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by

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ABSTRACT

In the Torbay map-area, the St. John;s and Gibbett Hill Formations of the Cabot Group and the upper part of the Conception Group form a continuous and conformable sequence of Late Hadrynian sedimentary rocks. The upper part of the Conception Group consists of green-gray and variegated graywacke, siltstone, argillite, and volcanic tuff. The St. John's Formation consists of six lithofacies and is divisible into two members; namely, in ascending order, Middle Cove and Outer Cove Members. The Middle Cove Member is represented by the laminated black shale and the Outer Cove Member by interbedded sandstone (or siltstone) and black shale with locally developed volcanic tuff. The Gibbett Hill Formation, overlying the St. John;s Formation, consists of green-gray arkosic sandstone, siltstone, argillite and volcanic tuffs. This formation is an equivalent of the lower member of the original Signal Hill Formation redefined in this thesis. The names "Battery Member" and "Cuckold Member" are proposed for the middle and upper members of the original Signal Hill Formation.

The presence of volcanic tuffs in these units indicates intermittent volcanic activity during late Precambrian time. Tentative correlation of the tuff beds in the Torbay map-area suggests a diachronous relationship of the boundary between the Gibbett Hill and Signal Hill Formations.

Aspidella terranovica Billings 1872 and associated surface markings in the Outer Cove Member of the St. John's Formation are considered to be inorganic sedimentary structures such as load casts and gas- or water-escape structure..

A model of the depositional environments of part of the Cabot Group and the upper part of the Conception Group is proposed. The upper part of the Conception Group was formed as turbidites in deep marine environment. The Middle Cove Member of the St. John's Formation was deposited in a prodelta and the Outer Cove Member in distal delta front. The Gibbett Hill Formation, transitional to subaerial deposition, was formed in a proximal delta front.

The source area for these units probably lies to the north of the Torbay map-area.

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CHAPTER I

INTRODUCTION

Location and Access

The thesis area centers around St. John's, Newfoundland and extends 48 miles southward to Ferryland, and 7 miles northward to Torbay (Fig.1-1). Most of the coastal exposures are easily accessible by paved highways, gravel roads, and trails. A boat was used in the examination of the coastal section between Middle Cove and Outer Cove. Inland exposures are poor and traversing is difficult because of the dense bushes, bogs, and rough terrane.

Previous Work

The first report and map on the geology of Newfoundland was by J. B. Jukes (1843). In that report for the Newfoundland Government, the rocks of Avalon Peninsula were named and classified as follow:

Upper Slate Formation	a. Belle Isle shale and gritstone
	b. Variegated slates
Lower Slate Formation	a. Signal Hill sandstones
	b. St. John's slate

As a result of their field work from 1864 to 1880, Alexander Murray and J. P. Howley published a report and a detailed geological map of the Avalon Peninsula in 1881. In the report the rocks of the Avalon Peninsula were divided, in ascending order, into "a, b, c, d, e, f, and g" divisions.

Walcott (1899) proposed the name "Avalon Terrane" to include the formations lying between the basal beds of the Cambrian System and the Archean gneisses of Newfoundland, and used the names Signal Hill, Momable, Conception, and Torbay for these formations.

Rose (1952) completed mapping of the Torbay map-area for the Geological Survey of Canada and proposed four main rock groups (Table 1).

In 1968, Singh undertook the first detailed petrological study of the Signal Hill and the Blackhead Formations. He concluded that the Signal Hill and Blackhead Formations are derived from a similiar source area and represent shallow marine, fluvial, and alluvial plain sediments (Singh, 1969).

Brueckner (1969) summarized the geology of the Avalon Peninsula. He concluded that the Cabot Group represents a sequence of deltaic sediments in which the St. John's Formation formed the bottomset beds, the Signal Hill Formation the foreset beds, and the Blackhead Formation the topset beds.

Present Study

This thesis was originally intended as a study of the problematic fossils known as <u>Aspidella terranovica</u> Billings 1872, exposed in the St. John's Formation.

During the preliminary field work at Ferryland in the summer of 1967, the author discovered volcanic tuffs in the St. John's and Signal Hill Formations. The contact between the Conception Group and St. John's Formation was found to be transitional rather than disconformable as reported by Rose in 1952. In order to ascertain the distribution of volcanic tuffs and the geometry of the St. John's Formation, the author decided to extend the study area.

The major part of the field program was carried out in the summer of 1970. Air photos at a scale of one inch to 1,420 feet and topographic map at a scale of 1: 50,000 were used to record field data. The geological map by Rose (1952) was the chief source of reference.

Areas selected for detailed study were Outer Cove to Middle Cove, Bay Bulls, Mobile Bay, Calvert Bay, and Ferryland. Aerial photographs were used in estimating the stratigraphic thickness of the St. John's Formation as measurements in the field were hampered by discontinuous exposures and by the presence of small scale folds and faults.

Nineteen thin sections of sandstone and siltstone were selected for modal analysis of the mineralogical composition and about 700 to 1,000 grains in each thin section were counted with a Swift Point Counter.

The qualitative mineralogical composition of the volcanic tuffs and black shale was determined by X-ray diffraction. Chemical analysis of the major inorganic elements in one black shale specimen was carried out by the Geochemistry Laboratory of the Geological Survey of Canada.

The present study is essentially a description and an interpretation of lithofacies and depositional environments of the upper part of the Conception Group, the St. John's Formation, and the lower member of the Signal Hill Formation. A relationship between time and lithostratigraphic boundaries using volcanic tuffs as key beds is proposed.

Acknowledgments

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CHAPTER II

STRATIGRAPHY

Introduction

The eastern part of the Avalon Peninsula is underlain by four main rock units of presumed Hadrynian age. They are, in ascending order, Harbour Main Group, Holyrood Plutonic Series, Conception Group, and Cabot Group. Table I illustrates the stratigraphic sequences in the eastern Avalon Peninsula and their presumed stratigraphic equivalents in the Whitbourne map-area. The general stratigraphic nomenclature of Rose (1952) and McCartney (1967) was used in the field but a relevent revision of the Cabot Group is proposed.

Harbour Main Group

Name

The Harbour Main Group is the oldest exposed unit in the map-area and is composed of mainly basic and acidic volcanic rocks and intercalated sedimentary rocks.

These rocks correspond to map units "a and b" of Murray and Howley (1881-b) and were first named "Avondale Volcanics" by Buddington (1919) after their type locality. Howell (1925) renamed them "Harbour Main Volcanics" as the name "Avondale" had previously been used elsewhere. Rose (1952) renamed them "Harbour Main Group".

Distribution, Correlation, and Thickness

The Harbour Main Group is distributed around the Holyrood Granite, and together they form the core of the Avalon Peninsula.

Table 1. Table of Formations.

Era, Period, or Epoch	Whitbourne Map-area McCartney, 1967	Torbay Map-area	
		Rose, 1952	Hsu, 1972
Precambrian	Hodgewater Group	Cabot Group	Cabot Group
	Snows Pond Formation	Blackhead Formation	Blackhead Formation
	Whiteway Formation	Signal Hill Formation	Signal Hill Formation
		Upper Member	Cuckold Member
		Middle Member	Battery Member
	Halls Town Formation	Lower Member	Gibbett Hill Formation
	Carbonear Formation	St. John's Formation	St. John's Formation
			Outer Cove Member
			Middle Cove Member
	Transition	Disconformity	Transition
	Conception Group	Conception Group	Conception Group
	Intrusive Contact		
	Holyrood Plutonic Series	Holyrood Batholith	Holyrood Plutonic Series
	Unconformity		
	Harbour Main Group	Harbour Main Group	Harbour Main Group

The base of this unit is unexposed and the stratigraphic thickness is at least 6,000 feet (McCartney, 1967). Volcanic rocks in the Burin Peninsula may be stratigraphic equivalents (McCartney, 1967).

Boundary Relationships

Rose (1952) stated that the Harbour Main Group in the Torbay map-area is unconformably overlain by the Conception Group at several localities. However, beds similar in lithology to the Conception Group occur with the Harbour Main Group and the time interval represented by the contact between the two groups is of minor significance. Brueckner (1969, p. 133) states that a conformable relationship exists between the Harbour Main and Conception Groups in the eastern Avalon Peninsula but an unconformable one in the western Avalon Peninsula.

Such ambiguous relationships, together with other evidence, lead Hughes (1970) and Hughes and Brueckner (1971) to propose that the Harbour Main and Conception Groups were actually penecontemporaneous facies.

The Harbour Main Group is intruded by granite of the Holyrood Plutonic Series; it is unconformably overlain by Cambrian sediments at the southeastern shore of Conception Bay.

Holyrood Plutonic Series

Name and Distribution

Granite and marginal facies of quartz monzonite and quartz diorite occurring in central Avalon Peninsula were named "Holyrood Batholith" by Rose (1952) and "Holyrood Plutonic Series" by McCartney (1967).

Boundary Relationships and Age

The Holyrood Granite intrudes the Harbour Main Group. Although Rose (1952) reported that the Holyrood granite intruded the lower part of the Conception Group, field relationships of the granite with the upper part of the Conception Group are not entirely clear. McCartney (1967) stated that in the Whitbourne map-area the intrusive relationship is uncertain.

The granite has been dated by the rubidium/strontium isochron as 574 ± 11 million year old (McCartney, et al., 1966).

Both the granite and the Harbour Main Group are unconformably overlain by the Cambrian sediments.

Conception Group

Name

The rocks in this unit correspond to the map units "b and c" of Murray and Howley (1881-a and 1881-b). Walcott (1899) used the name "Conception Slate" for the predominantly green and greenish gray rocks and "Torbay Slate" for the variegated beds. Both "Torbay Slate" and "Conception Slate" were included in the "Conception Group" named by Rose (1952).

Distribution, Correlation, and Thickness

The extent of the Conception Group is shown in Fig. 1-1. This group was correlated by Hayes (1948) and Christie (1950) with the Connecting Point Group in the Bonavista area and by McCartney (1967) with the Conception Group in the Whitbourne map-area. It has an exposed thickness of some 8,000 feet in the Torbay map-area (Rose, 1952).

Boundary Relationships

The Conception Group lies unconformably on the Harbour Main Group in the western part of the Avalon Peninsula. A conformable relationship exists between these two groups in the eastern part of the Avalon Peninsula (Brueckner, 1969).

The present study indicates a transitional relationship between the St. John's Formation and the underlying Conception Group rather than a disconformity as reported by Rose (1952).

St. John's Formation

Name

This unit was originally named by Jukes (1843) as "St. John's Slate" which was renamed "Aspidella Slates" by Murray and Howley (1881-a). Walcott (1899) used the name "Momable Slates", later renamed "St. John's Formation" by Rose (1952).

Distribution, Correlation and Thickness

The distribution of the St. John's Formation (Fig. 1-1) is very extensive; it extends southerly from Torbay to Aquaforte Harbour, on the north shore of Trepassey Bay (Misra, 1969; Koh, 1969), and on the east shore of St. Mary's Bay (Brueckner, personal communication, 1969). The St. John's Formation was correlated by McCartney (1967) with the Carbonear Formation in the Whitbourne map-area.

The thickness of the St. John's Formation varies from 2,000 feet in the Middle Cove - Outer Cove section to about 4,000 feet in the Ferryland area.

Boundary Relationships

A transitional contact exists between the St. John's Formation and Conception Group; it is about 150 feet thick at Middle Cove and attains maximum development of 250 feet in the Ferryland area.

Subdivision of the St. John's Formation

Studies of lithofacies have shown that the St. John's Formation is divisible into two members. They are best exposed in the Middle Cove - Outer Cove area and it is proposed that the lower member be named "Middle Cove Member" and the upper member "Outer Cove Member" (see Table 1). The Middle Cove Member consists of two facies; mudstone facies (facies A) and laminated black shale facies (facies B). The Outer Cove Member is mainly characterized by an interbedded sandstone and shale facies (facies C) with locally developed medium-bedded sandstone facies (facies D), channel sandstone facies (facies E), and volcanic facies (facies F) (Table 2). In all investigated sections the two members have transitional boundaries.

Signal Hill Formation

Name

The name "Signal Hill Formation" was proposed by Rose (1952) for the rocks which correspond to the "Signal Hill Sandstone" of Jukes (1843) and "Signal Hill Series" of Buddington (1929). The three members of the Signal Hill Formation are equivalent to the "e, f, and g" divisions of Murray and Howley (1881-b).

Distribution, Correlation, and Thickness

The Signal Hill Formation extends in a continuous exposure from Red Head in the north to Mobile and reappears at Cape Broyle and Ferryland. The lower member was correlated with the Halls Town Formation and the middle and upper members with the Whiteway Formation in the Whitbourne map-area (McCartney, 1967).

The stratigraphic thichness of this formation is 7,800 feet at Signal Hill, the type locality (Rose, 1952). This formation thins along the strike both northerly and southerly.

Boundary Relationships

The Signal Hill Formation is transitional with the underlying St. John's Formation through a zone of green-gray sandstone, argillite, and black shale, and is overlain conformably by the Blackhead Formation.

The three members of the Signal Hill Formation are transitional. The green-gray sandstone of the lower member passes upwards into the red sandstone through a zone of interbedded red sandstone and green-gray sandstone. The boundary, taken at the first appearance of red beds, is nevertheless very sharp because of the contrast in color. The middle member is transitional in turn with the red conglomerate.

Revision of Stratigraphic Boundary at Ferryland

In the Torbay map-area, three lithological criteria were used to define the boundary between the Gibbett Hill and St. John's Formations. The first two criteria were emphasized by the author in addition to the third one by Rose (1952).

(1) The St. John's Formation is characterized by alternating laminae and very thin beds of gray sandstone or siltstone and black shale (facies C of the Outer Cove Member).

(2) Green-gray argillite is typical of the Gibbett Hill Formation, while black shale is the representative rock type of the St. John's Formation.

(3) Predominance of green-gray, medium- to thick-bedded sandstone over argillite and black shale in the Gibbett Hill Formation.

These criteria support the placement of the boundaries established by Rose (1952) with a principal exception in the Ferryland area and the proposed revision is shown in Fig. 2-1.

Redefinition of the Signal Hill Formation

In a paper now under preparation by King, Hsu and Singh on the Cabot Group, Avalon Peninsula, it is proposed that the Signal Hill Formation be redefined for the following reasons:

(1) The three members of this Formation are mappable units (see geological map by Rose, 1952).

(2) The upper and middle members consist mainly of red beds and the middle member has a sharp boundary with the green-gray beds of the lower member because of the contrast in color. The red beds in the Torbay map-area can be easily correlated.

(3) The lower member of the Signal Hill Formation has been correlated with the Halls Town Formation and the red beds of the middle and upper members with the Whiteway Formation in the Whitbourne map-area.

Therefore, retention of the name "Signal Hill Formation" for only the red beds will be more natural and useful, particularly in regional correlation of rocks in the Avalon Peninsula.

The Signal Hill Formation can be redefined, as shown in Table 2. Either (1) Make the present lower member of the Signal Hill Formation the upper member of the St. John's Formation or (2) Raise the rank of the lower member to establish a new formation and retain the name "Signal Hill Formation" for the red beds of the upper and middle members.

Although the first alternative is not restricted by the Code of Stratigraphic Nomenclature, correlation of a member of the Signal Hill Formation with the Halls Town Formation is certainly undesirable because of the same reason given above.

The second alternative, though enabling correlation of stratigraphic units of the same rank, is seriously hampered by the Stratigraphic Code. Article 14 of the Code states that:

> "When a unit is divided into two or more of the same rank as the original, the original name should not be employed for any of the divisions .... For these reasons it should be normal practice to raise the rank of a unit when it becomes everywhere subdivisible into mappable units".

Consequently, it is not only necessary to abolish the name "Signal Hill" but also necessary to raise the rank of the original formation to a higher status as a group. Abolition of the name "Signal Hill" is unsatisfactory for it is well established type

Table 2. Redefinition of the Cabot Group.

STRATIGRAPHY BY ROSE, 1952	MAIN ROCK TYPE	FIRST ALTERNATIVE	SECOND ALTERNATIVE
BLACKHEAD FORMATION	Red sandstone	BLACKHEAD FORMATION	BLACKHEAD FORMATION
SIGNAL HILL FORMATION		SIGNAL HILL FORMATION	SIGNAL HILL FORMATION
Upper member	Red conglomerate	Cuckold Member	Cuckold Member
Middle member	Red sandstone	Battery Member	Battery Member
		ST. JOHN'S FORMATION	
Lower member	Green-gray sandstone	Gibbett Hill Member	GIBBETT HILL FORMATION
ST. JOHN'S FORMATION			ST. JOHN'S FORMATION
	Gray sandstone, siltstone and black shale	Outer Cove Member	Outer Cove Member
	Black shale	Middle Cove Member	Middle Cove Member

locality for the red beds. Raising the rank of the Signal Hill Formation would also mean raising the rank of "Cabot Group" to a supergroup and although in keeping with the Code would cause confusion rather than clarification.

The second alternative, although apparently invalid could clarify the stratigraphy of both the Tobay map-area and the regional stratigraphy of the Avalon Peninsula. Therefore, although normal practice to raise the rank of a unit, the author intends to appeal to the Commission on Stratigraphic Nomenclature that the name "Gibbett Hill Formation" be used for the lower member and the names "Battery Member" and "Cuckold Member" for the middle and upper members of the original Signal Hill Formation. These proposed and revised names will be used throughout the thesis.

Correlation of Volcanic Tuff

The stratigraphic distribution of tuff beds in the Torbay map-area is shown in Fig. 3-2. A tentative correlation of some of the tuff beds is attempted.

On the north shore of Calvert Bay, a 7-foot thick tuff bed is characterized by yellowish green color and irregular white and dark bands of diagenetic origin. A tuff bed, identical in color and mineralogical composition with diagenetic bands occurs on the north shore of Mobile Bay, about 18 miles to the north of Calvert Bay.

An 8-foot thick tuff bed on the north shore of Bay Bulls occurs as an intercalation in the red beds of the Gibbett Hill Formation. It is yellowish green in color and contains tiny white spheres of diagenetic origin; at the base of the tuff bed are concentrations of coarse detrital grains consisting mainly of pink feldspars. An identical tuff bed was also found in the White Hills, about 20 miles to the north of Bay Bulls, in the red beds at the base of the Battery Member of the Signal Hill Formation.

The striking resemblance of these tuff beds, traceable for a distance of up to 20 miles, suggests that they may be used as key beds to correlate rock units in the Cabot Group, not only in terms of lithology but on the basis of contemporaneity of origin (Fig. 3-2). The validity of these correlations can only be verified when the absolute ages of the tuff beds are determined; if the correlation is correct, the litho-stratigraphic boundary between the Gibbett Hill and the Signal Hill Formations is diachronous.

CHAPTER III

LITHOLOGICAL UNITS AND THEIR CHARACTERISTICS

Introduction

In the thesis area, the upper part of the Conception Group underlying the St. John's Formation is composed of green-gray and purplish red graywacke, siltstone, argillite, and volcanic tuffs. Common sedimentary structures include parallel bedding, graded bedding, flute markings and load casts. These beds are turbidites and volcanic ash deposits. Ripple marks and cross laminations are very rare.

The St. John's Formation overlies the Conception Group and consists mainly of black shale in the Middle Cove Member and approximately equal amount of gray sandstone-siltstone and black shale in the Outer Cove Member. The sedimentary structures in the Middle Cove Member are mainly parallel laminations indicative of sedimentation in quiet water bodies, and slump folding suggestive of the presence of a paleoslope. The Outer Cove Member shows sedimentary structures such as cross laminations, ripple marks, scour-and-fill, and channeling.

The Gibbett Hill Formation consists mainly of green-gray sandstone with less green-gray siltstone,argillite and black shale. Volcanic tuff beds become more abundant towards Ferryland. Sedimentary structures include both large and small scale cross bedding and ripple marks. Mud cracks were observed at Calvert Bay and

Ferryland, indicating subaerial exposure of sediments during deposition.

Conception Group

In the Ferryland area, the upper part of the Conception Group consists of parallel-bedded (Pl. 3-1), green-gray, and variegated graywacke, siltstone, argillite, and yellowish green or green-gray tuffs. The bed thickness ranges from fractions of an inch up to 5 feet, but in general less than 2 feet thick.

Graywacke

There are two structurally different types of graywacke; (1) Graded graywacke: graywacke of this type is generally coarse-grained and mainly occurs as graded beds or as the basal part of a graded bed. The graywacke is green-gray or purplish red in color. (2) Laminated graywacke: graywacke of this type is very fine- to medium-grained and green-gray in color.

Mineralogical Composition

In thin section, the bimodal distribution of the detrital grains is the distinguishing feature of the graywacke (Pl. 3-5). The poorly sorted, angular to well rounded detrital grains have very poor grain-to-grain contacts and appear as isolated particles in the groundmass. The detrital grains are composed of quartz (12-20 per cent), feldspar (19-40 per cent), and less than 10 per cent rock fragments. The modal analysis of graywacke is given in Table 2.

Table 3. Modal analysis of the sandstones of Conception Group, St. John's Formation and Gibbett Hill Formation.

		Conception Group				
		1	2	3	4	5
	Quartz	17	12	15	12	20
	Plagioclase	27				
	K-feldspar	2				
	Total feldspar	29	37	39	19	32
Rock Fragments	Meta-quartzite	-	-	-	Tr	Tr
	Quartzite	-	-	-	-	-
	Chert	1	4	2	1	3
	Argillite	4	Tr	-	Tr	-
	Rhyolite	2	1	1	5	-
	Basic volcanics	1	Tr	Tr	-	-
	Granite & granophyre	1	Tr	-	-	-
	Total rock fragments	9	5	3	6	3
	Matrix	45	36	36	60	30
Accessory Minerals	Biotite	-	Tr	Tr	-	-
	Hematite	-	5	1	-	6
	Epidote	-	-	-	Tr	-
	Sphene	-	Tr	Tr	Tr	-
	Apatite	-	-	-	-	-
	Zircon	-	-	-	Tr	-
Diagenetic Products	Chlorite	-	2	6	Tr	13
	Calcite	-	2	-	-	3
	Epidote	-	2	-	4	-
	Authigenic quartz	-	-	-	-	-

Table 3. (continued)

		St. John's Formation						
		6*	7*	8	9	10	11*	12
	Quartz	19	19	9	34	30	20	10
	Plagioclase				22	47		50
	K-feldspar				2	2		3
	Total feldspar	55	22	71	24	49	54	53
Rock Fragments	Meta-quartzite	-	-	-	Tr	-	-	1
	Quartzite	-	-	-	2	-	2	Tr
	Chert	-	-	-	2	-	-	6
	Argillite	Tr	Tr	-	10	2	2	4
	Rhyolite	-	-	3	19	1	1	8
	Basic volcanics	-	-	6	Tr	1	-	4
	Granite & granophyre	-	-	-	-	-	-	-
	Total rock fragments	-	-	9	33	4	5	23
	Matrix	27	59	10	4	5	16	5
Accessory Minerals	Biotite	Tr	-	Tr	Tr	Tr	Tr	2
	Hematite	-	-	-	-	-	-	-
	Epidote	-	-	-	-	-	-	-
	Sphene	-	-	-	-	-	-	-
	Apatite	-	Tr	-	-	-	-	-
	Zircon	-	-	-	-	-	-	-
Diagenetic Products	Chlorite	-	-	-	-	-	-	-
	Calcite	-	-	-	-	14	6	4
	Epidote	-	-	-	-	-	-	-
	Authigenic quartz	-	-	5	5	-	-	2

Table 3 . (continued)

		Gibbett Hill Formation						
		13	14	15	16	17	18	19**
	Quartz	38	35	17	16	28	25	23
	Plagioclase	19	27	36	39	39	32	17
	K-feldspar	8	1	6	3	1	2	36
	Total feldspar	27	28	42	42	40	34	53
Rock Fragments	Meta-quartzite	1	1	-	-	1	Tr	-
	Quartzite	1	-	-	-	-	-	-
	Chert	Tr	6	6	9	4	4	-
	Argillite	2	11	7	5	9	9	-
	Rhyolite	17	7	9	15	6	12	-
	Basic volcanics	Tr	Tr	2	2	1	1	-
	Granite & granophyre	Tr	-	-	-	1	1	-
	Total rock fragments	23	26	24	31	22	27	-
	Matrix	4	5	8	7	9	6	35
Accessory Minerals	Biotite	Tr	Tr	Tr	Tr	1	Tr	Tr
	Hematite	-	-	-	-	-	-	-
	Epidote	Tr	-	-	-	-	-	-
	Sphene	Tr	-	-	Tr	-	-	-
	Apatite	-	-	-	-	-	-	-
	Zircon	Tr	-	-	-	-	-	-
Diagenetic Products	Chlorite	-	-	-	-	-	1	-
	Calcite	9	Tr	2	-	-	-	-
	Epidote	-	Tr	7	6	4	6	-
	Authigenic quartz	3	-	-	1	-	1	-

Table 3. (continued)

* Volcanic tuff

** Tuffaceous sandstone

Sample location:

1 - 5	....	north shore of Calvert Bay
6	....	Broad Cove, Calvert Bay
7	....	Coldeast Point, Ferryland
8	....	Middle Cove
9 - 10	....	Outer Cove (channel sandstone)
11	....	Aquaforte Harbour
12	....	Bay Bulls (channel sandstone)
13- 16	....	Ferryland Harbour
17- 18	....	Calvert Bay
19	....	north shore of Bay Bulls

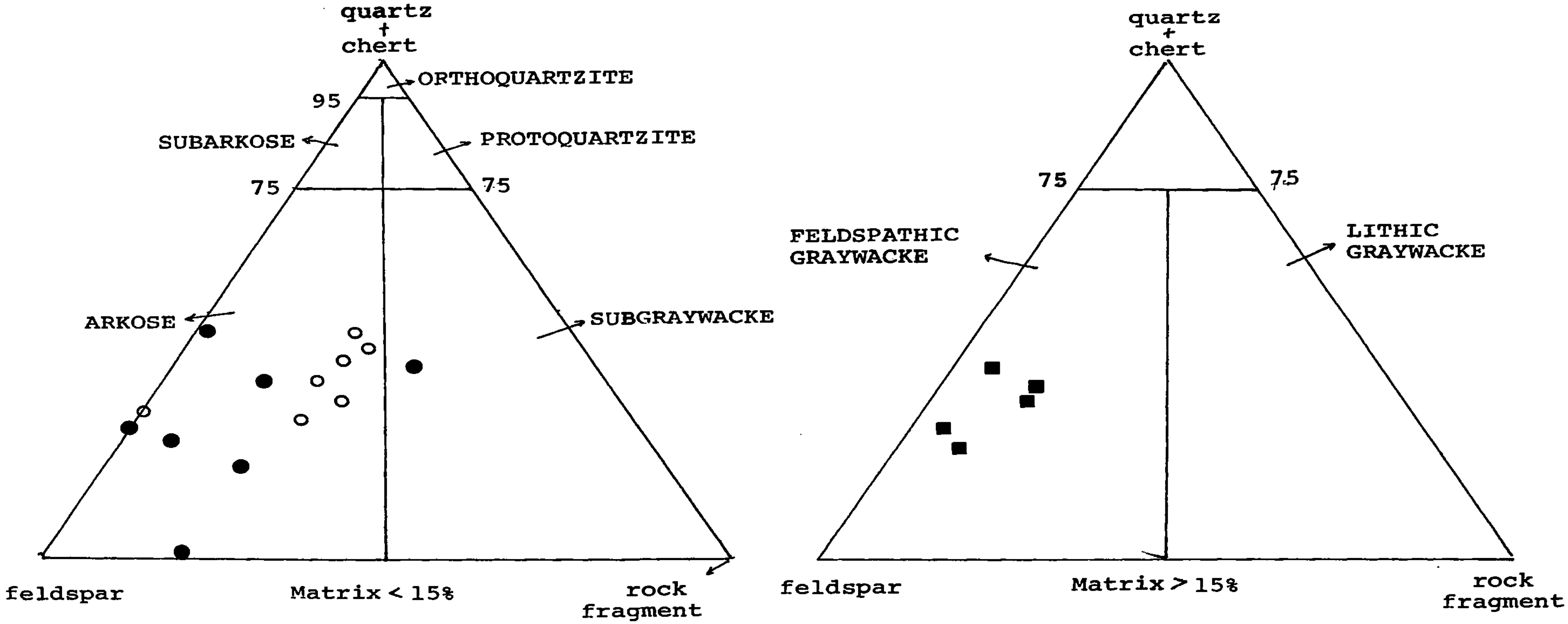

Fig. 3-1. Detrital composition of sandstones from the St. John's and Gibbett Hill Formation and the upper part of the Conception Group.
(see Table 2 for modal analysis of sandstones)
(sandstone classification by Pettijohn, 1957)
● St. John's Formation
○ Gibbett Hill Formation
■ Conception Group

The quartz grains are angular to well rounded, contain minute inclusions and show strain extinction. Quartz of volcanic origin are inclusion-free, show plain extinction, and have embayed grain boundaries. The feldspars are generally fresh but may show slight alteration to chlorite and sericite. Plagioclase is albite to oligoclase in composition.

The rock fragments include argillite, chert, rhyolite (?), basic volcanics, granitic rocks, metaquartzite (a rock which is composed of mosaic of stretched quartz with strong strain extinction) and quartzite (a rock which is composed of quartz mosaic with moderate strain extinction).

The groundmass of the graywacke constitutes from 15 to 60 per cent of the total rock, and consists of chlorite, sericite, quartz, and feldspar in varying proportions. In some graywacke, the groundmass is very siliceous, while in others very chloritic or sericitic. In the chloritic or sericitic groundmass, glass shards have been identified (Pl. 3-6) and indicate that the graywacke is tuffaceous. Epidote and leucoxene are commonly disseminated throughout the groundmass.

The purplish red graywacke is similar in mineralogical composition to the green-gray graywacke except they contain a greater amount of opaque hematite (up to 5 per cent).

Sedimentary Structures

The sedimentary structures of graywacke include graded bedding, convolute bedding, cross lamination, flute marking, and load casts.

Graded bedding - Repetitive graded beds are the most abundant structures in the upper part of the Conception Group. Most graded beds are less than one foot thick, but some are as much as three or four feet thick. Graded bedding results from an upward decrease in grain size from the basal graywacke to siltstone and then to argillite. Color grading from light to dark green-gray accompanies the size grading. The boundaries between the graded beds are invariably sharp because of the erosion of the top of the lower graded bed (Pl. 3-2).

Convolute bedding - The convolute beds are common and are characterized by a series of tight anticlinal and broad synclinal folds and are closely associated with the laminated graywacke in the graded beds.

Flute markings and load casts - Exposure of bedding surfaces are very rare and therefore sole markings such as flute markings and load casts are seldom seen in plan view. Flute markings observed on the bedding surfaces are of small size (Pl. 3-4) not more than 4 inches wide and 1/8 inch in height. They are blunt at one end and taper at the other with a shape of stretched water drops. The current direction indicated by the flute markings is from north to south.

Load casts or flame structures are common and are characterized by bowl-shaped protrusions at the lower surfaces of the graywacke with flames of argillite projecting upwards into the overlying graywacke.

Cross lamination - Cross lamination (Pl. 3-3) is very rare. In some graded beds, the basal laminated graywacke shows small scale cross laminations of solitary sets. The foreset laminations indicate that current direction is from north to south.

Siltstone

Green-gray and purplish red siltstones occur as parallel beds with bed thickness up to two feet. The siltstones are massive or laminated.

Except for the grain size and less rock fragments the mineralogical composition of siltstone is similar to that of graywacke.

Sedimentary structures such as graded bedding, flute marking, and convolute bedding as described above are also common in the siltstone.

Argillite

The argillite occurs mainly as thin beds up to 2 or 3 feet thick. In general, argillite occurs at the upper part of graded beds or above the graded beds.

The argillites are highly silicified and very cherty with subconchoidal fractures. The mineralogical composition of argillite as determined by X-ray diffraction consists of sericite, chlorite, albite, and quartz.

Round calcite nodules up to 3 mm in diameter are present in some argillites. Aggregates of nodules often form lenticular bodies. The size of these lenticular bodies is generally small but may be as much as six or seven feet in length and two feet thick at the center of lense. The weathered surface of the lenticular bodies is pitted with an appearance of honey comb. On top of a small hill about two miles due west of Ferryland, the lenses occur intermittently in the same argillite bed for over 200 yards.

In thin section, the nodules are composed of patches of calcite which exhibit twin lamellae. In many cases, detrital grains are enclosed at the center of nodules. The boundaries of nodules with the groundmass are hazy.

Tuff

Volcanic tuffs have not been previously reported in the upper part of the Conception Group in the Ferryland area, although they are known to occur in the Trepassey area of the southeastern Avalon Peninsula (Misra, 1969).

Many tuff beds were discovered by the author along the north and south shore of Calvert Bay and the north shore of Aquaforte Harbour. The tuffs are yellowish green or olive green in color with bed thickness ranging from a few inches to two feet. The tuffs are generally massive but some are laminated. Concentrations of detrital grains, consisting of mainly pink K-feldspar, volcanic quartz, and rock fragments, occur at the base of the tuff beds and show a decrease in grain size towards the top of beds.

In thin section, the groundmass of the tuff beds are composed of devitrified glass shards (Pl. 3-9), sericite, quartz, and albite with minor calcite. The detrital grains are composed of quartz, granophyre, K-feldspar, sodic plagioclase, rhyolite, and basic volcanics.

St. John's Formation

Introduction

The St. John's Formation is divisible into six lithological facies; namely, facies A - mudstone, facies B - laminated black shale, facies C - interbedded sandstone and black shale, facies D- medium bedded sandstone, facies E - channel sandstone, and facies F - volcanic tuff. The stratigraphic distribution of these facies is shown in Fig. 3-3 and their characteristics are summarized in Table 4.

The term "facies" used in the text refers to a sequence or a group of rocks which possess an association of particular sedimentary features such as color, grain size, composition, and sedimentary structures in such a way that it can be treated as a entity and can be distinguished from others.

Facies A - Mudstone

This facies is defined by a sequence of repetitive graded beds of mudstone and sandstone and is best exposed in Middle Cove and Ferryland as a transition zone between the Conception Group and the St. John's Formation. The rocks are green-gray or grayish black in color. Bed thickness decreases upward; the average thickness at the basal part of this facies is about 6 inches, but decreases to 1/4 to 1/6 inches at the top.

Sedimentary Structures

The sedimentary structures of this facies include graded

Table 4. Summarized characteristics of lithological facies of the St. John's Formation

Abundant ◉ Common ●

Uncommon • Rare ○

Sedimentary Structures	Facies A - Mudstone	Facies B - Laminated Black Shale	Facies C - Interbedded Sandstone and Shale	Facies D - Medium-bedded Sandstone	Facies E - Channel Sandstone	Facies F Tuff
Graded bedding	◉		◉			●
Parallel lamination	◉	◉	●	●		●
Slump folding		◉	○			
Gas- or water-escape markings			◉			
Cross lamination	•		●	◉		
Cross bedding					◉	
Ripple marks	○	○		◉	◉	
Channels and fills					◉	
Convolute bedding	◉					
Ripple-drift cross lamination			◉	●		
Scour-and-fill			◉			
Wavy bedding			◉			
Flaser bedding			•			
Lenticular bedding	○	○	•			

bedding, lenticular bedding, ripples, cross lamination, and convolute bedding. Among these structures, graded bedding is the most abundant.

Graded bedding - Graded beds (Pl. 3-10) are the prominent structure in this facies; laminated sandstone with a sharp basal boundary grades progressively upward to massive mudstone. Where the basal sandstone is absent, basal silty mudstone gradually grades upward into mudstone. In both cases, the graded beds are generally overlain by parallel-laminated mudstone.

Ripples, cross lamination, and lenticular bedding - The green-gray sandstones show distinct parallel bedding (at least within the extent of rock exposure). However, the gray sandstones at the upper part of this facies generally thin out. Such lateral impersistence is attributed to the impoverished supply of sand during deposition.

Although ripple marks were not observed, some of the sandstones show internal ripples and small scall cross laminations. Some of the gray sandstones contain many isolated ripples, which are generally lenticular in shape but some of which may be symmetrical and peaked. Such bed with isolated lenses closely resembles the "Linsenschichten" (or lenticular bedding) of Reineck (1960).

Convolute bedding - In the laminated green-gray sandstones, convolute bedding, which is characterized by a tight anticlinal crest and a broad synclinal trough, are common and may occur at the upper part of the green-gray sandstone bed. Convolute bedding is, however, not present in the gray sandstone.

Facies B - Laminated Black Shale

Facies B is the major lithological unit of the Middle Cove Member of the St. John's Formation and stratigraphically overlie facies A.

It includes alternating laminae of silty black shale and massive black shale with minor intercalations of sandstone and siltstone. The black shale is generally less than 1 cm. thick, although in some cases it may be as thick as 5 or 8 cm.

Since the intercalated sandstone or siltstone beds in the black shale occur at an interval of 3 to [illegible] inches in average, the ratio of sandstone-siltstone to black shale is estimated to be 1:4.

Mineralogical Composition

The mineralogical composition of the black shale as qualitatively determined from X-ray diffraction consists of chlorite, sericite, albite, and quartz. In thin section, there is an abundance of dark brown, isotropic, possibly carbonaceous, matter. The micaceous minerals and chlorite flakes are of diagenetic origin and are oriented parallel to the cleavage.

One black shale specimen from the south shore of Calvert Bay was analyzed for major inorganic elements (Table 5) and its mineralogical composition calculated with the method of Imbrie and Poldervaart (1959) is shown in Table 6. The Significance of this single analysis is uncertain and further

Table 5. Chemical analysis of black shale from the Middle Cove Member, south shore of Calvert Bay, Ferryland.

Constituent	1	2	3	4
SiO_2	60.90	58.10	56.30	60.64
TiO_2	0.80	0.65	0.77	0.73
Al_2O_3	17.38	15.40	17.24	17.32
Fe_2O_3	4.96	4.02	3.83	2.25
FeO	1.02	2.45	5.09	3.66
MnO	0.13		0.10	
MgO	2.29	2.44	2.54	2.60
CaO	1.56	3.11	1.00	1.54
Na_2O	2.99	1.30	1.23	1.19
K_2O	2.96	3.24	3.79	3.69
P_2O_5	0.15	0.17	0.14	
CO_2	1.05	2.63	0.84	1.47
H_2O	0.16	5.00	0.38	0.62
H_2O	3.30		3.31	3.51
S	0.12	0.64*	0.28*	
C	0.16			
Total	99.93	99.95	100.00	99.60

1. Black shale from St. John's Formation: analysis done by Geochemistry Laboratory, Geological Survey of Canada, Ottawa.
2. Average shale (Clark, p.24)
3. Unweighted average of 33 samples of Precambrian slates (Nantz, 1953).
4. Unweighted average of 36 samples analyzed of slates (29 Paleozoic, 1 Mesozoic, 6 early Paleozoic or Precambrian) (Eckel, 1904).

* SO_3

Column 2, 3, and 4 are from Pettijohn, 1957, p.344, Table 61.

Table 6: Mineralogical composition of black shale from Middle Cove Member, south shore of Calvert Bay; norm calculation based on the chemical analysis given in Table 5.

Mineral	%
Quartz	17.08
Montmorillonite	20.05
Sericite	26.80
Chlorite	8.03
Albite	25.27
Calcite	2.40
Dolomite	0.61
Pyrite	0.07
Apatite	0.04
Total	100.35

chemical analysis of additional samples is necessary before any meaningful interpretation can be made. In comparison with the average composition of shales and slates from various sources (Table 5) it is relatively low in potassium oxide and high in sodium, probably due to the very alkaline composition of the source area. The ferrous oxide is high compared with ferric oxide.

Sedimentary Structures

The sedimentary structures of facies B include penecontemporaneous slump folding, ripple marks, cross laminations, and lenticular bedding. Among these, the former is by far the most distinct and abundant structure.

Penecontemporaneous slump folding - Recumbent folds involving sedimentary units up to 30 feet thick are very abundant. Because the deformed bed is overlain by undisturbed strata with a sharp contact but without any sign of thrusting and has an unconformable contact with underlying undeformed strata, the recumbent folds were considered to be formed by gravitational slumping of sediments on a sloping surface. The slumping was followed by deposition of the overlying sediments.

Some slumped beds are so fragmental that they appear to be homogenous units. In the Ferryland area, the relative slumping direction is from north to south as indicated by the style of the folds and the relative movements of the detached isoclinal fold limb (Fig. 3-4).

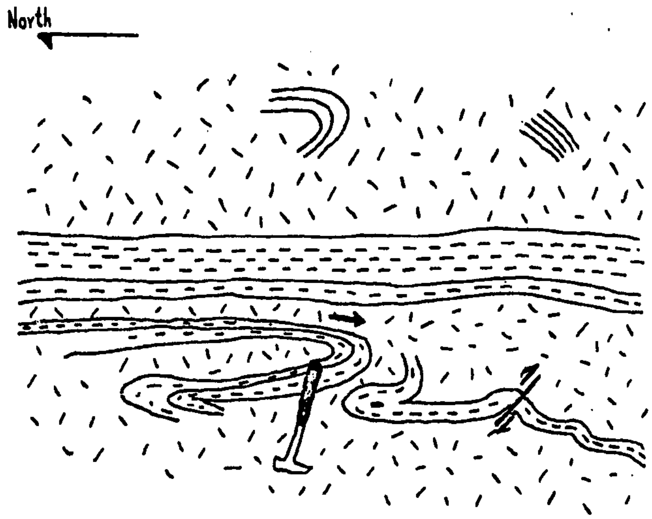

Fig.3-4-a. Character of slump overfolds and sandstone relics in homogeneous slump bed. Sandstone in solid line, shale in broken line.

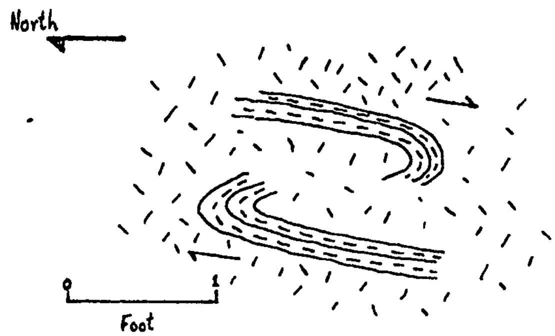

Fig3-4-b. Detached limbs of the recumbent slump fold. Sandstone in solid line, shale in broken line.

Cross lamination, ripple marks, and lenticular bedding - Asymmetrical and symmetrical ripple marks and small scale cross laminations of solitary sets are rare. Rare lenticular beddings represent impoverished sandstone ripples.

Facies C - Interbedded Sandstone and Shale

This facies is stratigraphically above facies B and forms the major lithological unit of the Outer Cove Member of the St. John's Formation.

It is recognized by alternating laminae and very thin beds of siltstone, sandstone, and black shale. The bed thickness is generally less than 1.5 cm but may be as thick as 3 cm. The alternating laminae or beds may show irregular or wavy stratification due to the disturbance by ripples, cross laminations, and other sedimentary structures.

In this facies, the ratio of the sandstone-siltstone to black shale is approximately 1 : 1.

Sedimentary Structures

The sedimentary structures in this facies include graded beds, lenticular beddings, ripple marks, cross lamination, ripple-drift cross laminations, flaser bedding, scour-and-fill, flow rolls, and gas- or water-escape surface markings. As a whole, the facies show more wave or current agitation than facies B.

Ripple marks - Ripple marks are common in the sandstone or siltstone. The ripple marks observed on the bedding surface are of small scale and are characterized by low-relief mounds as shown in Fig. 3-15. Although the ripple marks on the bedding surface are of symmetrical type, asymmetrical ripples indicated by the internal structure in the sandstone are common.

Wavy bedding - Wavy bedding is characterized by non-parallel stratification due to the presence of ripples and cross laminations. The black shale in vertical view pinches and swells; black shale is thick in the ripple trough but thin or absent at the ripple crests of the rippled sandstone.

Lenticular bedding - Lenticular bedding (pl. 3-12), which consists of isolated sandstone lenses due to impoverished sand ripples, is a common structure in this facies.

Cross lamination - Cross lamination is a common structure in sandstone and siltstone. Both solitary sets and cosets of cross laminations are present. Most of the cross laminations are tabular but trough cross laminations occur in sandstone at Bay Bulls.

Flaser bedding - Flaser bedding is uncommon. In the cross laminated or rippled sandstone, mud flasers occur in parallel alignment with the ripple or cross laminations, particularly at the stoss sides of the ripple or cross laminations. Flaser bedding is a characteristic of sediments reworked by tidal currents (Hantzschel, 1939) and a common structure observed in the recent tidal sediments in the Jade Bay of North Sea (Reineck and Singh, 1967).

Ripple-drift cross lamination - This structure results from successively climbing ripples (Pl. 3-13) and is uncommon. At Ferryland and Outer Cove the structure is formed of cosets with a low climbing angle.

Flow rolls - Flow rolls (Pl. 3-17), formed by the sinking of sands due to their own weight into soft hydro-plastic muds, are uncommon. They are small scale and are characterized by flat tops and bulbous or lobate bottoms. Where the sand rolls sank deeply into and became entirely enclosed in the muds, "pseudonodules" were formed.

Graded bedding - Graded beds are common in this facies and are formed by the gradation in grain size of the basal sandstone upwards into shale. Unlike those in facies A, the graded beds in facies C generally pinch out in a few feet along the strike and laterally are replaced by sandstone beds. Such lateral impersistence is probably due to a gradual decrease of the amount of mud in the direction of current flow during the deposition of sands.

Scour-and-fill - Scour-and-fill (Pl. 3-14) is common in this facies and is best observed in the Ferryland area and on the north shore of Torbay about mid-way between Middle Cove and Outer Cove. At both localities and sediments of facies C

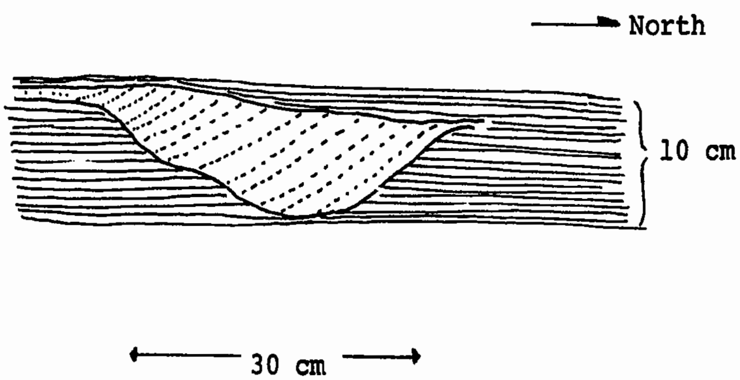

Fig.3-5. Scour-and-fill structure in interbedded sandstone and shale of facies C. The cross-laminated sandstone indicates a relative current from north to south. Coldeast Point, Ferryland.

have been deeply scoured and filled with fine-grained sandstones. The bottom profile of the scourings are invariably asymmetrical and may attain a size up to one foot deep and 4 or 5 feet wide. Most of the sandstone fillings are massive. However, laminations were observed in some cases. The laminations are invariably discordant with the stratification of the scoured sediments, resembling cross stratification in vertical view (Fig.3-5). Such discordance may indicate a current from north to south.

Gas- or water-escape surface markings - This structure is abundant in this facies and is attributed to gas or water escaping from the sediments which left marking on the bedding surface of the sediments. The surface markings, which have been treated as problematic fossils and named as "Aspidella terranovica", will be described in detail in Chapter IV.

Facies D - Medium-bedded Sandstone

This facies is locally developed on the northwestern shore of Outer Cove. It alternates with the sediments of facies C (Pl. 3-18) in such a way that there is a resemblance to the graywacke-shale interbeds which are often encountered in turbidite sediments.

Mineralogical Composition

The sandstone of facies B, C, and D are similiar in mineralogical composition.

In thin section, the sandstones are composed of fine- to medium-grained, moderately well sorted, angular to subangular detrital grains, which consist of quartz, sodic plagioclase and dark rock fragments (argillite?). Rock fragments such as quartzite, basic volcanics, tuffs, and siliceous fragments (rhyolite?) are rare in sandstone of facies B and C but are relatively abundant in sandstone of facies D. Pyrite, biotite, zircon, magnetite, and epidote are common accessory minerals.

Replacement of feldspars and groundmass by secondary calcite is an obvious feature of sandstone. Commonly the sandstones become calcareous.

Sedimentary Structures

The sedimentary structures include ripple marks, ripple-drift cross laminations, and ribbon-like sandstone bodies. Among these the ripple marks are the most abundant.

Ripple marks - Ripple marks are observed on the bedding surfaces of nearly all of the sandstone beds. Both symmetrical and asymmetrical ripple marks are present.

Most of the crests of the ripple marks are parallel-trending (parallel type of McKee, 1957). Interference ripple marks (Pl. 3-20) are also common and often occur on the same bedding surfaces as the parallel type of ripple marks.

Ripple-drift cross lamination - Cosets of ripple-drift cross lamination (Pl. 3-19) are common sedimentary structure in the sandstones. The stoss and lee sides of most of the cross laminations are preserved. Although in some the stoss side is eroded.

Ribbon-like sandstone bodies - This structure is characterized by narrow and elongated sandstone bodies embedded in the sediments of facies C (Pl. 3-21). The sandstones have erosional basal boundaries with the surrounding sediments and are less than six inches in thickness and width. The extent of elongation is unknown because of limited exposure.

Small scale ripple marks of parallel type are present on the top surface of the elongated sandstone bodies. The ripple crests are perpendicular to the elongation of sandstone. The ripple marks indicate that the sandstone bodies are unlikely to be sand-injection structures such as sandstone dykes or sandstone sills.

To the author's knowledge, such sedimentary feature has not been reported in the literature. The mechanism of how they were formed is uncertain. Based on the presence of erosional boundaries with the surrounding sediments, the sandstones may be fillings of small elongated channels which were formed by some strong anastomosing bottom currents.

Facies E - Channel Sandstones

This facies is locally developed on the northwestern shore of Outer Cove and in a small quarry about half a mile north of Bay Bulls and consists of thick-bedded, medium- to coarse-grained sandstones which occur as channel fillings.

Mineralogical Composition

Modal analysis of sandstones of this facies are shown in Table 3. In thin section, the sandstones are composed of medium- to coarse-grained, poorly sorted, angular to well rounded quartz, albite, K-feldspar, biotite, and rock fragments of rhyolite, argillite, chert, and quartzite with minor basic volcanics.

Sedimentary Structures

Channels - The channels are recognized by erosion of the sediments of facies C and the non-uniform thickness of the channel-filling sandstones. At Outer Cove the basal profile of a channel is characterized by deep troughs in the scoured sediments. At Bay Bulls, the basal boundaries of channels are slightly discordant with underlying sediments.

The geometry and size of channels are unknown because of the lack of exposures in three dimension. However, the channels are considered to have a north-south elongation for two reasons: (1) The crest of ripple marks exposed on the top surface of channel-filling sandstones at Outer Cove are parallel to the exposed vertical section of channels, indicating a north to south current. (2) The foreset of the trough cross bedding in the channel-filling sandstone at Bay Bulls exposed in a north-south vertical section indicate a current flowing from north to south. The suggested trends of the channels at both localities are illustrated in Fig.3-6 and Fig.3-7.

Channel-fill - At Outer Cove, the channel-filling sandstone is 8-feet thick at the trough of channel (Pl. 3-24) but 3 or 4 feet thick above the trough (Fig.3-6). The sandstone shows graded bedding; the coarse-grained sandstone occur at the base and graded upwards to medium-grained at the top of trough. The coarse-grained sandstone is parallel-laminated and contains a few intraformational rock fragments derived from the underlying sediments of facies C. The medium-grained sandstone is characterized by cosets of trough cross beddings (Pl. 3-25). Asymmetrical and symmetrical ripple marks of parallel types occur on the top surface of the sandstone.

At Bay Bulls, the channel-fill is a lenticular shaped sandstone with maximum thickness of 5 feet (Pl. 3-22 and Fig. 3-7). The sandstone is grade-bedded with coarse sandstone at the base which grades upwards into medium-grained sandstone at the top. The basal sandstone is parallel-laminated with a few intraformational rock fragments while trough cross beddings

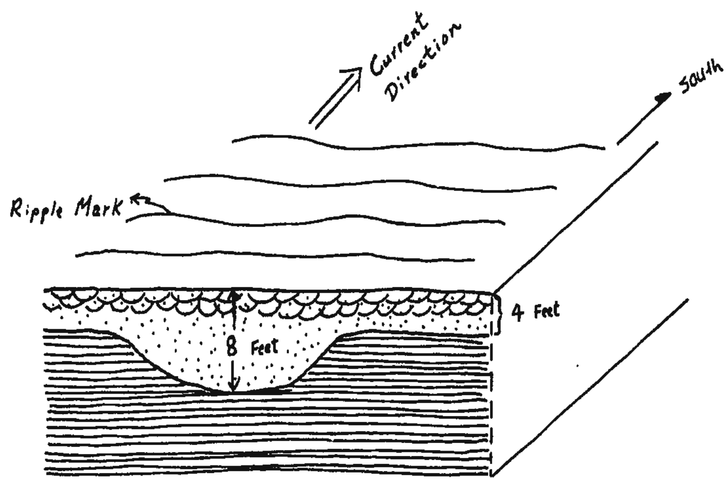

Fig.3-6.Vertical profile of a simple channel. Sandstone fillings show parallel laminations at the base of the trough and large scale cross bedding at the top. Facies E - channel sandstone, Outer Cove.

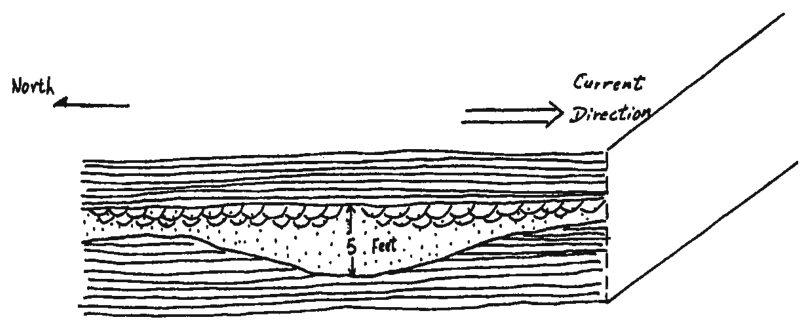

Fig.3-7. Vertical profile of channel fill deposit. Sandstone within the trough shows parallel lamination at the base and large scale cross bedding at the top. Facies E - Channel sandstone, Bay Bulls.

(Pl. 3-23) are characteristic of the medium-grained sandstone. Because of the lack of the exposure of bedding surface, ripple marks were not observed.

Facies F - Volcanic Tuff

Volcanic tuffs occur in facies C at Broad Cove on the north shore of Calvert Bay and at Coldeast Point, Ferryland (Fig. 2-1). Coarse-grained tuffaceous sandstones occur in facies A at Middle Cove and on the north shore of Aquaforte Harbour.

At Broad Cove the bed thickness of the tuff beds range from 3 to 11 feet. At Coldeast Point, about 1.2 miles to the south of Broad Cove, two tuff beds each have a thickness of less than two feet. The tuffaceous sandstones at Middle Cove and Aquaforte Harbour are 4 and 5 inches thick, respectively.

Mineralogical Composition

(1) Volcanic Tuffs

The volcanic tuffs are composed of sericite, quartz, albite, and minor carbonate as qualitatively determined by X-ray diffraction. In thin section, the tuffs are composed of sericite and minor chlorite. The detrital grains, ranging from two to as much as 65 per cent, are poorly sorted, angular to subangular and consist of quartz (19 per cent), feldspar (55 per cent), and very minor rock fragments (less than 1 per cent). The quartz grains show volcanic characteristics; inclusion-free, plain extinction, and embayments of the grain boundaries. The sodic plagioclase, albite to oligoclase in composition, are euhedral to subhedral and are invariably strongly altered. K-feldspars are relatively fresh and show patches of alteration.

Both quartz and feldspar are fractured (Pl. 3-32). A few quartz grains show strong strain extinction while plagioclase are wedged open along the cleavage. As the tuff beds are not tectonically deformed, fracturing of grains may have resulted from explosion of the source volcano.

(2) Tuffaceous sandstone

At Middle Cove, tuffaceous sandstones are composed of coarse-grained albite (over 70 per cent) and minor amount (about 2 per cent) of quartz and fragments which consist of basic volcanics, rhyolite (?), and argillite. The groundmass makes up about 16 per cent of the rock. The sodic plagioclase are euhedral to subhedral and are strongly fractured. A few shards were identified in the sericitic groundmass.

At Aquaforte Harbour, the tuffaceous sandstone consists of sodic plagioclase, quartz and rock fragments of basic volcanics, rhyolite, and argillite. The general features of the tuffaceous sandstone are similar to the tuffaceous sandstone at Middle Cove but quartz content is as much as 15 per cent. There is a great deal of calcite replacement of the feldspar and groundmass.

Sedimentary Structures

The volcanic tuffs and tuffaceous sandstones are massive and are generally devoid of sedimentary structures. However, some tuff beds are graded and show a decrease upwards in the amount of detrital grains (Pl. 3-30).

Gibbett Hill Formation

Introduction

The Gibbett Hill Formation is here divided into four descriptive lithofacies which are facies A_g (Conglomerate), facies B_g (green-gray sandstone), facies C_g (siltstone and argillite), and facies D_g (volcanic tuff). A summary of their characteristics is shown in Table 7.

Facies A_g - Conglomerate

Conglomerate occurs only at the eastern headlands on the north shore of Calvert Bay and Ferryland Harbour (Fig. 2-1).

At Calvert Bay, the conglomerate pinches and swells with an average thickness of 8 inches. It is composed of subangular to subrounded pebbles and granules, averaging 4 mm in diameter and consist of over 60 per cent quartz, quartzite, chert, and rhyolite (?). Intraformational fragments of black shale are abundant (about 10 per cent). The detrital grains are closely packed with less than 10 per cent of interstitial groundmass. Sorting of the conglomerate is poor to moderate.

Two beds of sandy conglomerate, each between 8 to 10 inches thick, occur at Ferryland Harbour (Fig. 2-1). The sand content is about 40 per cent of the rock. The mineralogical

Table 7. Summarized characteristics of the lithological facies in the Gibbett Hill Formation.

Sedimentary Structure	Facies A_g Conglomerate	Facies B_g Green-gray sandstone	Facies C_g Siltstone & Argillite	Facies D_g Tuffs
Massive bedding	⬤	⬤		●
Parallel bedding	⬤	⬤	⬤	⬤
Wavy bedding			●	
Scour-and-fill	●			
Cross bedding		•		
Cross lamination	●	●	●	●
Ripple marks		●	●	
Ripple-drift cross lamination		●	●	
Load cast		•		
Graded bedding		○		
Mud cracks			○	
Convolute bedding		○		

⬤ Abundant ● Common • Uncommon ○ Rare

composition of the conglomerate is similiar to that at Calvert Bay but the intraformational black shale fragments are very rare.

Sedimentary Structures

The conglomerate at Calvert Bay is massive and devoid of other sedimentary structures. However, the sandy conglomerates at Ferryland Harbour shows parallel bedding and scour-and-fill structures (Pl. 3-35). Cross lamination is also present. In general, the cross lamination indicates a current flowing from north to south. However, the cross stratification in the scour-and-fill (Pl. 3-35) suggests a current direction from south to north.

Facies B_g - Green-gray Sandstone

The sandstones are very fine-grained at the basal part and medium to coarse-grained at the upper part of the Gibbett Hill Formation. They are thin to very thick-bedded ranging from a few inches to 15 feet and show progressive upward thickening from the basal part to the upper part of the Gibbett Hill Formation.

The sandstones are parallel-bedded and laterally persistent in thickness along strike. However, lateral pinching out and interfingering of the thick-bedded sandstones with sediments of facies C_g were observed at Outer Cove and Bay Bulls.

Mineralogical Composition (Table 6 and Fig. 3-7).

In thin section, the sandstones are moderately well sorted and are composed of closely packed, angular to sub-angular detrital grains. The sandstones show quartzitic texture characterized by interpenetrative or sutured grain boundaries (Pl. 3-46).

The detrital grains consist of quartz (17-38 per cent), sodic plagioclase (17-39 per cent), K-feldspar (1-8 per cent), and rock fragments (22-31 per cent) of basic volcanic, rhyolite, chert, granitic rocks, argillite, quartzite, and metaquartzite. The common accessory minerals are biotite, epidote, sphene, zircon, hematite, granophyre, myrmekite, and microcline.

Authigenic quartz is very common. Outgrowth of plagioclase was also observed.

The groundmass forms less than 10 per cent of the sandstones and consists mainly of varying proportions of sericite and chlorite. Diagenetic calcite and epidote commonly replace much of the groundmass. Glass shards, invariably devitrified to sericite, are recognized in the groundmass of many sandstones.

The presence of glass shard and the abundance of volcanic tuffs of Facies D_g in the Gibbett Hill Formation indicate that most of the sandstones are tuffaceous at least in part.

According to Pettijohn's (1957) classification, the sandstones are arkose (Arkose is a sandstone in which the groundmass makes up less than 15 per cent of the rock and in which feldspar exceeds that of rock fragments).

Sedimentary Structures

Nearly 50 per cent of the sandstones appear to be massive. The others show parallel lamination, ripple marks, cross laminations, cross bedding, ripple-drift cross-lamination, load casts, convolute beddings, and graded beds.

Parallel lamination - Parallel lamination is the most abundant structure in the sandstones. It is attributed to the varying grain size of the sandstone laminae. Careful examination of the weathered surface of the rock exposure indicates that some apparently massive sandstones are parallel-laminated. Elsewhere, radiographic methods have been successfully applied to detect sedimentary structures which are otherwise non-existent to the naked eye.

Ripple marks - Small scale symmetrical ripple marks (Pl. 3-41) of parallel type (McKee, 1957) are common in the very fine- to fine-grained sandstones. In the medium- to coarse-grained sandstones both symmetrical and asymmetrical ripple marks of parallel type are common.

Cross bedding - Large scale tabular cross bedding (Pl. 3-36) with a set thickness of 1/2 to 2 feet were observed on the north shore of Mobile Bay and the south shore of Bay Bulls. Fragments of argillite occur parallel to the foreset laminations.

Paleocurrents indicated by the cross beddings are from north to south.

Cross lamination - Cosets of small scale tabular cross laminations are common in the fine-grained sandstones. However, cosets of trough cross laminations (Pl. 3-37) are rare and were observed only at the eastern headland of Calvert Bay. Paleocurrent indicated by the cross laminations are from north to south.

Ripple-drift cross lamination - Coset of ripple-drift cross laminations (Pl. 3-38) are common in the very fine- to fine-grained sandstones. Most of the cross laminations are continuous (type 1 of Walker, 1963). In some cases, minor erosion of the stoss side of ripples was observed (type 2 of Walker, 1963).

Load casts - Load casts are uncommon in the sandstones; they are characterized by the bulbous protrusions on the undersurface of sandstones (Pl. 3-39).

Graded bedding - Graded bedding due to the upward decrease in grain size is uncommon in the sandstones. It was observed in some medium- to coarse-grained sandstones at Bay Bulls and on the north shore of Mobile Bay. Massive or parallel-laminated coarse-grained sandstones, having erosional and sharp boundaries with the underlying sediments of facies C_g, gradually pass upwards into fine-grained sandstones with ripple-drift cross laminations or tabular cross laminations (Fig. 3-8), indicating a gradual waning of the currents.

Convolute bedding - This structure is very rare and was observed only on the north shore of Calvert Bay. It is characterized by the tight anticlinal crests and broad synclinal troughs (Pl. 3-40).

Facies C_g - Siltstone and Argillite

This facies consists of alternating laminae or thin beds of green-gray siltstone and argillite and is very similar to facies C of the St. John's Formation. This facies alternates with the thicker-bedded sandstones of facies B_g and with minor beds of black shale.

Sedimentary Structures

Sedimentary structures in this facies include parallel bedding, wavy bedding, ripple marks, cross lamination, ripple-drift cross lamination, and mud cracks.

Parallel bedding - This is the most distinctive

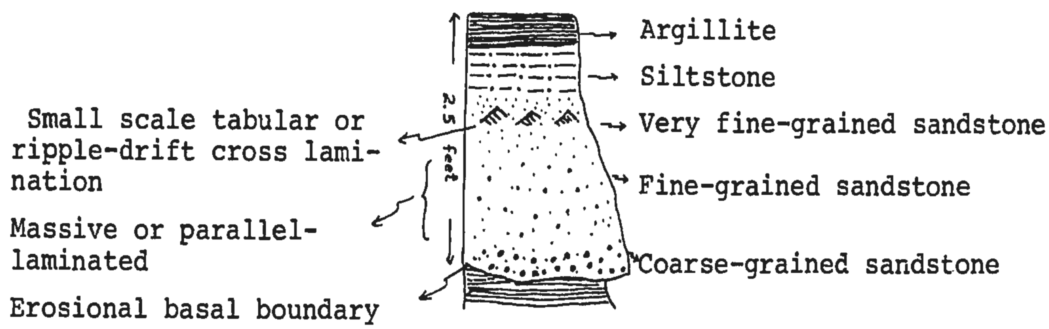

Fig. 3-8. Graded bed of sandstone in which waning of current is indicated by upward decrease in grain size and change of sedimentary structure from massive bedding, parallel lamination to small scale cross lamination. Facies B_G - Sandstone, Gibbett Hill Formation, south shore of Bay Bulls.

structure of this facies and is characterized by the uniform thickness of the beds along strike.

Wavy bedding - Wavy bedding is also a common feature of this facies and is due to disturbance of the stratification by the presence of current structures such as ripples and cross laminations.

Ripple marks, cross laminations, ripple-drift cross lamination - These structures are common and are similiar to those in the very fine- to fine-grained sandstones of facies B_g.

Mud cracks - Mud cracks are rare and are present only in the black shale and green-gray argillite at the eastern headlands of Calvert Bay and Ferryland Harbour. The black shale and argillite are overlain by thin beds of sandstone. Granules are scattered at the base of the sandstone. Plates of black shale are common and are generally parallel to the bedding. The mud cracks (Pl. 3-42) are wedge-shaped and are small in size, less than 4 cm in vertical length and less than 1 cm wide at the upper opening of the cracks. The cracks are filled with sand and granules and are overlain by sandstone. They are formed by shrinkage of the muddy sediments which were subjected to subaerial exposure during deposition. The black shale plates in the overlying sandstones formed as a result of scouring of the loose, cracked muddy sediments by sand-laden currents.

Facies D_g - Volcanic Tuffs

Yellowish green or greenish yellow tuffs occur at Ferryland, Calvert Bay, Mobile Bay, Bay Bulls, and White Hills of St. John's, and are thick-bedded ranging from 5 to 15 feet. The stratigraphic distribution of the tuffs is shown in Table 2.

Mineralogical Composition

X-ray diffraction analyses indicate that the tuffs are composed of albite, quartz, and sericite with a minor amount of calcite.

In thin section, the tuffs contain less than 5 per cent of detrital grains of quartz, K-feldspar, and albite with a minor amount of rock fragments of argillite and basic volcanics.

The groundmass consists of sericite, quartz, and minor chlorite, and abundant glass shards. Glass shards are recognized by their micro-tubule, round bubble structure, and Y-shape (Pl. 3-47). They are generally devitrified into sericite and feldspar. Diagenetic replacement of glass shards by epidote is also very common.

Sedimentary Structures

Small scale cross lamination and graded bedding are common structures in the tuff beds.

Cross lamination - Most of the tuffs show parallel laminations and cosets of tabular cross lamination (Pl. 3-43 and 3-44). Paleocurrents indicated by the cross laminations are from north to south.

Graded bedding - Graded beddings are common in the tuff beds. The detrital grains are concentrated at the base but decrease in amount toward the upper part of the tuff beds. Microscopic graded beddings were observed in thin section; the grading is due to upward decrease in the size of glass shards in the laminae of tuff.

Megascopic structures of probably diagenetic origin are common in many tuff beds at Mobile Bay, Ferryland and Calvert Bay. They are characterized by irregular white bands parallel to the local stratification (Pl. 3-45). In some tuff beds at Ferryland Harbour, specks of calcite (?) in megacrystal form (Pl. 3-48) are very abundant and become conspicuous on the weathered surface of the rock exposure.

CHAPTER IV

PROBLEMATIC MARKINGS

Previous Work

Problematic markings were first discovered in the St. John's Formation in 1866 by Alexander Murray. Specimens of these markings were sent to E. Billings for identification. Billings considered them to be fossils and in 1872 named them "Aspidella terranovica". He described Aspidella as:

> "Small ovate fossils, five or six lines in length and about one fourth less in width. They have a narrow roof-like ridge, from which radiate a number of grooves to the border. The general aspect is that of a small chiton or patella flattened by pressure. It is not probable that they are allied to either of these genera."

In 1881, Alexander Murray described their distribution:

> ".....the vertical range of this fossil as far as yet ascertained is limited to the slate (d) of the section, which immediately underlie the Signal Hill Group .... Similar organisms are found in equivalent strata in Trinity Bay, at several parts of the valley of the Rocky River and at Ferryland showing its wide range laterally; in some cases literally covering extensive surfaces of the rock with forms large and small, while in others they were found scantily sprinkled here and there in isolated individuals ...."

The organic origin of Aspidella suggested by Murray and Billings remained unchallenged until 1898 when G. F. Mathew (in Packard, 1898) argued that Aspidella were slicken-sided mud concretions. Mathew's interpretation was apparently accepted by Häntzschel (1962) who consequently classified Aspidella as problematic fossils of inorganic origin.

R. D. Hughes (personal communication, 1966), formerly on the staff of the Geology Department of Memorial University, considered that Aspidella was a jellyfish comparable with the medusoid of the late Precambrian Ediacara fauna of South Australia described by Glaessner and Wade (1966, 1968).

Goldring (1967) examined the author's collection of specimens of Aspidella in the Geology Department of Memorial University and contended that they are load structures and definitely not fossils.

Hofman (1971), in his report on Precambrian fossils, pseudofossils, and problematica in Canada, cited numerous references on the possible origin of Aspidella. As shown in his summary of references, reproduced here in Table 8, the markings have been variously interpreted as crushed mollusks, crustaceans, and inorganic structures such as sites of gas vents, pressure cones, gas bubbles, spall marks, etc. Hofman concluded:

> "The structure itself is of mechanical origin resulting from differential movement of mud. Some structures may have formed by local breakup of the silt layer and subsequent sinking of the pockets into the shale layer, later to be sheared and striated. Some structure may be flattened concretions and others are wrinkled laminae of coarse siltstone, possibly made cohesive through binding algae."

Present Study

The markings were classified into six types and their occurrence, mode of preservation, preferred orientation, morphology and internal structure are described. They are considered to be load casts and gas- or water-escape structures.

Table 8*: Summary of References to Aspidella Billings 1872

(*Reproduced from Fig. 5 of Hofmann, 1971)

Author	Date	Interpretation of Aspidella Billings
Hofmann	1971	X of mechanical origin; focussed surface of rupture
Cloud	1968	X Concretion or spall mark
Hantzschel	1965	X Inorganic; pressure cone or gas bubble crater
Glaessner	1962	X Inorganic; cites Walcott 1900 and Schindewolf 1956
A. E. Wilson	1957	? No opinion; cites interpretation of earlier authors
Schindewolf	1956	X Diagenetic; pressure cone or buckling through escaping gas
Rose	1952	? No opinion; quotes Walcott 1900
M. E. Wilson	1939	? No opinion; quotes Mathew 1898
Metzger	1927	? Of questionable nature; like Chuaria
Clark	1923	X Sites of vents from which gas escaped
Buddington	1919	O Possible fossil
Van Hise and Leith	1909	O Probably organic, but questionable
Sollas	1909	O Plainly organic
Walcott	1901	X Inorganic
Walcott	1900	X Spherulitic concretion
Mathew	1898	X Slickensided mud concretion
Packard	1898	O Mollusk
Weston	1898 (1896)	X Probably concretion
Dawson	1897	O May be crustacean or mollusk
Murray	1873	O Fossil
Billings	1872	O Fossils, resemble, but are different from Chiton or Patella
Murray	1868	O Obscure organic remains

Occurrence and Mode of Preservation

Aspidella and associated markings occur in abundance in facies C at the base of the Outer Cove Member of the St. John;s Formation exposed at Outer Cove, St. John;s (Prescott and Duckworth Streets), and in the Ferryland area (see Fig. 2-1 for detailed locations).

The surface markings occur on the sandstone (or siltstone)/ black shale interfaces and are preserved in positive relief (convex downward) on the lower surface of bed of sandstone or siltstone, and their counterparts, in negative relief (concave upward) on the upper surface of bed of the underlying black shale. Most of the markings have low relief, but some may have elevation of up to 4 or 5 mm. The higher-relief forms are generally associated with the thicker beds of sandstone or siltstone.

Preferred Orientation

The markings are round to elliptical in shape and both forms may occur on the same surface. The ratio of long axis to the short axis of the elliptical forms ranges from 4 : 1 to 6 : 1.

The elliptical forms clearly show a preferred orientation on bedding surfaces. In the Calvert Bay to Aquaforte Harbour area, several bedding surfaces on which elliptical forms occur were randomly chosen in order to compare the orientation of the long axis of the elliptical forms with the direction of the strike of the bedding surfaces. The results indicate that the long axis of the elliptical form makes an angle of 40 to 60 degrees with the strike of the beds on which they occur. The preferred orientation

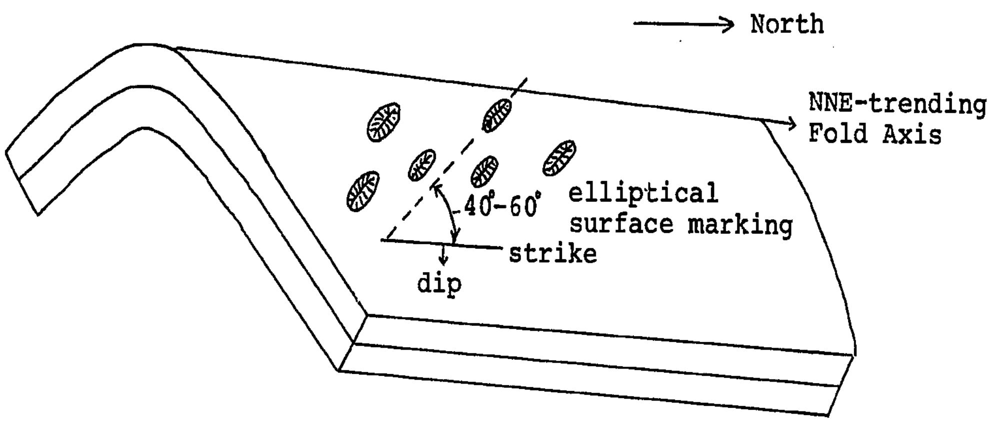

Fig. 4-1. Preferred orientation of the elliptical markings and its relationships with the strike of the sedimentary beds and fold axis.

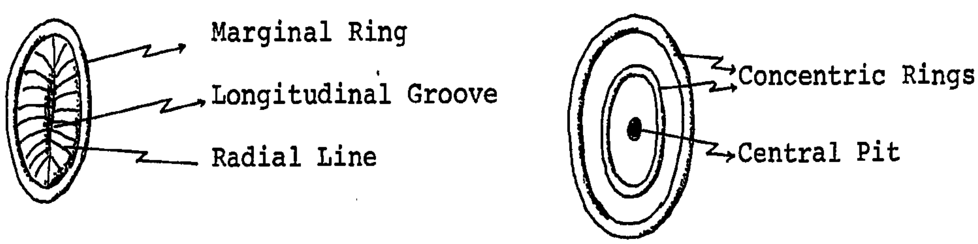

Fig. 4-2. Terminology of the morphological features of the surface markings in the St. John's Formation.

also makes an acute angle with the general NE-trending fold axis of the beds in the Ferryland area (Fig. 4-1). The author considers that the elongation represents stretching due to tectonic deformation; probably related to the E-W stress which overturned the beds of the Gibbett Hill and Signal Hill Formations on the north shore of Calvert Bay.

Morphology and Internal Structure

Morphological features such as size, shape, number of concentric rings, central longitudinal groove, and radial lines were used in the classification of the markings (Fig. 4-2).

Six types of markings are recognizable but distinction between them in the field is generally very difficult because they are morphologically transitional. For this reason, statistical estimate of their relative abundance was unsuccessful.

The internal structures of the markings was studied by means of sections cut perpendicular to their long axis and on sections exposed in the field.

Type 1 (Pl. 4-1 and 4-7)

Morphology: characterized by simple ovoid mounds on the lower surfaces of sandstone beds or laminae and ovoid depressions on the upper surface of the underlying black shale beds or laminae.

Size: generally small, less than 1.5 cm in diameter.

Internal structure: In section, the markings are present at the interfaces of sandstone or siltstone and black shale as pockets of sandstone protruding into the

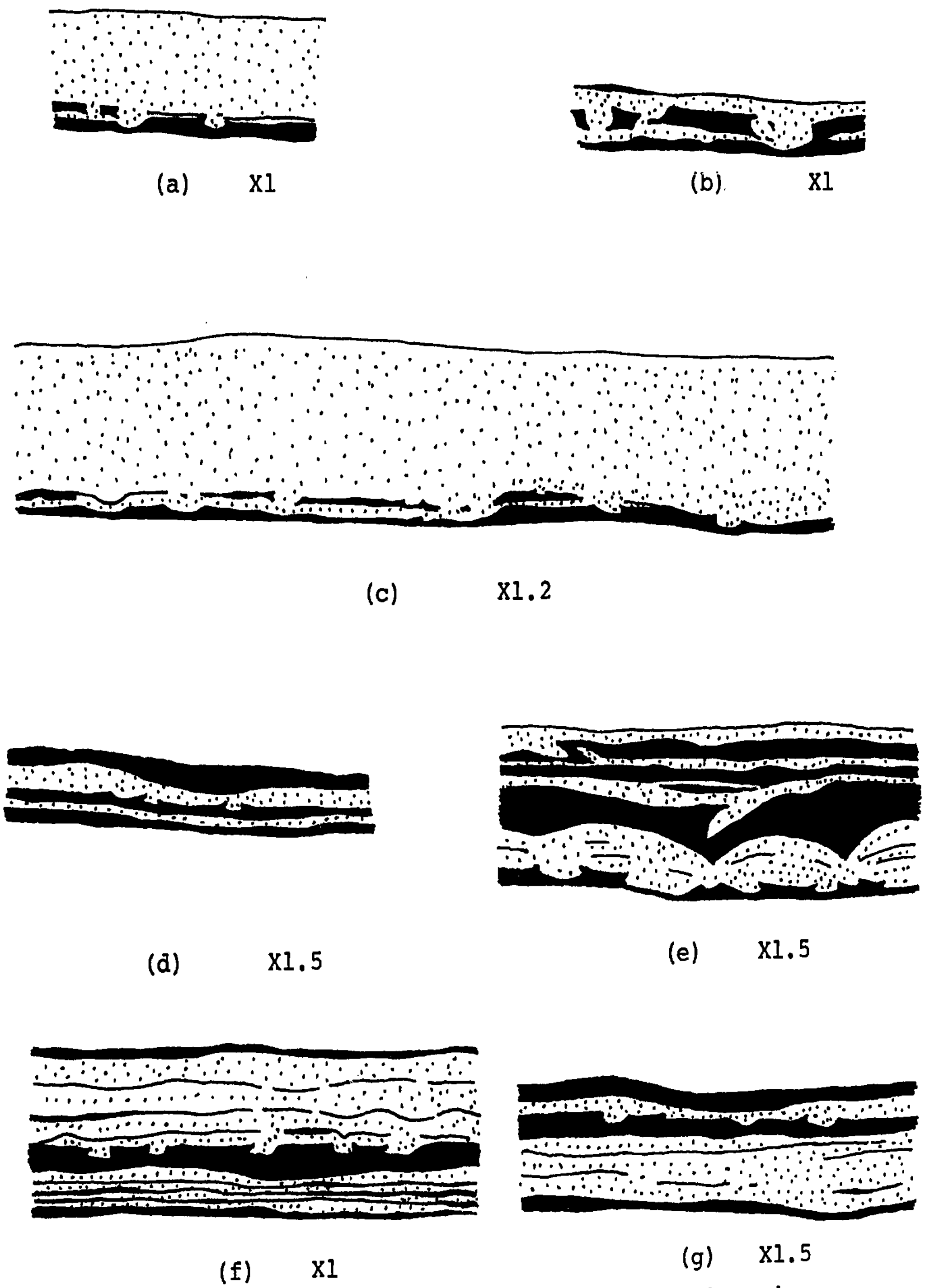

Fig. 4-3. Internal structures of surface markings in the St. John's Formation. Sandstone in stipples, black shale in black.

underlying black shale.'Flames' of black shale project from both sides of load cast into the sandstone. Above the sandstone/black shale interface, there may occur an intercalation of black shale lamina in the sandstone. Immediately above the load cast, disruption of the shale intercalation is common (Fig.4-1-a, 4-1-b, and 4-1-c). Such disruption may represent soft-sediment deformation; the disruption being formed by the sinking of overlying sands through the mud intercalation during the formation of load casts.

Type 2 (Pl. 4-2)

Morphology: On the lower surface of sandstone or siltstone bed, markings characterized by ovoid shape with marginal broad convex ring and a convex or concave central disc.

Size: 0.4 to 1.5 cm in diameter.

Internal structure: Load cast and flame structures occur at where the convex ring is situated (Fig. 4-1-c and 4-1-d). Disruption of black shale lamina (see Type 1) above the load cast is also common.

Type 3 (Pl. 4-3 and 4-4)

Morphology: On the lower surface of sandstone or siltstone bed, markings characterized by ovoid shape, central basin-like depression, convex marginal ring, and radial lines.

Size: 0.3 to 1.5 cm in diameter.

Internal structure: Generally similar to that of Type 1 and characterized by load cast and flame structures. However, "inverted volcano structure" was observed in two sections (Pl. 4-3-e) and is characterized by the downward drawing, in a form of an inverted volcano, of the black shale into the underlying sandstone bed, on the lower surface of which the markings occur. The peak of the "volcano" is immediately above the center of the markings. The lamination of sandstone follow the configuration of the inverted volcano. The structure is considered to be an indication of the movement of sediments during the formation of load casts.

Type 4 (Pl. 4-5 and 4-6)

Morphology: The prototype of Aspidella terranovica, Billings 1872. On the lower surface of sandstone bed, markings characterized by an elliptical shape, a central longitudinal groove and radial lines with or without a marginal ring.

Size: less than 1.5 cm in length.

Internal structure: Load cast and flame structures as described in Type 1.

Type 5 (Pl. 4-1, 4-5, 4-8, and 4-9)

Morphology: On the lower surface of sandstone bed, markings characterized by elliptical or ovoid shape and concentric rings, ranging in number from 2 to 9. Concentric rings separated either by simple lines or grooves. A central pit or boss may be present.

Size: 3 to 17 cm in diameter or length.

Internal structure: Markings with high relief also characterized by load cast and flame structures (Fig. 4-1-g).

Type 6 (Pl . 4-10)

Morphology: On the upper surface of black shale, markings characterized by elliptical shape with a central pit and radial lines from center to margin of the marking.

Size: only two specimens were found at Ferryland. They are 7 and 8 cm in length, respectively.

Internal structure: The markings occur on a weathered top surface of black shale. The overlying sandstone was not present; the internal structure, therefore, is not available for study.

Origin of Problematic Markings

The following summary of features is important in the interpretation of markings in the St. John's Formation.

(1) There is transition in morphology between the six types; such transition excludes the possibility that the markings represent different types of fossils.

(2) Most of the markings have limited size range; they are generally less than 3 cm. Medusoids, such as Cyclomedusa and Medusinite in

the late Precambrian Ediacara fauna of South Australia, are much larger.

(3) Morphology of larger markings may be simpler than that of smaller markings. In view of morphological development of an organism, growth in size is generally accompanied by more complete or more complicated morphology. However, the morphology of Aspidella and associated markings is obviously contradictory to this general rule; for example, larger markings of Type 5 may have fewer concentric rings than the smaller markings.

(4) The internal structures of the markings indicate load casts and soft-sediment deformation. The markings were often referred to by previous workers as concretions but their interpretations were mainly based on external morphology rather than internal structure.

Conclusion

The markings are interpreted as sedimentary structures. They may be initiated with the escape of water or gas from soft mud with high plasticity. A depression was formed on the interface of water and sediments as a result of the release of pressure after the escape of water or gas. This depression was quickly filled with sand which subsided in an unconsolidated state and finally gave rise to a load cast structure.

The formation of the load casts may have continued after several laminae of sediments were deposited because disruption of black shale lamina above the load cast is apparently due to the sinking of sands overlying the black mud. Moreover, deformational structure of soft-sediment origin are supported by the presence of inverted volcano structure (described under Type 3 markings).

Markings of Type 5 with several concentric rings were probably formed by successive escape of gas or water through a common central vent. The process is in general similar to the concentric gas blisters formed in the mudpots of thermally active areas (Cloud, 1960).

The elongation and radial lines of the markings are not primary features and were formed as result of stretching by shrinkage due to water loss during the compaction of sediments and also by tectonic stress. Similiar markings of inorganic origin are reported from Cambrian rocks of Grand Canyon, Arizona, Carboniferous slates of Massachusetts (Shrock, 1948; McKee, 1945), and Devonian rocks of Pennsylvania (Cloud, 1960). These markings were described by Shrock as pit-and-mound structure and by Cloud as gas-evasion marks.

CHAPTER V

DISCUSSION

Introduction

In this chapter, a model of both the depositional environment (Fig. 5-1) and the source area of the upper part of the Conception Group and the St. John's and Gibbett Hill Formation is proposed.

In late Precambrian time, the upper part of the Conception Group originated as turbidites in a relatively deep marine environment which eventually became shallow. The St. John's Formation represents a distal part of a prograding deltaic system. The Middle Cove Member was deposited as a prodelta and the Outer Cove Member as a distal delta front. The Gibbett Hill Formation represents a proximal delta front transitional between marine and subaerial alluvial plain deposition of the red beds in the Signal Hill Formation.

Volcanic tuffs in the Conception Group, St. John's and Gibbett Hill Formations were probably derived from a distant source. They may represent intermittent volcanic activity and the similarity of the mineralogical compositions of tuff beds in widespread area indicate that the composition of the source material did not change during the late Precambrian time. The source area for these rock units probably lies to the north or northwest of the present study area and is underlain by rocks of Harbour Main and Holyrood granite types.

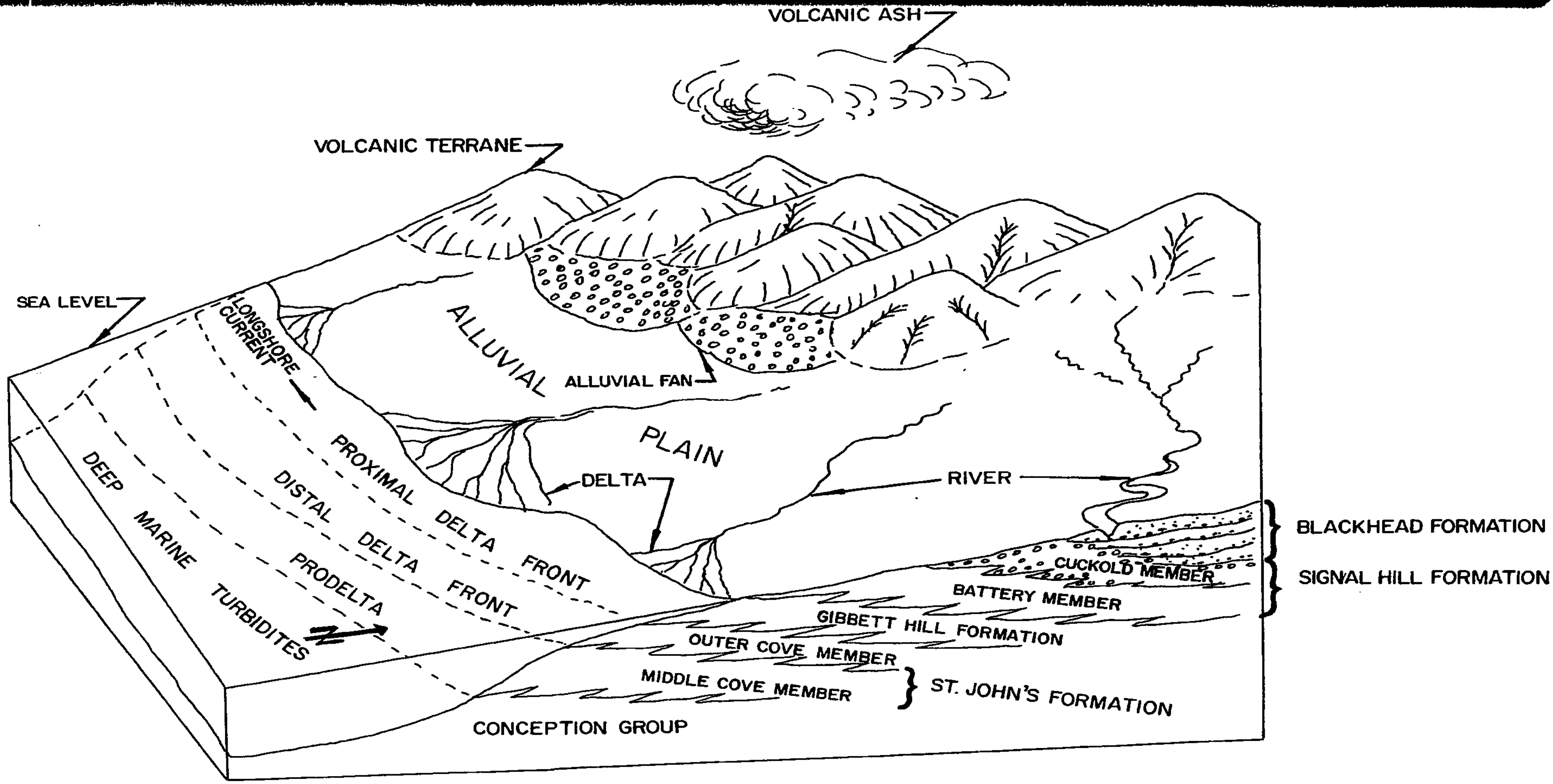

Fig. 5-1. Model of the depositional environments in the upper part of the Conception Group and the Cabot Group. (Interpretations of the Signal Hill and Blackhead Formations given by Singh, 1969 and King, 1972)

Depositional Environment

Conception Group

Rose (1952) interpreted the depositional environment of the Conception Group as follows:

> "...... near the top of the group, the alternating red and green beds of the 'Torbay Slate' indicate that the sediments were exposed for a short period of time to alternating oxidizing and reducing conditions....... ripple marks, cross bedding, cut-and-fill structures, and bedding whorls in the 'Torbay Slate' also attest to deposition in a turbulent shallow-water environment..... Thin beds of conglomerate in the 'Torbay Slate' are illustrative of near-shore shallow water deposition".

McCartney (1967, p.37) suggested that the green-gray graywacke and siltstone of the Conception Group were formed in deep marine environment and the purplish red beds of the Hibbs Hole Formation were laid down in a relatively shallow marine basin.

In the Ferryland area, the upper part of the Conception Group shows the following features suggestive of deposition by turbidity currents in a relatively deep marine environment:

(1) Bimodal grain-size distribution.

(2) Abundant graded beds with erosional tops.

(3) Abundant flute markings at the base of graded beds.

(4) Rare ripple marks and cross laminations.

Although graded bedding, sole markings and bimodal grain-size distribution may also be observed in shallow water sediments, particularly fluvial deposits (Stanley, 1968), the presence and widespread distribution of repetitive graded beds in contrast with rapid lateral facies changes and relatively abundant cross stratification of fluvial deposits indicate that deep water sedimentation is a more likely explanation.

Deltaic Sequence

The St. John's and Gibbett Hill Formations are considered to be prodelta and delta front deposits in a prograding delta for the following reasons:

(1) The upper part of the Conception Group represents a deep water deposit and, at the other extreme, the Signal Hill and Blackhead Formations have been interpreted as subaerial alluvial fan, fluvial, and alluvial plain sediments (Singh, 1969; King, 1972).

(2) There is a stratigraphically ascending increase in grain size and sand content from the black shale of the Middle Cove Member, through the very fine-grained sandstone, siltstone and black shale of the Outer Cove Member, to the green-gray sandstone of the Gibbett Hill Formation.

(3) Sedimentary structures indicate a progressive increase in both current and wave agitation (Table 4).

(4) The similarity of the deposits in lithology and sedimentary structures to areas of deltaic sedimentation such as the Orinoco delta (Van Andel, 1967), the Mississippi delta (Coleman and Gagliano, 1965) and the Niger delta (Allen, 1963).

St. John's Formation

Depositional environments of the lithofacies of the St. John's Formation are shown in Table 9.

Facies A - transition zone

The mudstone of facies A represents a transition from deep

Table 8. Depositional environments of the lithofacies of the St. John's Formation.

Facies	Lithology	Depositional Environment
A	Mudstone	Transition zone from deep to shallow water
B	Laminated black shale	Prodelta
C	Interbedded sandstone and shale	Distal delta front
D	Medium-bedded sand- stone	Subtidal flat
E	Channel sandstone	Tidal channel fillings

water to shallow marine water environments. The abundant graded beds in this facies indicate that the turbidity currents, which deposited the sediments of the upper part of the Conception Group, were still active during this time. Towards the top of this facies the sandstone shows lenticular bedding and cross lamination indicative of an impoverished supply of sand, a condition which persisted throughout the whole of the St. John's Formation times.

Facies B - Prodelta

A prodelta is the area of deposition of fine clays which is associated with a prograding delta system (Fisk, 1955, 1961). In Facies B, parallel lamination is the most significant sedimentary structure which suggests deposition of black muds/clays from suspension under quiet marine conditions. The rarity of ripple marks probably indicate deposition below wave base.

The clayey sediments in the prodelta of the Mississippi delta are also characterized by the presence of parallel laminations (Coleman and Gagliano, 1965). However, the prodelta of the Mississippi delta has abundant plant debris and worm burrows.

Facies B show a thickening towards the south (Fig. 3-3). Such an increase in thickness may suggest that the thicker the facies, the more likely it is to be the distal margin of a prodelta area; in other words, at some distance from the shoreline.

Facies C - distal delta front

A delta front is the area where active deposition of a prograding delta occurs. Facies C of the Outer Cove Member is characterized by the rapidly alternating laminae and thin to flaggy beds of black shale and sandstone-siltstone in which ripple marks, cross laminations, ripple-drift cross laminations, flaser bedding and sand volcanoes are common. Current structures in the sandstone and siltstone indicate deposition under bed load conditions, while black shale was formed by the settling of clayey materials from suspension.

Such rapid alternations of mud and sand due to scour and lag effects of tidal currents are common along the coast of the North Sea (Reineck, 1967; Van Straaten, 1959; Wunderlich, 1970), and the Wash of England (Evans, 1965).

Although facies C shows similarity in both lithology and sedimentary structures to the tidal deposits, the absence of tidal channel and tidal flat in the areas to the south of Outer Cove suggests that the sediments were not deposited as tidal flat between the high- and low-tide levels, but in the distal reaches of the subtidal flat in the delta front.

In the cross section between Torbay and Ferryland facies C exhibits a lenticular shape with a maximum development in the Bay Bulls and Mobile Bay areas. This feature suggests that during the deposition of facies C subsidence occurred in the latter areas.

Facies D - tidal flat

Locally developed at Outer Cove, facies D is characterized by an abundance of ripple marks and cross laminations, it is thought to represent subtidal flat conditions. This interpretation is mainly based on the comparison of facies D with the tidal flat sediments in Cholla Bay, Sonora, Mexico (McKee, 1957) and Netherland (Van Straaten, 1959, 1960), where ripple marks are characteristic features in the lower part of the tidal flat. Van Straaten considered that a sheltered environment such as the lower part of a tidal flat offers more favourable condition for the preservation of ripple marks and the ripple marks in the upper part of tidal flat tend to be destroyed by the stronger and constantly changing tidal currents.

The ribbon-like sandstone bodies of this facies are characterized by erosional basal boundaries with the underlying sediments of facies C and this may indicate that scouring is due to tidal currents.

Facies E - tidal channel

Facies E is considered to represent the fillings of tidal channels. Although this interpretation poses difficulties.

In a tidal channel sand, there is vertically upward decrease in grain size from concentrated gravel-sized particles to sand- and silt-sized particles; the associated vertically upward distribution of primary structures from basal lag concentrate beds through cross-stratified beds into micro-cross-laminated beds, indicates a vertical decrease in flow energy and competency (Van Straaten, 1954; Klein, 1965).

In the sandstones of facies D both the vertical sequence of size-grading and the primary structures are not very clearly shown in the field. Sand grains at the base of sandstones are only slightly coarser than those at the top. The basal part shows massive or parallel-laminated bedding, while cross bedding is present near the top. Only a few intraformational fragments are seen in the basal part of the sandstone. It is uncertain whether the massive or parallel-laminated bedding originated under conditions of the upper flow regime, although the author is inclined to think so.

Large scale cross bedding observed in the channel sandstones are thought to be formed by the migration of large scale linguoid ripples (Allen, 1963). Large scale ripple marks are, however, not observed in facies D, but there are small scale ripple marks on top surface of the sandstone beds. The association of large-scale cross beddings and ripple marks may indicate that there was a decrease in current competency during the filling of the channels.

Gibbett Hill Formation

Flow conditions

Sediments of the Gibbett Hill Formation were deposited mainly by weak currents in the lower part of the lower flow regime (Harms and Fahnestock, 1965) for the following reasons:

(1) Channel deposits are lacking.

(2) Parting lineation and large scale ripple marks are not present. Large scale cross beds are very rare or inconspicuous and have been observed only in a few coarse-grained sandstones. These sedimentary structures form in the upper part of the lower flow regime and upper flow regime.

(3) Abundant small-scale cross laminations and ripple marks indicate a flow condition in the lower part of the lower flow regime.

Proximal delta front

The Gibbett Hill Formation represents the transition from a marine environment to subaerial sedimentation of the red beds of the Signal Hill Formation; it is considered here to have formed as the proximal delta front of a prograding delta.

The near-shore deposition of this formation is evidenced by mud cracks in the black shale and green-gray argillite at Ferryland and Calvert Bay, indicating subaerial exposure of the sediments during a temporary retreat of marine waters.

Provenance

The source are of the sediments constituting the upper part of the Conception Group and the St. John's and Gibbett Hill Formations cannot be established with certainty because of insufficient time for the quantitative measurement of paleocurrents.

Qualitative estimates of paleocurrents based on casual observation of cross stratification and asymmetrical ripple marks indicate a general southward current direction.

Recumbent slump-folds in facies B of the St. John's Formation indicate a paleoslope dipping to the south.

The source area for these units therefore lies to the north of the Avalon Peninsula.

Rock fragments and constituent detrital minerals of sandstone indicate that the upper part of the Conception Group as well as both the St. John's and Gibbett Hill Formations are derived from the same source area which is underlain by rocks consisting of sedimentary, acidic igneous, and acidic to basic volcanic rocks. These source rocks are in general similar to those of Harbour Main Group and Holyrood Plutonic Series.

Volcanic Activity

The presence of water-lain volcanic tuffs in the upper part of the Conception Group, at the base and the uppermost part of the St. John's Formation and throughout the whole Gibbett Hill Formation indicate frequent volcanic activity during late Hadrynian time.

Volcanic activity occurred during the deposition of the upper part of the Conception Group and the lower part of the St. John's Formation. Volcanic activity resumed, after a period of quiescence, by the late St. John's time and during Gibbett Hill times enormous amounts of volcanic tuff were laid down in the Ferryland area.

Although tuffs and tuffaceous sandstones are abundant in these units, no lava flows have yet been found in the Cabot Group. For this reason, it is considered that the volcanic tuffs may have been transported from a distant source; or, if volcanoes were in existence near the eastern Avalon Peninsula, the volcanic activity of the source volcanoes was mainly of explosive type without outpouring of lava flows, although there is the possibility that lava flows were later eroded away.

The volcanic tuffs at various stratigraphic levels have nearly identical mineralogical composition and probably indicates that volcanic activity during the time of deposition of the Cabot and Conception Group rocks are of the same explosive phase with the same distant source.

The particular abundance of volcanic tuffs in the

Ferryland area and the sparse occurrences elsewhere is also worthy of notice. Probably physiographic condition and proximity to source may have influenced the settling of the transported ashes at Ferryland.

Geological History

From the foregoing arguments, the geological events in the thesis area may be summarized as follows:

(1) The sediments were deposited as turbidites in a relatively deep marine basin during upper Conception time.

(2) A transition from deep to shallow water environment occurred at the beginning of St. John's time. The transition is marked by mudstone facies A of the St. John's Formation. Supply of sand to depositional environment decreased.

(3) Black shale of facies B of the Middle Cove Member of the St. John's Formation was deposited on a paleoslope dipping to the south in the prodelta of a prograding delta.

(4) During the deposition of the Outer Cove Member of the St. John's Formation, the interbedded sandstone and shale of facies C were formed in the distal delta front of a prograding delta. Tidal channel and subtidal flat were locally developed in the Outer Cove area.

(5) At time of deposition of the Gibbett Hill Formation, the rate of supply of sand and volcanic ash increased. The sediments were deposited in a proximal delta front near a shoreline where river-borne sediments were re-distributed by waves and longshore currents. Subsidence occurred in the Bay Bulls - Mobile Bay area.

(6) At the time of deposition of the Signal Hill and Blackhead Formations, red beds were formed as the topset of the delta sequence and as alluvial plain and alluvial fan deposits.

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Plate. 3-1 Parallel-bedded sedimentary rocks of the Conception Group (Aquaforte Harbour).

Plate.. 3-2 Repetitive graded beds of the Conception Group. Note the sharp basal boundaries. Scale in inch. (Calvert Bay)

Plate. 3-3 Close-up of Fig. 3-2 showing cross laminations in graywacke. Current from north (left) to south (right). Scale in inch. (Conception Group, Calvert Bay).

Plate. 3-4 Flute markings on the base of graywacke. Scale in inch. (Conception Group, Calvert Bay).

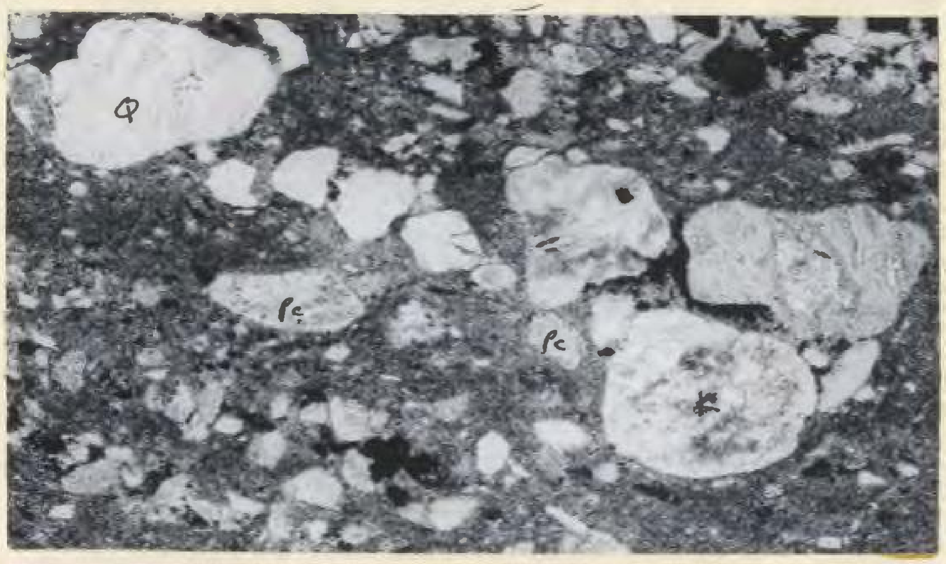


Plate. . 3-5- Bimodal distribution of detrital grains in graywacke. Quartz (Q), K-feldspar (K), sodic plagioclase (Pc). X 40, transmitted light. (Conception Group, Aquaforte Harbour)

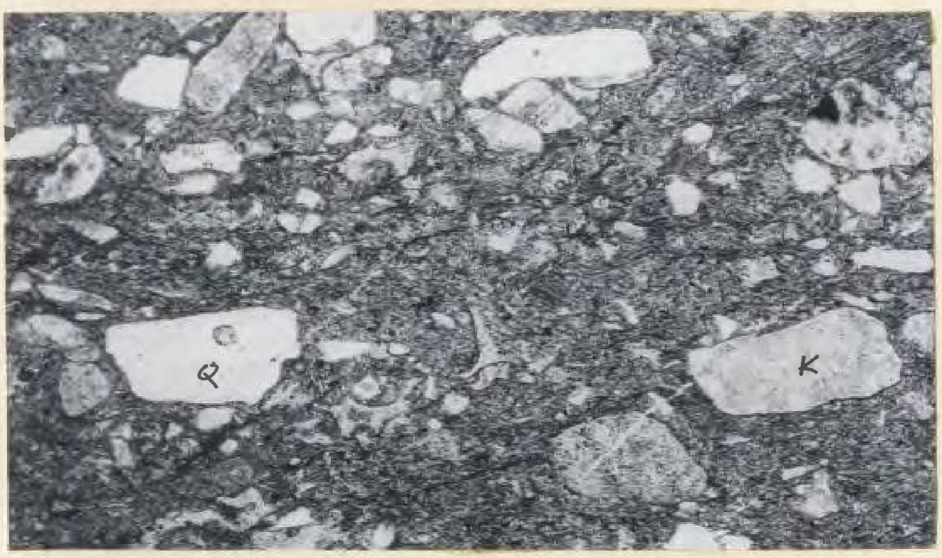


Plate.. 3-6- Tuffaceous graywacke with volcanic quartz (Q) and K-feldspar (K). Glass shards show typical Y-shape. X 40, transmitted light. (Conception Group, Calvert Bay)

Plate. 3-7- Fine-grained purplish red graywacke. Turbid detrital grains are sodic plagioclase. Opaque mineral is hematite. X 40, transmitted light. (Conception Group, Aquaforte Harbour)

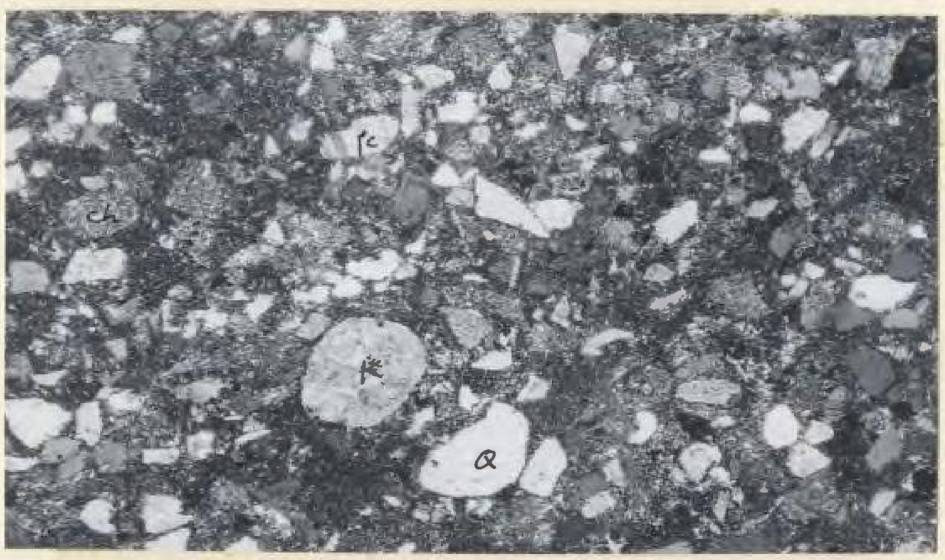


Plate. 3-8- Graywacke showing well rounded K-feldspar (K) and subangular sodic plagioclase (pc), quartz (Q), chert (Ch). X 40, transmitted light. (Conception Group, Aquaforte Harbour)

Plate. 3-9 Volcanic tuff. Note the coarse glass shards at the lower part of the photo. Dark minerals are diagenetic epidote. X 40, transmitted light. (Conception Group, Calvert Bay)

Plate. 3-10 Graded beds in facies A (mudstone). Note the ripple laminations in the sandstone at the tip of hammer. (Middle Cove Member of the St.John's Formation, Aquaforte Harbour.

Plate; 3-11 Facies B of the Middle Cove Member of the St. John's Formation (Bay Bulls).

Plate. 3-12 Facies C (interbedded sandstone and shale) of the Outer Cove Member of the St. John's Formation. Note the lenticular sandstone bed just under the hammer. (Ferryland)

Plate. 3-13 Solitary set of ripple-drift cross laminations in Facies C. Current from north (right) to south (left). (Outer Cove Member of the St. John's Formation, Ferryland).

Plate. 3-14 Scour-and-fill structure in Facies C (Outer Cove Member of the St. John's Formation).

Plate. 3-15 Ripple marks in the sandstone of facies C. (Outer Cove Member of the St. John's Formation, Ferryland).

Plate. 3-16 Rippled sandstones of facies C. Note the lenticular bedding due to the impoverished sands. (Outer Cove Member of the St. John's Formation, Bay Bulls).

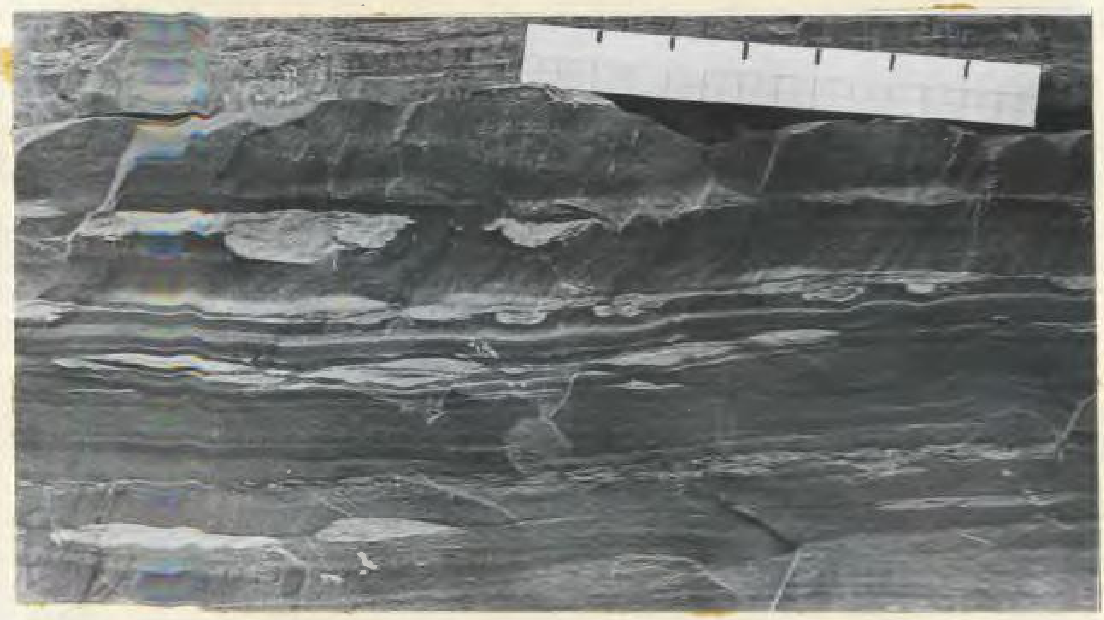


Plate. 3-17 Flow rolls, pseudo-nodules and cross lamination in facies C. (Outer Cove Member of the St. John's Formation, Bay Bulls).

Plate. 3-18 Facies D (Medium-bedded sandstone). The thickness of sandstone at the southeast corner is 6 inches. (Outer Cove Member of the St. John's Formation, Outer Cove).

Plate. 3-19 Coset of ripple-drift cross laminations in facies D. Note the erosion of the stoss sides of the ripple lamination. (Outer Cove Member of the St. John's Formation, Outer Cove).

Plate. 3-20 Interferrence ripple marks in facies D (Outer Cove Member of the St. John's Formation, Outer Cove).

Plate. 3-21 Ribbon-like sandstone body in facies C. Note the sharp contact to the right of the note book. (Outer Cove Member of the St. John's Formation, Outer Cove).

Plate. 3-22 Facies E (Channel sandstone). Note the pinch-and-swell of the channel-filling sandstone (Outer Cove Member of the St. John's Formation, Bay Bulls).

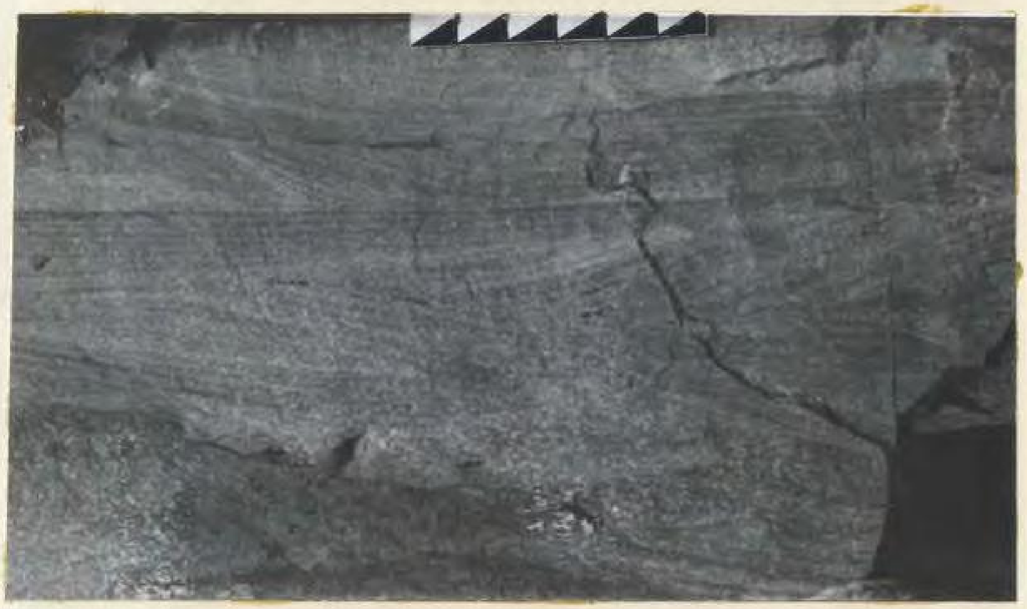


Plate. 3-23 Large scale trough cross beddings in the channel-filling sandstone of Fig. 3-26. Scale in inch. (Outer Cove Member of the St. John's Formation).

Plate. 3-24 Facies E (channel sandstone). The channel is characterized by the troughs with their sandstone fillings and a dome of the underlying sediments at the center of the photo. The sandstone at the northeast corner is 8 feet thick (Outer Cove Member of the St. John's Formation, Outer Cove).

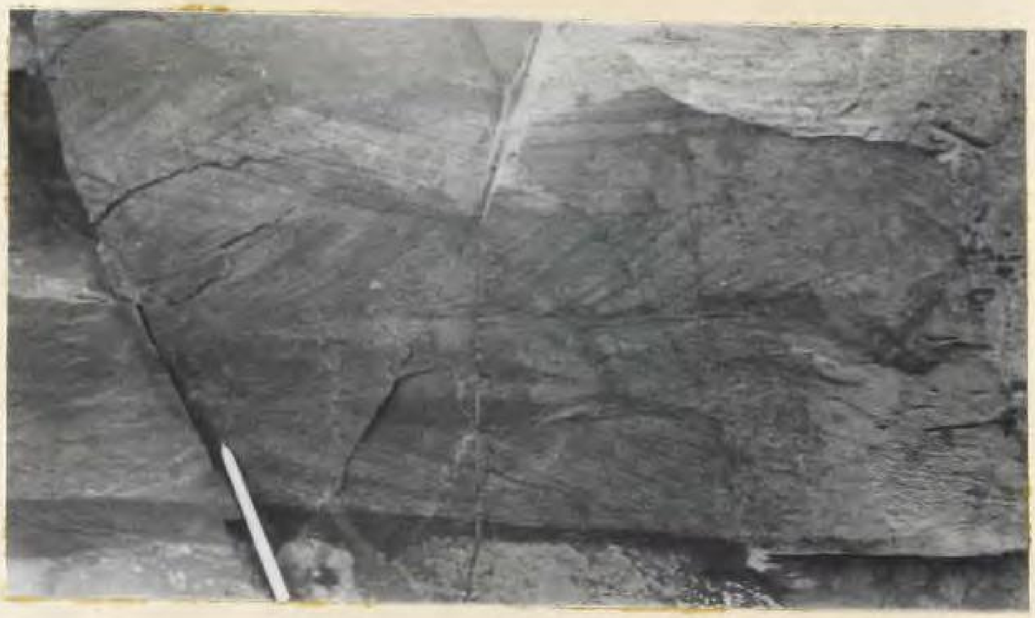


Plate. 3-25 Coset of large scale cross beddings in the channel-filling sandstone of Fig. 3-28. (Outer Cove Member of the St. John's Formation, Outer Cove).

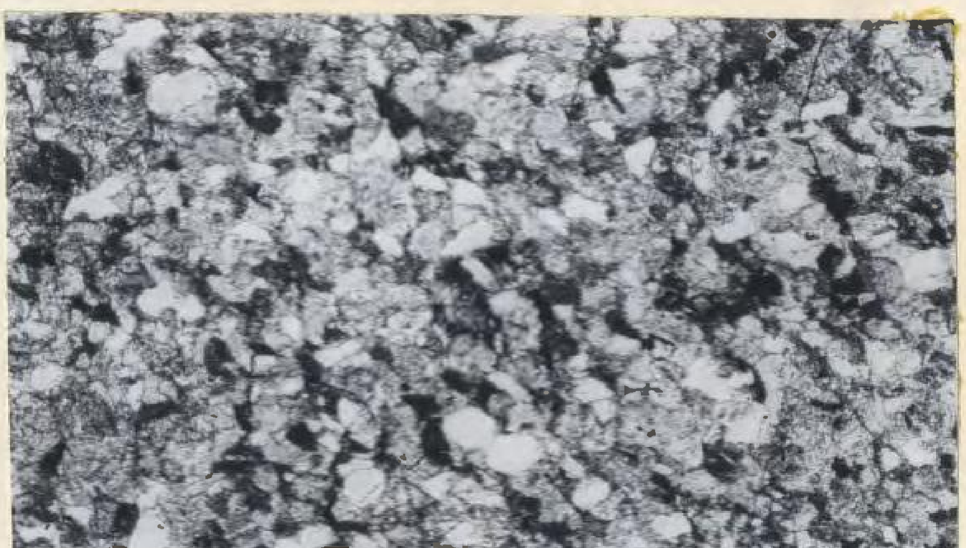


Plate. 3-26- Typical very fine-grained sandstone of the St. John's Formation. Dark grains are probably argillite. X 40, transmitted light. (Ferryland)

Plate. 3-27- Quartzitic texture of the coarse-grained sandstone in facies E. Volcanic quartz (Q), rhyolite (R), K-feldspar (K) and authigenic quartz (Aq). X 40, transmitted light. (Outer Cove Member of the St. John's Formation, Outer Cove)

Plate. 3-28- Volcanic tuff in facies C. Note the embayed and inclusion-free volcanic quartz (Q), K-feldspar (K), and sodic plagioclase (Pc). The elongation of detrital grains is parallel to the bedding. (Outer Cove Member of the St. John's Formation, Calvert Bay) X 40, transmitted light.

Plate. 3-29- Tuffaceous sandstone in facies C, showing volcanic quartz (Q), K-feldspar (K), and sodic plagioclase (Pc). (Outer Cove Member of the St. John's Formation, Ferryland) X 40, transmitted light.

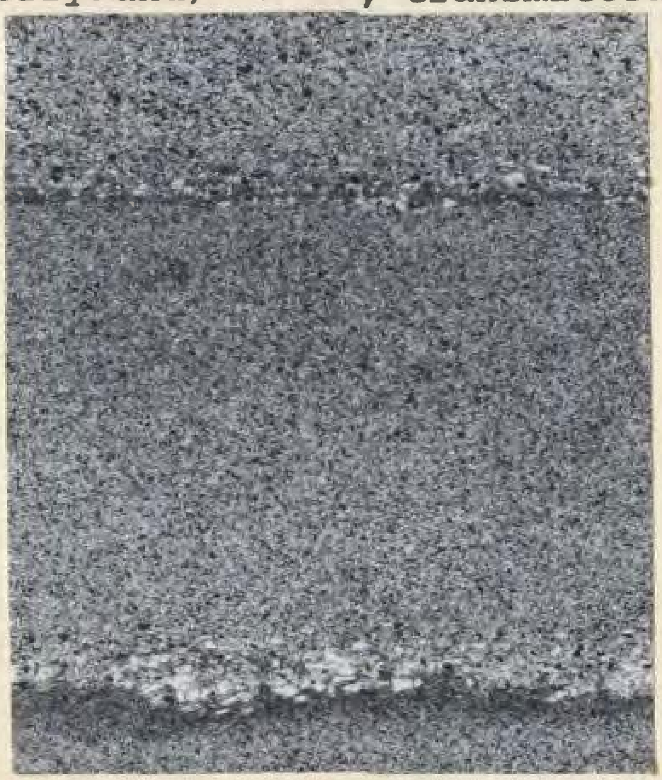


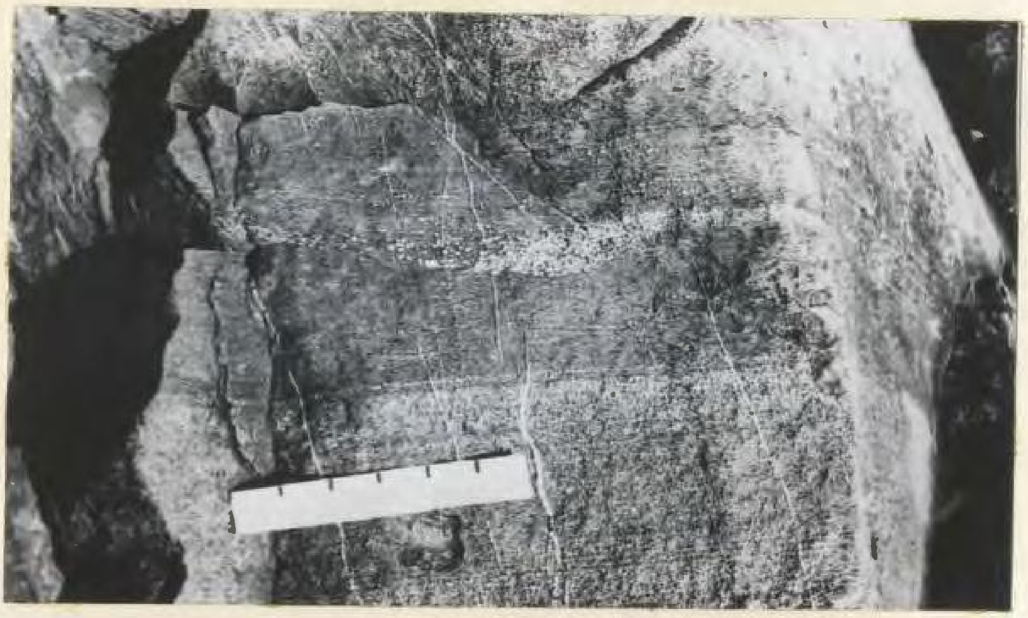
Plate. 3-30- Micrograded bedding in volcanic tuff. Note the silty detrital grains at the base of graded beds and the upward decrease in the coarseness of glass shards. X 40, transmitted light. (Outer Cove Member of the St. John's Formation, Ferryland Harbour)

Plate. 3-31- Tuffaceous sandstone in facies A. Subhedral sodic plagioclase makes up over 80 per cent of the rock. X 40, transmitted light. (Middle Cove Member of the St. John's Formation, Middle Cove)

Plate. 3-32- Tuffaceous sandstone in facies A. Note the fractured volcanic quartz (light) and strongly altered plagioclase (turbid). X 40, transmitted light. (Aquaforte Harbour)

Plate. 3-33- Tuffaceous sandstone in facies A. Note the basic volcanics, volcanic quartz. X 40, transmitted light. (Middle Cove Member of the St. John's Formation, Aquaforte Harbour)

Plate. 3-34 Conglomerate in the Gibbett Hill Formation (Calvert Bay).



Plate, 3-35 Parallel bedding and scour-and-fill structures with cross stratification in the sandy conglomerate of the Gibbett Hill Formation. South to the right of the photo. Scale in inch. (Ferryland).

Plate. 3-36 Large Scale tabular cross bedding in the coarse-grained sandstone of the Gibbett Hill Formation. South is to the right of the photo. Scale in inch. (Bay Bulls).

Plate. 3-37 Cosets of small scale trough cross lamination in the sandstone of the Gibbett Hill Formation. Scale in inch. (Calvert Bay).

Plate. 3-38 Cosets of ripple-drift cross lamination in the very fine-grained sandstone the Gibbett Hill Formation. Scale in inch. (Calvert Bay).

Plate. 3-39 Load casts at the base of the coarse-grained sandstone of the Gibbett Hill Formation (Calvert Bay). Scale in inch.

Plate. 3-40 Convolute bedding in the sandstone of the Gibbett Hill Formation (Calvert Bay). Scale in inch.

Plate, 3-41 Oscillatory (symmetrical) ripple marks in the very fine-grained sandstone of the Gibbett Hill Formation (Calvert Bay). Scale in inch.

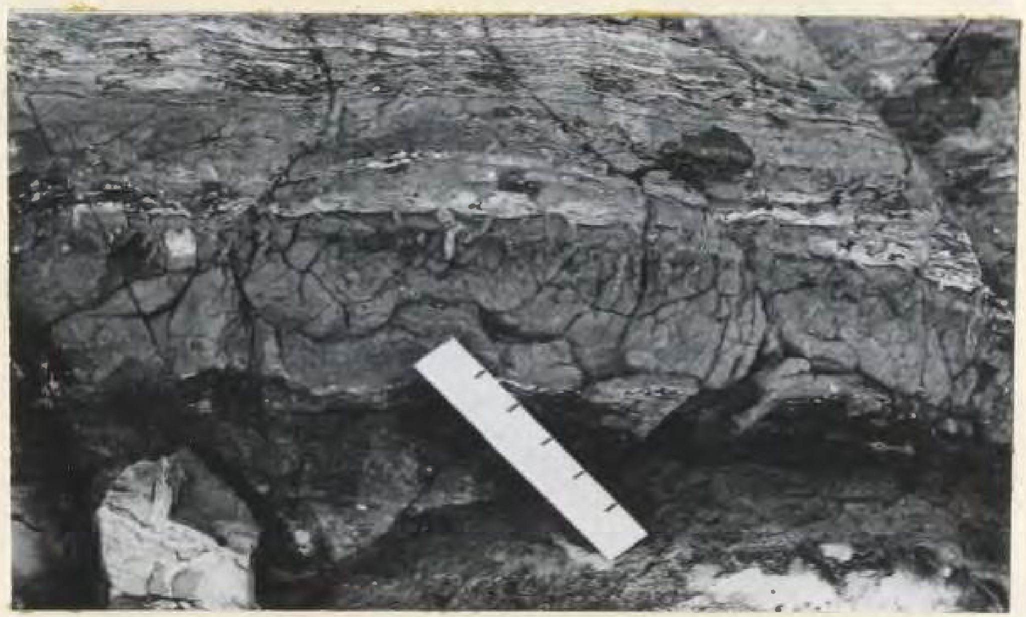


Plate. 3-42 Mud cracks in black shale of the Gibbett Hill Formation (Calvert Bay). Scale in inch.

Plate. 3-43 Volcanic tuff of the Gibbett Hill Formation, showing parallel lamination and cross lamination (Ferryland). South is to the right of the photo.

Plate. 3-44 Tabular cross laminations in volcanic tuff of the Gibbett Hill Formation (Ferryland). South is to the right of the photo.

Plate. 3-45 Diagenetic white bands in the volcanic tuff of the Gibbett Hill Formation (Calvert Bay).

Plate. 3-46- Quartzitic texture of the sandstone, showing pressure-solution and sutured grain boundaries. X 40, cross nicols. (Gibbett Hill Formation, Ferryland)

Plate. 3-47- Laminated volcanic tuff, showing the round bubble and micro-tubule structures of glass shards. X 40, cross nicols. (Gibbett Hill Formation, Ferryland)

Plate. 3-48- Megacrystals of diagenetic calcite (?) in the volcanic tuff of the Gibbett Hill Formation (Ferryland). X 40, transmitted light.

Plate. 3-49- Glass shards in the volcanic tuff of the Gibbett Hill Formation (Ferryland). X 120, transmitted light.

Plate. 3-50- Tuffaceous sandstone showing volcanic quartz (Q) and feldspar. Note the fractured quartz and feldspar. X 40, cross nicols.

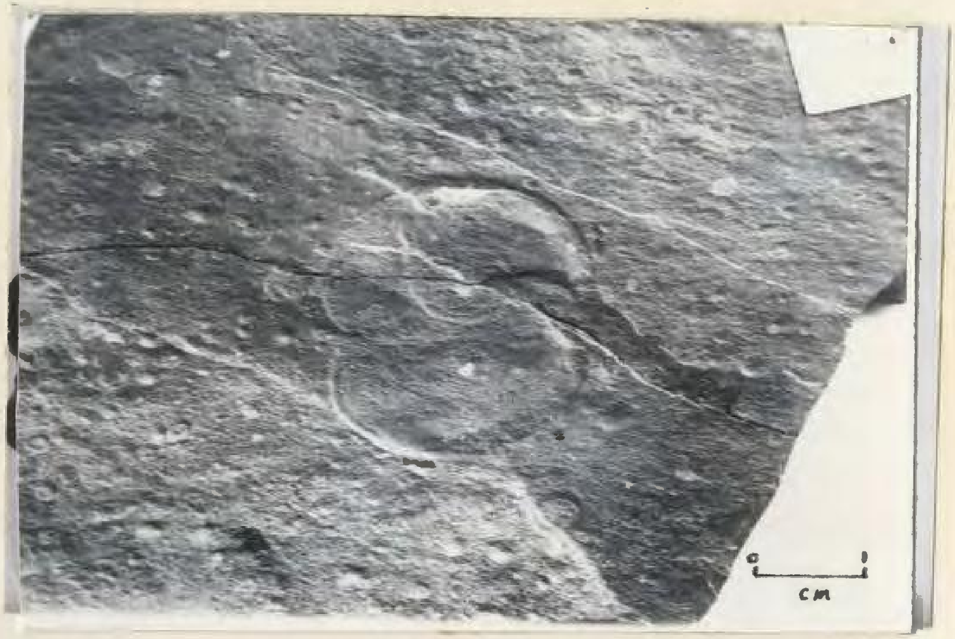


Plate. 4-1- Type 1 pit-like markings and the overlap of Type 5 markings (center of photo) showing concentric rings. Top surface of black shale. (Outer Cove Member of the St. John's Formation, Ferryland)

Plate. 4-2- Type 2 markings showing marginal ring and a central pit. Lower surface of sandstone bed (lower half of photo) and top surface of black shale (upper half of photo). Outer Cove Member of the St. John's Formation, Ferryland)

Plate. 4-3- Type 3 markings showing ovoid shape and radial lines. Lower surface of sandstone bed. (Outer Cove Member of the St. John's Formation, Ferryland)

Plate. 4-4- Type 3 markings showing radial lines and concave central pit with marginal ring. Lower surface of sandstone bed. Outer Cove Member of the St. John's Formation, Ferryland.

Plate. 4-5- Type 4 markings showing the longitudinal groove and radial line. Note the preferred orientation of the markings. Lower surface of sandstone bed. Outer Cove Member of the St. John's Formation. Ferryland.

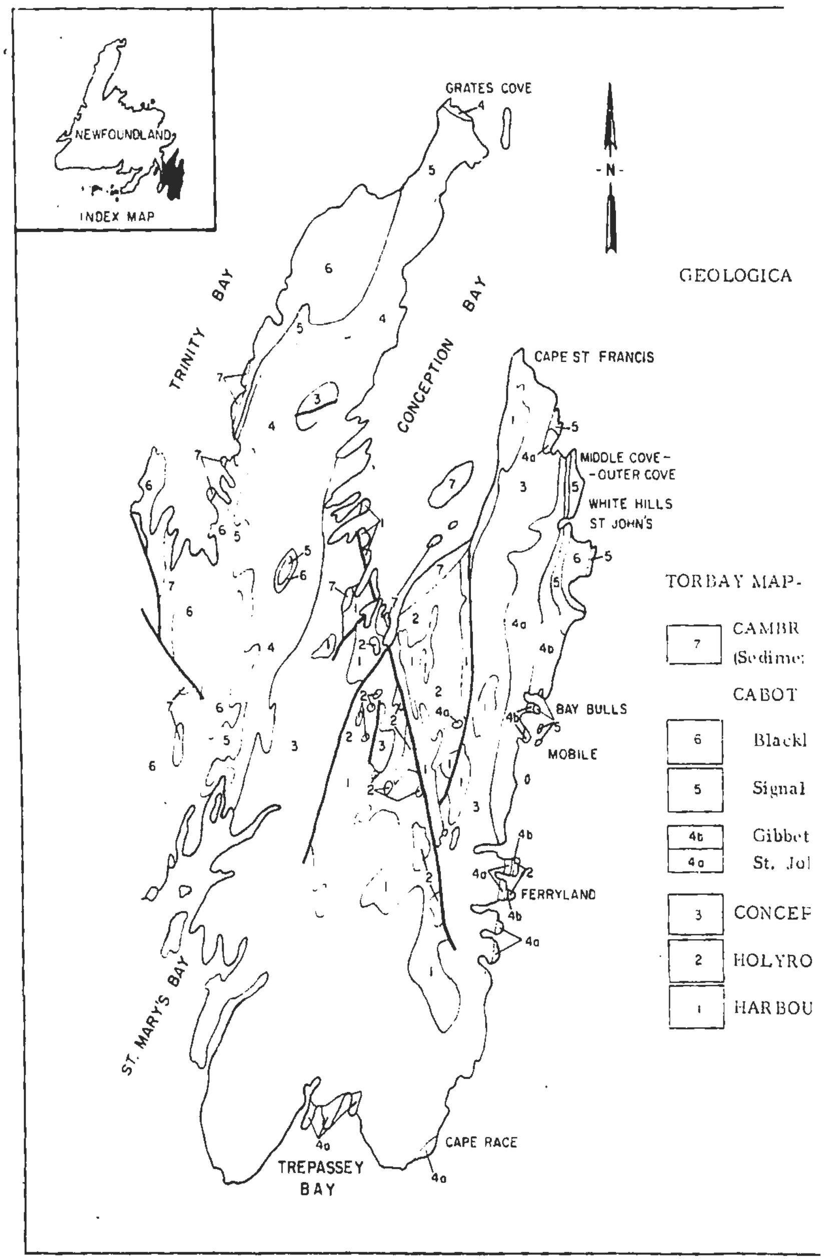
Plate. 4-6- Type 4 markings showing the longitudinal ridge and radial lines. Top surface of black shale. (Outer Cove Member of the St. John's Formation)

Plate. 4-7- Type 1 and Type 5 markings. Note the overlap of Type 5 markings. Lower surface of the sandstone bed. (Outer Cove Member of the St. John's Formation, Ferryland)

Plate. 4-8- The largest Type 5 marking showing concentric rings. Top surface of black shale. Outer Cove Member of the St. John's Formation, Ferryland.

Plate. 4-9- Type 5 markings showing concentric lines and high relief. Lower surface of black shale. (Outer Cove Member of the St. John's Formation, Ferryland)

Plate. 4-10- Type 6 marking showing the central pit and radial lines. Top surface of black shale. (Outer Cove Member of the St. John's Formation, Ferryland)



NEWFOUNDLAND
INDEX MAP
GRATES COVE
N
GEOLOGICA
TRINITY BAY
CONCEPTION BAY
CAPE ST FRANCIS
MIDDLE COVE - OUTER COVE
WHITE HILLS
ST JOHN'S
TORBAY MAP-
BAY BULLS
MOBILE
FERRYLAND
ST. MARY'S BAY
TREPASSEY BAY
CAPE RACE
7 CAMBR
(Sedime
CABOT
6 Blackl
5 Signal
4b Gibbet
4a St. Jol
3 CONCEF
2 HOLYRO
1 HARBOU

'ANCIS

E COVE –
TER COVE

E HILLS
OHN'S

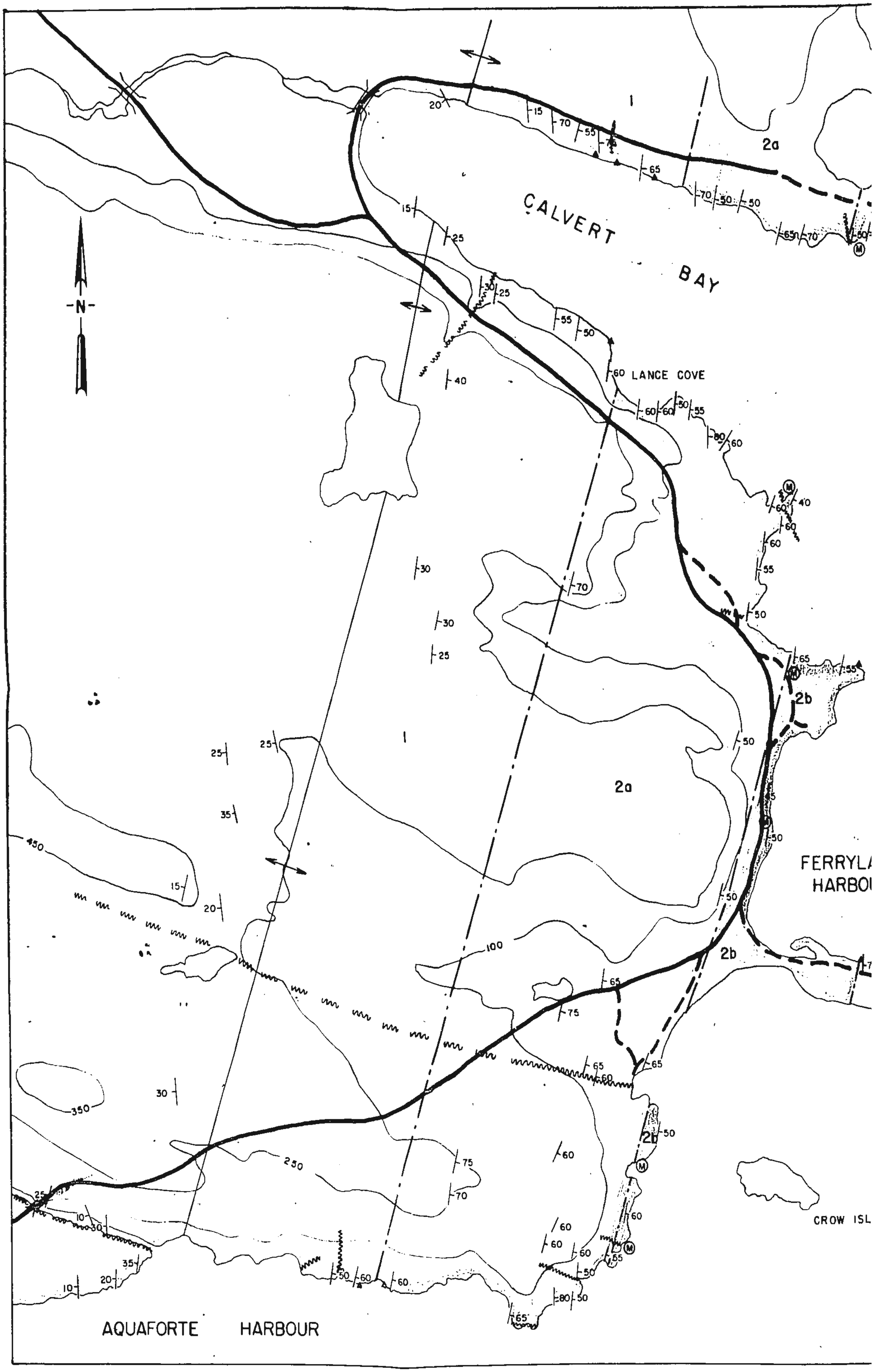
Fig. 1–1

GEOLOGICAL MAP OF CENTRAL AND EASTERN AVALON PENINSULA

NEWFOUNDLAND

LEGEND

TORBAY MAP-AREA		WHITBOURNE MAP-AREA	
7	CAMBRO-ORDOVICIAN (Sedimentary Rocks)	7	CAMBRO-ORDOVICIAN (Sedimentary Rocks)
	CABOT GROUP		HODGEWATER GROUP
6	Blackhead Formation	6	Snows Pond Formation
5	Signal Hill Formation	5	Whiteway Formation
4b	Gibbett Hill Formation	4	Halls Town Formation
4a	St. John's Formation		Carbonear Formation
3	CONCEPTION GROUP	3	CONCEPTION GROUP
2	HOLYROOD PLUTONIC SERIES	2	HOLYROOD PLUTONIC SERIES
1	HARBOUR MAIN GROUP	1	HARBOUR MAIN GROUP



N
CALVERT BAY
LANCE COVE
FERRYLA
HARBOU
CROW ISL
AQUAFORTE HARBOUR
1
2a
2b

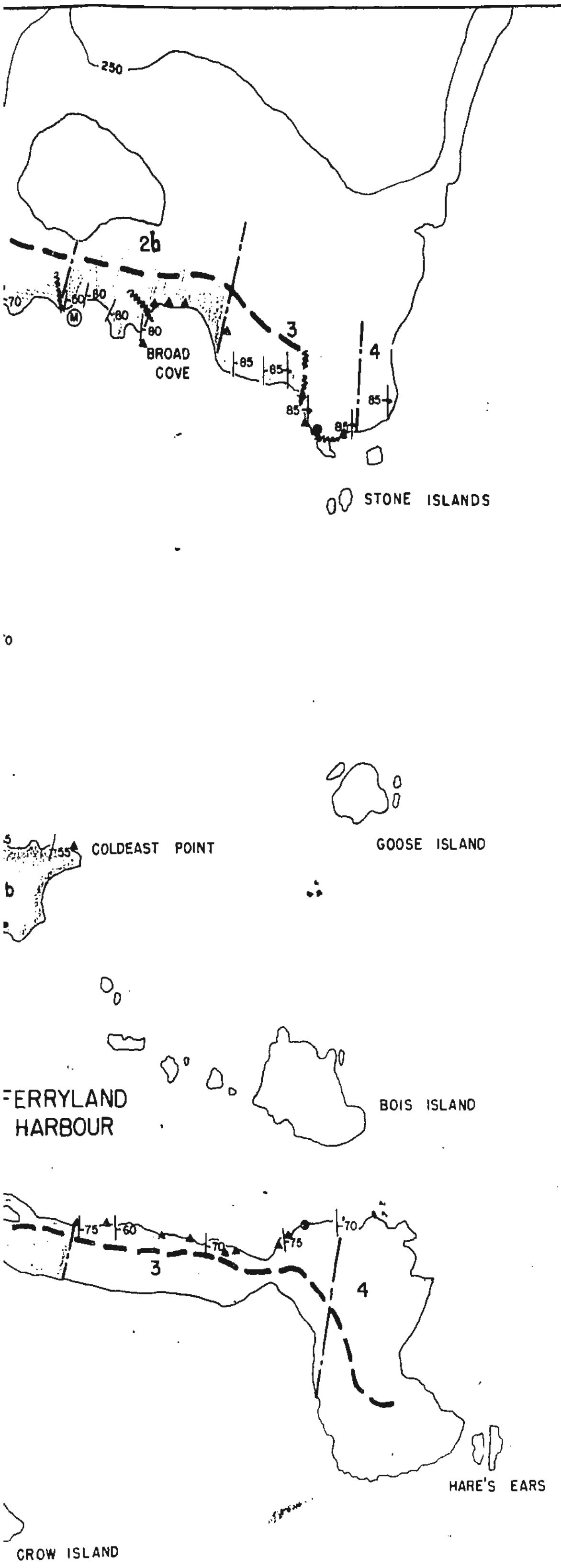
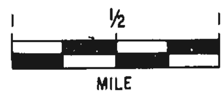


Fig. 2-1

GEOLOGICAL MAP OF FERRYLAND AREA, NEWFOUNDLAND



LEGEND

LATE PRECAMBRIAN

CABOT GROUP

4	SIGNAL HILL FORMATION: red arkosic sandstone and conglomerate. Minor thin beds of black shale, red and green argillite, siltstone.
3	GIBBETT HILL FORMATION: green-gray arkosic sandstone, argillite. Minor black shale, conglomerate, and volcanic tuff.
	ST. JOHN'S FORMATION:
2b	OUTER COVE MEMBER: interbedded gray sandstone, siltstone and black shale. Minor tuffaceous sandstone and tuff.
2a	MIDDLE COVE MEMBER: laminated black shale. Minor sandstone and siltstone.
1	CONCEPTION GROUP: green-gray and variegated graywacke, siltstone, argillite, and volcanic tuff.

Bedding (inclined, vertical, overturned)

Fault (defined, assumed)

Anticlinal axis

Geological boundary

Surface markings (Aspidella terranovica Billings)

Conglomerate

Volcanic tuff

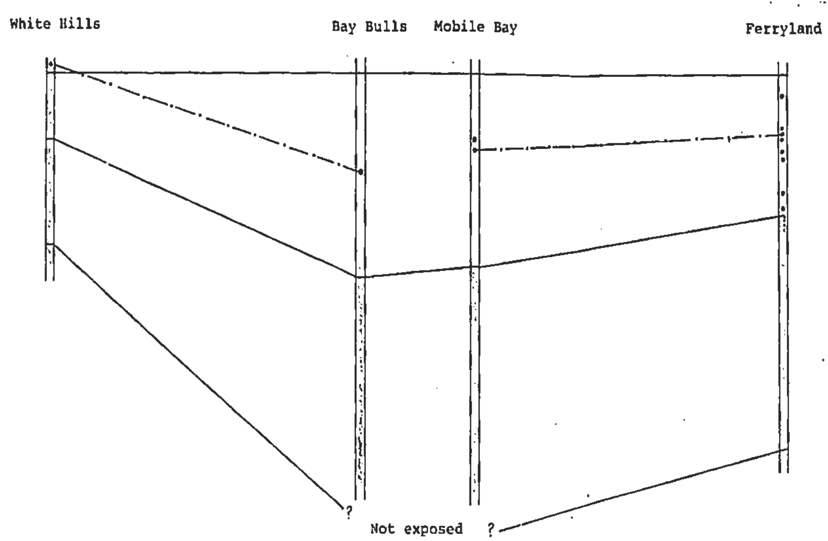
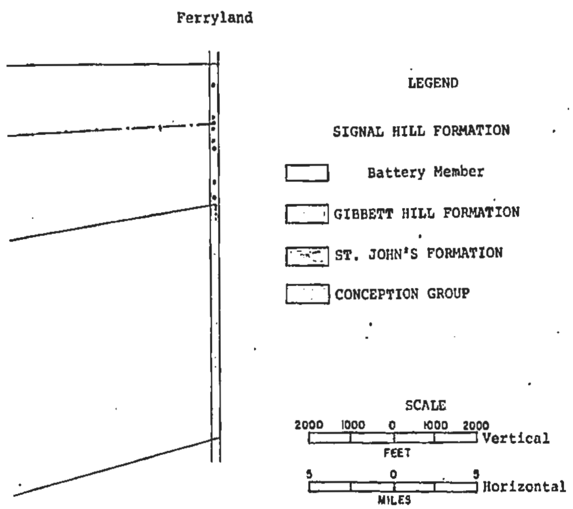
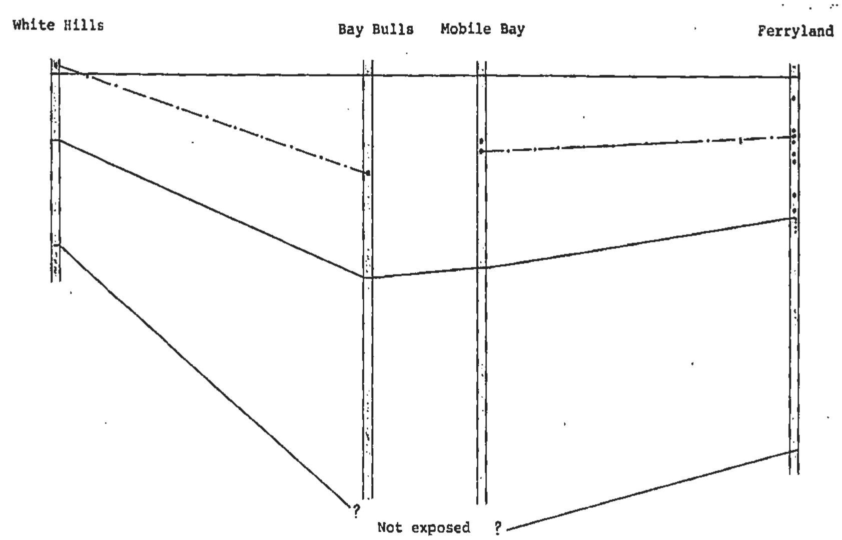


Fig.3-2. Stratigraphic distribution and tentative correlation of the volcanic tuffs in the St. John's and Gibbett Hill Formations in the Torbay map-area. Black dot represents the tuff bed.



:relation
.bbett Hill
:epresents



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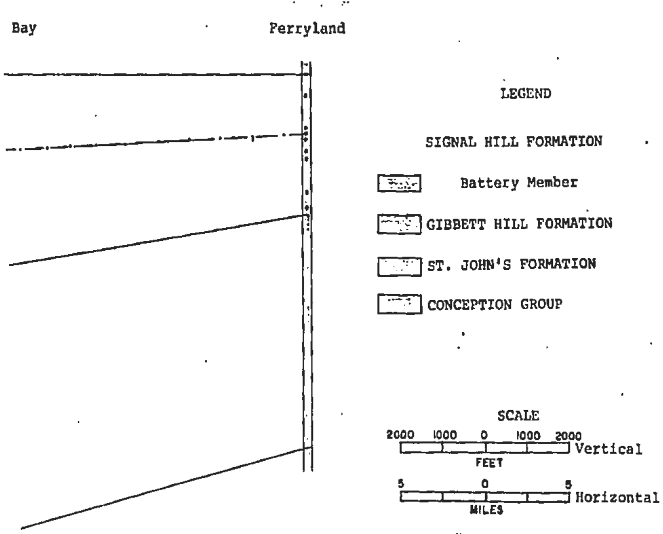


ntative correlation
hn's and Gibbett Hill
Black dot represents

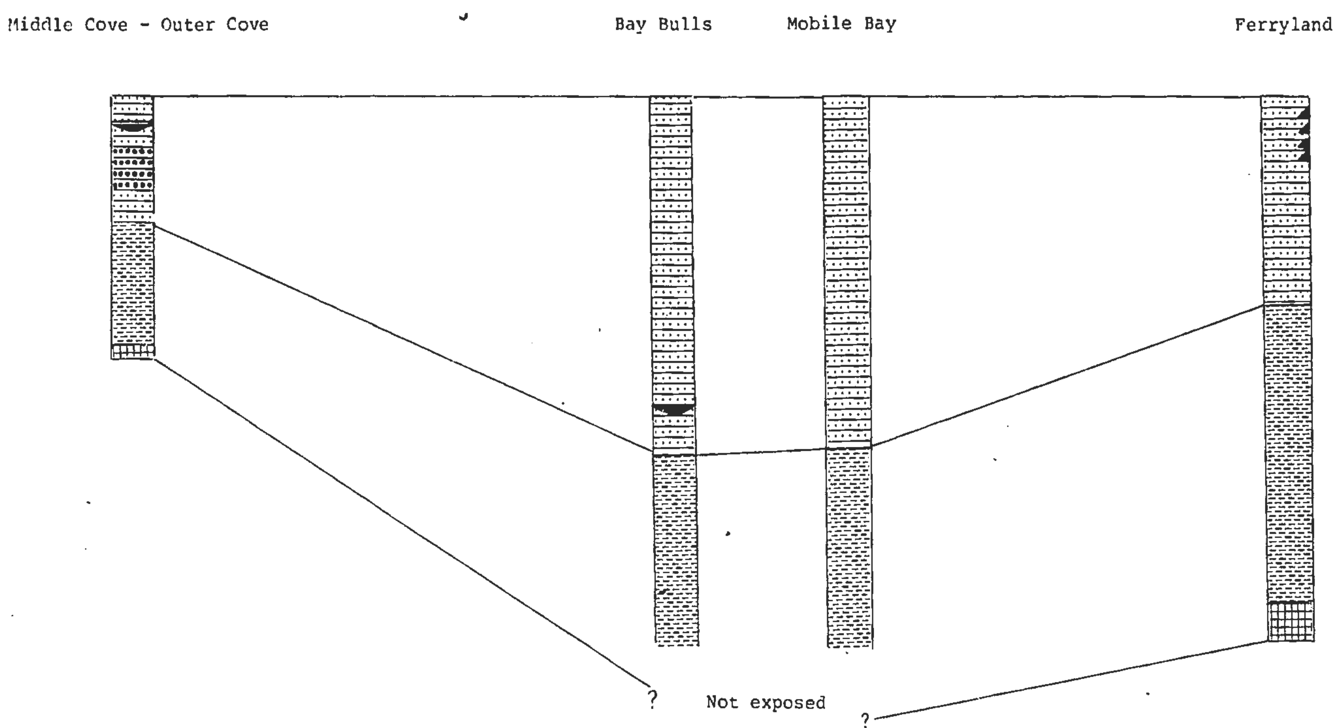
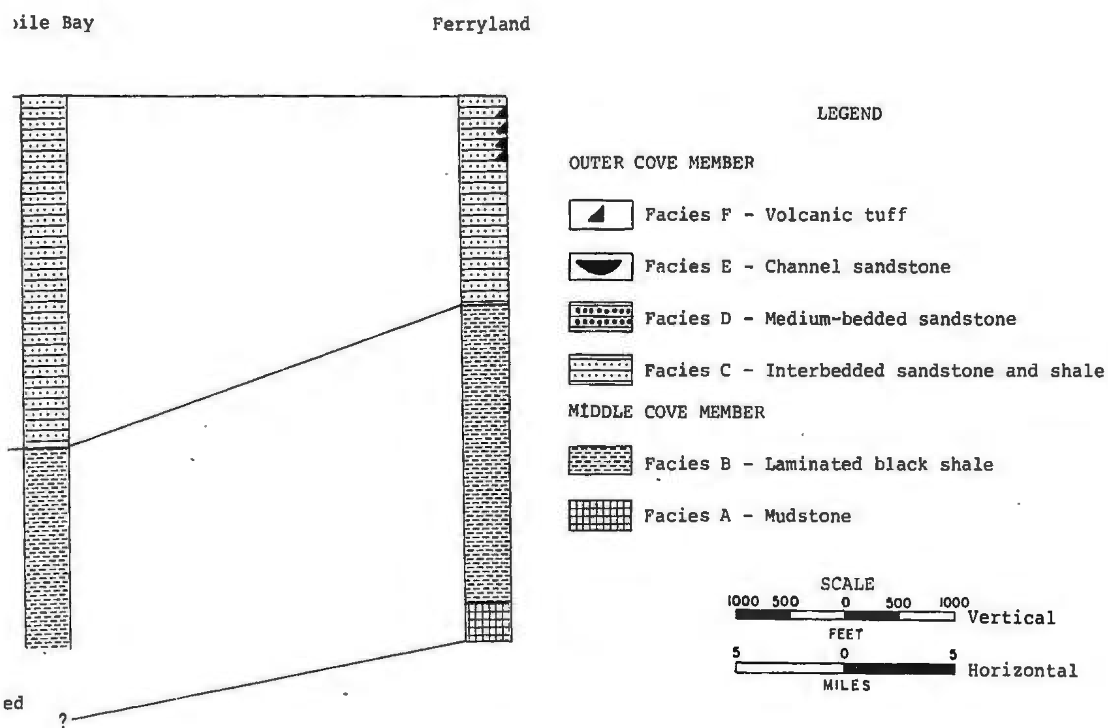


Fig.3-3. Stratigraphy and lithofacies of the St. John's Formation in the Torbay map-area.



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n in the Torbay map-area.