

THE LOWER PALEOZOIC ROCKS AND KLIPPEN OF THE FISTOLET BAY AREA
NORTHERN NEWFOUNDLAND

by

Michael Francis Tuke

A thesis submitted in partial fulfillment
of the requirements for the degree of

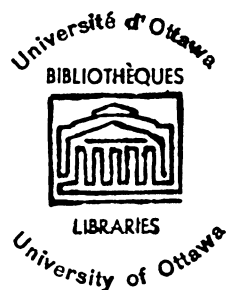
Doctor of Philosophy

in the

Department of Geology

University of Ottawa

May 1966



VANIER LIBRARY
UNIVERSITY OF OTTAWA
OTTAWA, ONTARIO, CANADA;

UMI Number: DC52587

INFORMATION TO USERS

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleed-through, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

UMI[®]

UMI Microform DC52587
Copyright 2007 by ProQuest LLC
All rights reserved. This microform edition is protected against
unauthorized copying under Title 17, United States Code.

ProQuest LLC
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106-1346

Abstract

Rocks of two major sedimentary facies, shelf and eugeosynclinal, outcrop in the most northern part of Newfoundland. The area is similar in geological setting to the west coast of Newfoundland where the juxtaposition of two such facies of equivalent ages has been the subject of much discussion.

Strata of the shelf facies occur in three units:
1) Lower and Middle Ordovician limestones, (St. George and Table Head Formations) forming the western half of the region; 2) Middle Ordovician shale and greywacke, (Goose Tickle Formation) lying to the east of the limestone; 3) clean white Cambrian (?) sandstone restricted to islands off the east coast.

Eugeosynclinal rocks lie to the east of the limestone. Black and green shale of the Lower Ordovician Northwest Arm Formation is contemporaneous with the nearby limestone but is surrounded by faults. The remainder of the eugeosynclinal rocks lie further east in two thrust slices, one on top of the other. The lower slice consists of volcanic rocks, greywacke, and shale whereas the upper slice is composed of volcanic rocks intruded and metamorphosed by peridotite.

Intensity of structural deformation increases from west to east but also varies with the lithologies involved. The massive limestones are gently folded whereas the volcanic

and clastic rocks in the east are more tightly folded, and are overturned towards the west. In addition to the major thrust planes that underlie parts of the eugeosynclinal group several smaller thrusts cut the shelf rocks. Movement of the thrust slices was towards the northwest. The eugeosynclinal rocks are thought to have originated 60 km to the southeast and to have been moved to their present position by gravity sliding.

CONTENTS

Introduction	1
The problem	1
Access	3
Relation of topography and geology	4
Exposure	5
Map coverage	6
History of investigation	6
Acknowledgements	8
Stratigraphy	9
Introductory statement	9
Autochthonous sequence	10
Bradore Formation	10
St. George Formation	13
Paleontology	16
Age and correlation	19
Table Head Formation	19
Paleontology	22
Age and correlation	23
Goose Tickle Formation	24
Paleontology	27
Age and stratigraphic position	29
Correlation	29
Allochthonous sequence	30
Goose Cove Formation	30
Maiden Point Formation	32
Age and correlation	35
Northwest Arm Formation	36
Age and stratigraphic position	39
Correlation	40
Sedimentology	41
St. George Formation	42
Environment of deposition	44
Table Head Formation	45
Goose Tickle Formation	46
Paleo-ecology	47
Current directions	49

Maiden Point Formation	51
Sandstones	52
Mode of deposition of the sandstones	56
Slates	57
Limestones	58
Current directions	58
Source and depositional environment	58
Northwest Arm Formation	59
Environment of deposition	61
Summary of current directions	62
Sedimentological conclusions	63
Igneous intrusions	65
Gabbro	65
Dikes	65
Ultrabasic bodies	65
Thickness of White Hills intrusions	67
Age of the intrusions	69
The metamorphic aureole	70
The problem posed by the aureole	70
Structure	73
History of investigation	73
General structural description	74
Folds and associated structures	77
Goose Tickle Formation	77
Northwest Arm Formation	78
Structural comparison of the Goose	
Tickle and Northwest Arm Formations	80
Maiden Point Formation	81
Mechanism of folding	83
Thrusts	83
Raleigh thrust	84
Hare Bay thrust	86
Other thrusts	90
Normal and other faults	92
Normal faults striking NNE	92
Normal faults striking NW	93
Age of Normal faults	94
Joints	94
Other faults	95
Sequence of structural events	95

Origin and movement of the allochthon	98
Mechanism of movement	99
Original distribution and order of arrival	103
Source area	105
The date of movement	108
The Long Range - a possible obstacle	108
The cause of gravity sliding	109
Comparison with other areas	111
Canada Bay and Hare Bay	111
The west coast of Newfoundland	112
Geological History	116
Cambrian	116
Lower Ordovician	117
Middle Ordovician	117
Upper Ordovician	118
Future research	120
Summary	122
Appendix	124
The breccias and conglomerates of the Goose Tickle Formation	
Breccias	124
Conglomerates	133
References	135
Plates (1 - 39)	at end

<u>List of Figures</u>	<u>Page</u>
1. Northern Appalachians, distribution of Cambro-Ordovician lithofacies	1
2. Roads	4
3. Exposure	5
4. Distribution of the St. George Formation	14
5. Columnar sections of the St. George Formation	15
6. Distribution of the Table Head Formation	20
7. Distribution of the Goose Tickle Formation	25
8. Facies of the Goose Tickle Formation	26
9. Composite section of the Goose Tickle Formation	27
10. Stratigraphic relation of the Table Head and Goose Tickle Formations	29
11. Distribution of the Goose Cove Formation	30
12. Distribution of the Maiden Point Formation	32
13. Lithologies of the Maiden Point Formation	33
14. Columnar sections of the Maiden Point Formation	34
15. Distribution of the Northwest Arm Formation	37
16. Grain size frequency curve for the Maiden Point sandstone	54
17. Current azimuths, Goose Tickle Formation	62
18. Current azimuths, Northwest Arm and Maiden Point Formations	63
19. Distribution of ultrabasic masses	65
20. Pistolet Bay area structure	74
21. Locations where measurements were made on fold axes and slickensides	82
22. Relationship of slickensides to folds	82
23. Trends of slickensides	82
24. Trends of slickensides, Maiden Point Formation	82
25. Orientation of fold axes	82
26. Orientation of fold axes in the Maiden Point Formation	82
27. Distribution of thrusts	84
28. Distribution of normal faults	92
29. Order of movement of allochthonous beds	106
30. Original position of klippe	107
31. Relationship of Cambrian and Ordovician current directions and the Long Range	109
32. The Northern Newfoundland klippe and adjacent beds	111
33. Generalised geological map of western Newfoundland	112
34. Geological History	116-119
35. Distribution of breccias and conglomerates	124
36. Pistolet Bay area, Geological map	in pocket
37. Cross sections of the Pistolet Bay area	in pocket

List of Tables

1. Facies in the Northern Appalachians	2
2. Stratigraphic nomenclature	7
3. Stratigraphy of the Pistolet Bay area	9
4. Comparison of structures in the Goose Tickle and Northwest Arm Formations	81
5. Thickness of breccia beds and average of 10 largest clasts	127
6. Thickness of conglomerate beds and average of 10 largest clasts	134

NORTHERN APPALACHIANS

Distribution of Cambro-Ordovician lithofacies

scale of kilometres
0 100 200 300

N

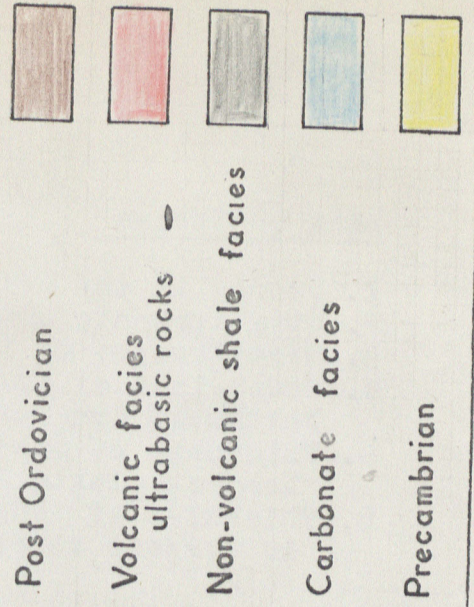


Fig.1

INTRODUCTION

The problem

In the northern segment of the Appalachians, rocks of three main facies were deposited during the Cambrian and Ordovician periods. They are:

- 1) Quartz sandstone-carbonate facies = shelf facies
- 2) Shale with thin limestone and limestone breccia beds
= miogeosynclinal facies
- 3) Greywacke shale and volcanic beds with ultrabasic intrusions = eugeosynclinal facies.

The stratigraphic and structural relationships of these facies have long been puzzling. The beds of the shelf facies are flat lying or gently folded whereas those of the eugeosynclinal facies are highly folded. Thrust faults are known throughout the area but the extent of their movement is the subject of much speculation. Patches of eugeosynclinal strata in New England and Newfoundland are completely surrounded by beds belonging to the orthoquartzite-carbonate facies. The problem is to discover whether or not these strata were deposited in their present position, and if not, the mechanism of their emplacement.

If the eugeosynclinal beds were laid down where they are at present then a complicated stratigraphic history with very abrupt facies changes is required. If on the other hand, they have slid or have been thrust into their present position, it is necessary to invoke a mechanism

Table 1. FACIES IN THE NORTHERN APPALACHIANS

	<u>New England</u>	<u>Quebec</u>	<u>Newfoundland</u>
<u>Shelf</u>			
Orthoquartzite- carbonate facies	CHAMPLAIN SEQUENCE	RICHELIEU SEQUENCE	LABRADORE, ST. GEORGE AND TABLE HEAD
<u>Miogeosynclinal</u>			
Shale with thin limestones and limestone breccias	TACONIC SEQUENCE	LEVIS BEDS	GREEN POINT AND COW HEAD BEDS
<u>Eugeosynclinal</u>			
Greywacke, shale, GREEN MNTS. volcanic beds and MAGOG TROUGH ultrabasic intrusions		MEMPHRAMAGOG TROUGH	HUMBER ARM FM.

of long distance tectonic transport and to find a suitable source area for the beds. Both solutions present difficulties.

The earliest ideas developed in the New England area were that the various strata were deposited in the areas they now occupy and that sudden facies changes separated the facies. The first controversy over the facies arose when Ulrich (1902) suggested that the Taconic sequence (shale with thin limestone and breccia) had been deposited in a separate basin from the surrounding Champlain sequence (orthoquartzites and carbonates). In Ulrich's paper, thrusting was only implied. Ruedemann (1909) was the first to propose (definitely) that the Taconic strata had been thrust into their present location. Because of the lack of an obvious source area and the long distance the beds must have been transported, Lochman-Balk (1956) and Bucher (1957) have argued against this explanation and have tried instead to fit all the beds into one succession with lithologies changing suddenly with time (vertically) rather than laterally. Zen (1961) favoured the thrust hypothesis because in the northern end of the Taconic Mountains newly discovered fossil evidence indicated that there were two separate contemporaneous sequences without intermediate facies. The structures he found were consistent with the hypothesis that the miogeosynclinal strata form a klippe which had been thrust over the shelf sequence.

It is only recently that the same arguments have been applied to the eugeosynclinal strata of Newfoundland. Rodgers and Neale (1963) compared the strata on the west coast of Newfoundland to the beds found in the Champlain valley and the Taconic Mountains. On the basis of the similarity they enlarged upon a suggestion made by Johnson (1941) and Kay (1945) that the eugeosynclinal beds had been thrust over the shelf rocks. They concluded that the eugeosynclinal rocks in Western Newfoundland formed a klippe similar to that in the Taconic area.

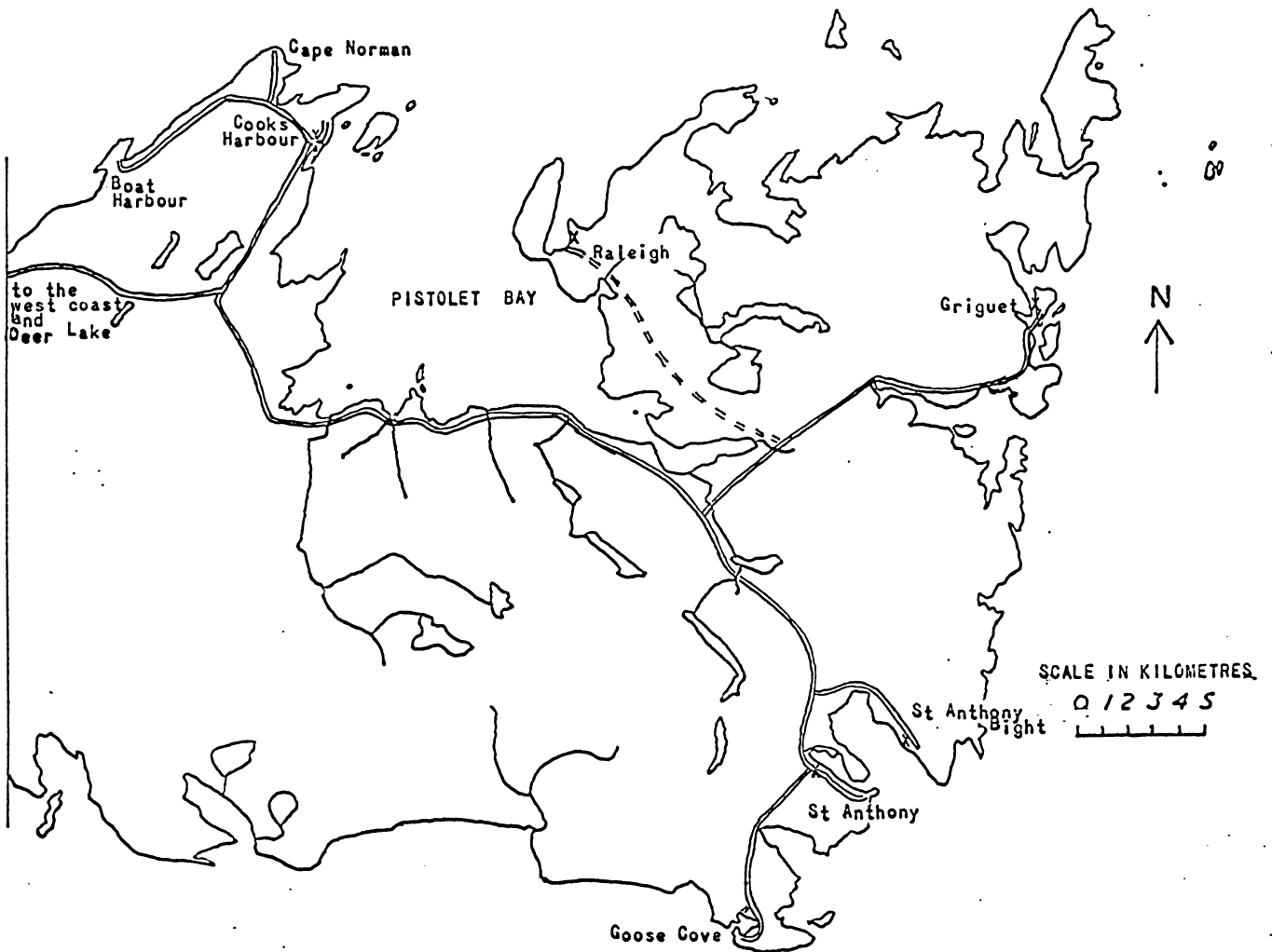
In the same paper Rodgers and Neale suggested that the clastic beds found in the northeast part of the Great Northern Peninsula formed a second klippe. Their evidence was taken from a report of the geology of Hare Bay by Cooper (1937) and of Canada Bay by Betz (1939). The area north of Hare Bay which forms a large part of this second klippe and has not previously been mapped in detail.

The purpose of ^ethe present investigation is to examine the stratigraphy and structure of the region north of Hare Bay with particular emphasis on facies relationships and thus to test the validity of Rodgers and Neale's hypothesis in this northern area.

Access

St. Anthony is connected by road to Deer Lake which is both the nearest point on the Trans Canada Highway and

PISTOLET BAY AREA



Roads

built before 1964

under construction in 1964

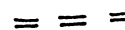
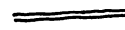


Fig.2

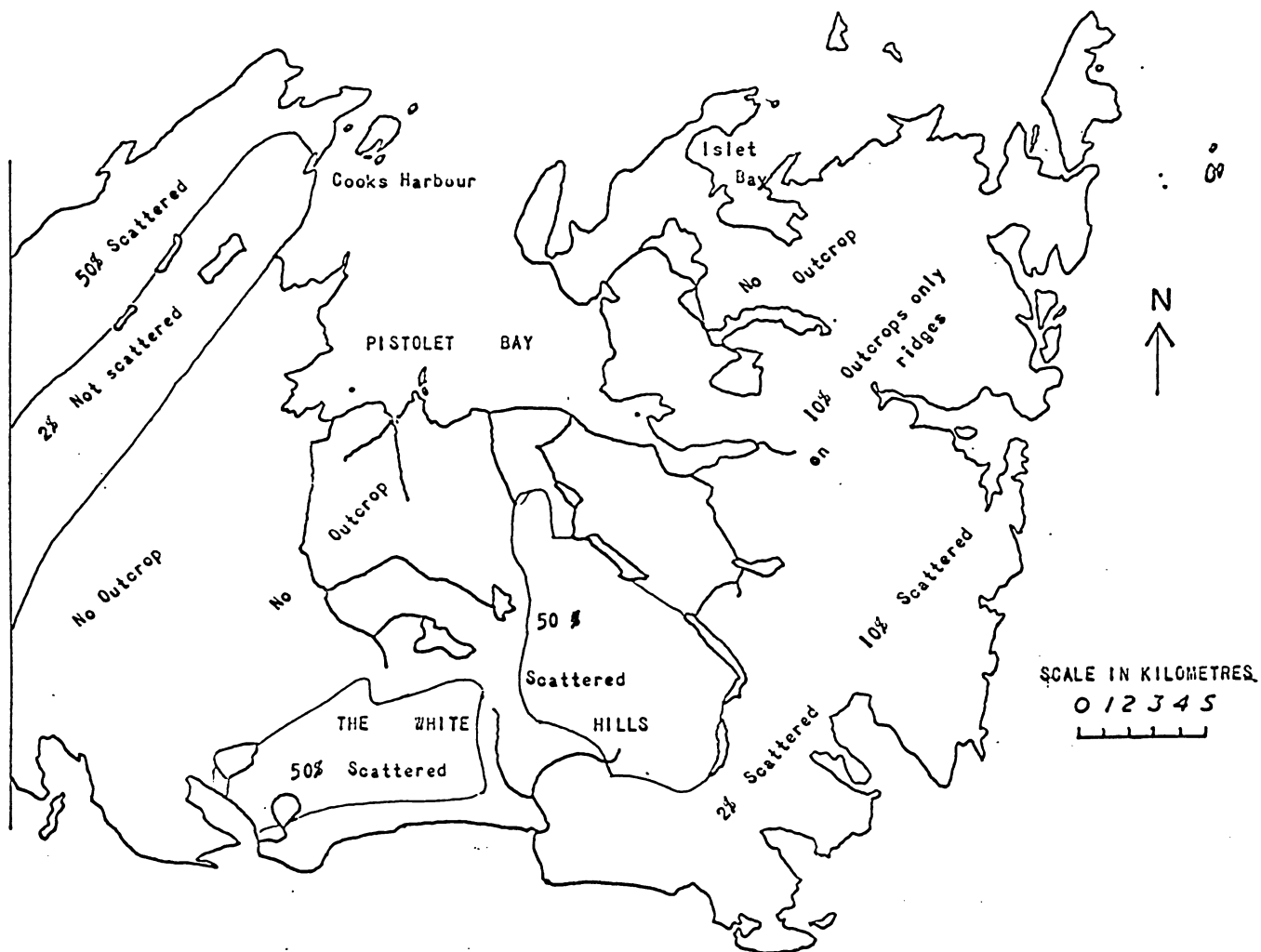
the nearest railhead. Branch roads within the St. Anthony region lead to the main villages as can be seen on fig 2 (the map opposite). Eastern Provincial Airways runs a twice weekly air service from Gander to St. Anthony and the Canadian National Steamships call at St. Anthony and several of the villages round the coast.

The west and north coastlines can be followed on foot without any difficulty but cliffs and scrub make parts of the eastern and southern coastlines hard to follow. The interior of the western part of the area is bare rock or gravel and is easy to walk across but further east thick bush makes travelling slow. South of Pistolet Bay muskeg and lakes make walking tiring and slow. The White Hills are difficult to climb because of bush but once on top walking is very easy because it is flat with no vegetation. Much of the eastern part of the area has thick bush in the bottom of the valleys and this makes traversing the country very slow. Foot paths exist between most of the villages but they are often difficult to find.

Relation of topography to geology

The western part of the area is flat lying land about 20 m above sea level. The barren section adjacent to the west coast is the outcrop area of the dolomite of the St. George Formation, whereas the thickly wooded area immediately to the east is underlain by the limestones

PISTOLET BAY AREA



Exposure

Fig. 3

of the Table Head Formation. A NNE-trending escarpment separates the area just described from the flat marshy land south of Pistolet Bay which is almost devoid of outcrop because the bedrock is soft shale of the Goose Tickle and Northwest Arm Formations. Further to the east and south are the White Hills, the highest land in the area, which are underlain by peridotite and associated metamorphic aureole. In the northeast segment of the area undulating lowlands rising no higher than 80 m are where greywacke and shale of the Maiden Point Formation outcrop.

Exposure

Exposure (Fig. 3) just inland from the west coast is continuous. Further to the east, on the other hand, the land is thickly covered by vegetation except around Cooks Harbour where it is rubble covered. No exposures are found south of Pistolet Bay except in streams and even then only rarely. The top of the White Hills is bare rock but on the sides exposures are found only in the streams, sometimes in abundance and sometimes very scattered. In the northeastern part of the area, just inland from Pistolet Bay, the exposure is virtually non-existent but further east sandstones are exposed on the ridges and near the eastern coastline the exposures are small but not infrequent. Along the coastline the exposure is nearly continuous except in the Pistolet and Islet Bays where stretches of good exposure are separated by mud flats.

Map coverage of the area

Topographic maps (1 : 50,000 and 1 : 250,000) are available for the whole area.

The geology was plotted on maps with a scale of 1 : 50,000 except for the west coast and Pistolet Bay where a larger scale was used.

History of investigation

The first geological information on the northern tip of Newfoundland was provided by Richardson (in Logan 1863). He noted the limestones on the west side of Pistolet Bay and the shales within the bay. He also reported the volcanic beds and thick sandstones in Milan Arm.

Schuchert and Dunbar (1934) made a study of the geology of western Newfoundland. They made only brief mention of the beds in Pistolet Bay but their descriptions of the beds on the west coast of Newfoundland have proved very useful for correlating the beds in the area of this report with the better known areas to the south.

Cooper (1937) studied the geology around Hare Bay and mapped as far north as Pistolet Bay and St. Lunaire Bay. Although much of his mapping was of a reconnaissance nature, his work outlined the structure and stratigraphy of the region. He recognised all the formations used in this report (except the Bradore Formation the outcrops of which are not found in the area he mapped). He thought

Age	Logan 1863 West Coast	Schuchert and Dunbar 1934 West Coast	Cooper 1937 Hare Bay	Betz 1939 Canada Bay	Tuke 1966 Pistolet Bay
Middle Ordovician	Q	HUMBER ARM SERIES	MAIDEN POINT SAND- STONE IRELANDS BIGHT VOLCANICS GOOSE TICKLE SLATE	CANADA HEAD FM	
	P O	COW HEAD SERIES LONG POINT SERIES	NORTHWEST ARM FM.	ENGLEE FM.	GOOSE TICKLE FM
	K - N	TABLE HEAD SERIES	HARE ISLAND LIMESTONE	BIDE ARM FM.	TABLE HEAD FM.
	D - I O in part	ST. GEORGE SERIES GREEN POINT SERIES	SOUTHERN ARM LIMESTONE	CHIMNEY ARM FM.	ST. GEORGE FM. NORTHWEST ARM FM.
Upper Cambrian			BRENT ISLAND LIMESTONE		MAIDEN POINT FM GOOSE COVE FM.
Middle Cambrian				TREXTOWN PONDS FM. CLOUD RAPIDS FM.	
Lower Cambrian	C B A	HAWKE BAY SERIES FORTEAU SERIES BRADORE SERIES		FORTEAU FM. DEVILS COVE FM. CLOUD MTS. FM.	BRADORE FM.
Precambrian	LAURENTIAN	LAURENTIAN		PRECAMBRIAN	

Table 2 Stratigraphic Nomenclature

that the beds formed a continuous sequence, the St. George Formation being the oldest and the Goose Cove the youngest. The Northwest Arm Formation he suggested was a local facies of the Goose Tickle Formation. His most important structural discovery was the Hare Bay thrust along which he concluded there had been a displacement of 11 miles (16 km).

Betz (1939) mapped Canada Bay, 70 km to the south of St. Anthony on the east Side of the Great Northern Peninsula. The lithologies and structures are similar to those of the Hare Bay area, and the beds there form the southern part of the northeastern klippe proposed by Rodgers and Neale (1963).

Kindle (1945) collected fossils from the St. George and Table Head Formations in Pistolet Bay. The lithologies of the two formations are in many places very similar and it was largely because of his work that it has been possible to map them as separate units.

The Patino Mining Company mapped the geology of the White Hills in detail and investigated the mineral possibilities, (Shepherd 1962).

The present work was begun in 1963 and the field work was completed in 1964. The author was the first to map the area in detail and this led to the discovery of the Raleigh thrust and to a much more detailed knowledge of the stratigraphy. Most significant was the discovery of graptolites of Lower Ordovician age in the Northwest Arm

Formation which indicated that this is coeval with the St. George Formation and thus that two sequences are present as predicted by Rodgers and Neale (1963).

Acknowledgements

The author is deeply grateful to N.A.T.O. for giving him a grant to work at a Canadian university. Thanks are also due to the National Advisory Committee for support.

The author is grateful to his supervisor, Dr. D.M. Baird for suggesting this thesis topic and for help received from him while doing the research. Thanks are also due for the help received from Dr. W.K. Fyson and other members of the staff at the University of Ottawa. The author would also like to thank Dr. L.M. Cumming, Dr. M. Kay and Dr. J. Rodgers who visited him in the field and made a number of helpful suggestions.

Finally the author is grateful for the help and companionship provided by his two assistants, G. Gauss in 1963 and G. Chapman in 1964.

Table 3.

STRATIGRAPHY OF THE PISTOLET BAY AREA

<u>Age</u>	<u>Name and lithology</u>	<u>Evidence for age</u>	<u>Thickness</u>
<u>AUTOCHTHONOUS SEQUENCE</u>			
MIDDLE ORDOVICIAN	GOOSE TICKLE FORMATION		
- - - - -	Shale and greywacke	graptolites	500 m
- - - - -	Disconformable	- - - - -	- - - - -
- - - - -	- - - - -	- - - - -	- - - - -
TABLE HEAD FORMATION			
- - - - -	Limestone with shale lenses near top.	trilobites	30 m
- - - - -	Conformable	- - - - -	- - - - -
- - - - -	- - - - -	- - - - -	- - - - -
LOWER ORDOVICIAN	ST. GEORGE FORMATION		
- - - - -	Limestone and dolomite	trilobites	100 m
- - - - -	Faulted	- - - - -	- - - - -
- - - - -	- - - - -	- - - - -	- - - - -
LOWER CAMBRIAN	BRADORE FORMATION		
- - - - -	Quartz sandstone	lithological similarity with type section	700 m
- - - - -	- - - - -	- - - - -	- - - - -

ALLOCHTHONOUS SEQUENCE

LOWER ORDOVICIAN	NORTHWEST ARM FORMATION	
- - - - -	Black and green shale	graptolites
- - - - -	and greywacke	65 m
- - - - -	Thrust	- - - - -
- - - - -	- - - - -	- - - - -
- - - - -	- - - - -	- - - - -
LOWER ORDOVICIAN OR OLDER	MAIDEN POINT FORMATION	
- - - - -	Greywacke and slate	intrusive relation-
- - - - -	and volcanic beds	ship (see p.35)
- - - - -	Thrust	2000 m
- - - - -	- - - - -	- - - - -
- - - - -	- - - - -	- - - - -
- - - - -	GOOSE COVE FORMATION	
- - - - -	Amphibolite and slightly	intrusive relation-
- - - - -	metamorphosed volcanic beds	ship (see p. 31)
- - - - -	- - - - -	150 m
- - - - -	- - - - -	- - - - -
- - - - -	- - - - -	- - - - -

STRATIGRAPHY

Introductory statement

The beds in the Pistolet Bay area have been divided into two sequences, shelf and eugeosynclinal, on the basis of their facies, and on their stratigraphic and structural relationships to each other.

The shelf sequence contains four formations. The lowest, the Bradore Formation is Lower Cambrian and consists of quartz sandstones which outcrop on islands off the east coast. Lower Ordovician shallow water limestone and dolomite referred to as the St. George Formation crop out on the west coast south of Cape Norman. These are conformably overlain by the Middle Ordovician Table Head Formation which is an argillaceous limestone without shallow water features. Lying above this and in sedimentary contact with it are shales and greywackes of the Goose Tickle Formation which is also Middle Ordovician. It can be seen that formations form a sequence which was deposited in progressively deepening water. The sequence represents both shelf and miogeosynclinal facies but will be referred to as the shelf sequence, and is autochthonous.

The beds of the eugeosynclinal sequence are all in fault contact with the beds of the shelf sequence. Three formations belong to the eugeosynclinal sequence. The

earliest, called the Goose Cove Formation, is Lower Ordovician or older volcanic material metamorphosed by the intrusion of peridotite. The formation outcrops on the White Hills. Greywacke, slate and volcanic beds, which are thought to be younger than the Goose Cove Formation but still Lower Ordovician or older, form the eastern part of the area and are called the Maiden Point Formation. The youngest beds in the eugeosynclinal sequence, the Lower Ordovician black and green shale and greywacke of the Northwest Arm Formation, occur as fault slices in the Goose Tickle Formation.

The stratigraphy is summarised in Table 3.

The Autochthonous Sequence

Bradore Formation

The Bradore Formation was named by Schuchert and Dunbar (1934, p.17) and corresponds to Division A of Logan (1863). The type section at Bradore in Labrador consists of red arkose and quartz sandstone. White arkosic sandstone, thought to belong to the Bradore Formation because of lithological similarity, forms the White Islands six km due east of Quirpon and small islands nearer the coast. *Little Bay?*

The sandstone is white or very pale green with some pale pink grains of feldspar. The average grain size is 1 mm and the maximum is 2 mm. The grains are well rounded and the sandstone is well sorted. Bedding is very regular

and individual beds can be traced across the island. The beds range in thickness from 15 to 60 cm and each has a sharp upper and lower contact. Pale green partings separate some of the beds. Between the two largest islands seen on the map (Fig.36) is a band of black sandstone in the middle of which occurs a black phyllitic slate bed. It contains quartz grains commonly the same size as those in the sandstone. Many small patches of iron staining in the slate may be due to weathered pyrite.

It is estimated that 700 m of beds are present on the island but neither top nor bottom of the formation was seen in this area.

Age and correlation

No trace of fossils was seen in the White Islands. ^{Sediment?}

The only thick sequences of clean sandstones known in this area of northern Newfoundland are the lower Cambrian beds of the Bradore Formation. In the type section in Labradore, Schuchert and Dunbar describe the beds as follows:

"The Bradore sandstone is made up almost entirely of reddish arkose and sandstone with some small conglomerates. In general it is coarsest and reddest at the base, some of the upper members being fairly pure quartz sand of pink or even light grey colour.".....

"These red sandstones are capped by a conspicuous white fine grained sandstone 15 to 25 feet in thickness."

The thickness of the Bradore Formation in Labrador is 90m.

Betz has described the lower Cambrian beds of the Cloud Mountains Formation in Canada Harbour 115 km to the South as follows:

"The Cloud Mountains Formation is composed largely of moderately fine grained sandstones of red, purplish or brown colour. Interstratified with the sandstones are dark red to black quartz conglomerates." (Betz, 1939, p.12).

Betz measured this formation and found it to be 585 feet (195 m) but Murray's division A of the Potsdam Group (Lower Cambrian) measured in the same area is quoted as 2000 feet (650 m), (Murray 1864).

The lithologies are not exactly comparable. In the White Islands the sandstone is white, not red, and there are no conglomerates. The only other thick sandstone ^{in the region} successions_^ are_^ all greywackes. Kindle (1945, p.3) attributed the rocks of the White Islands to the Lower Cambrian and Baird in his 1954 map of Newfoundland also suggested they were Cambrian. The writer agrees that beds on the White Islands are best correlated with the Lower Cambrian Bradore Formation.

St. George Formation

The St. George Formation may be said to consist of limestones and dolomites of Lower Ordovician age in western Newfoundland. The type section of the formation is at St. George Bay in southwestern Newfoundland. It was first named by Schuchert and Dunbar (1934, p.46) and corresponds to division D - I of Richardson (in Logan 1863).

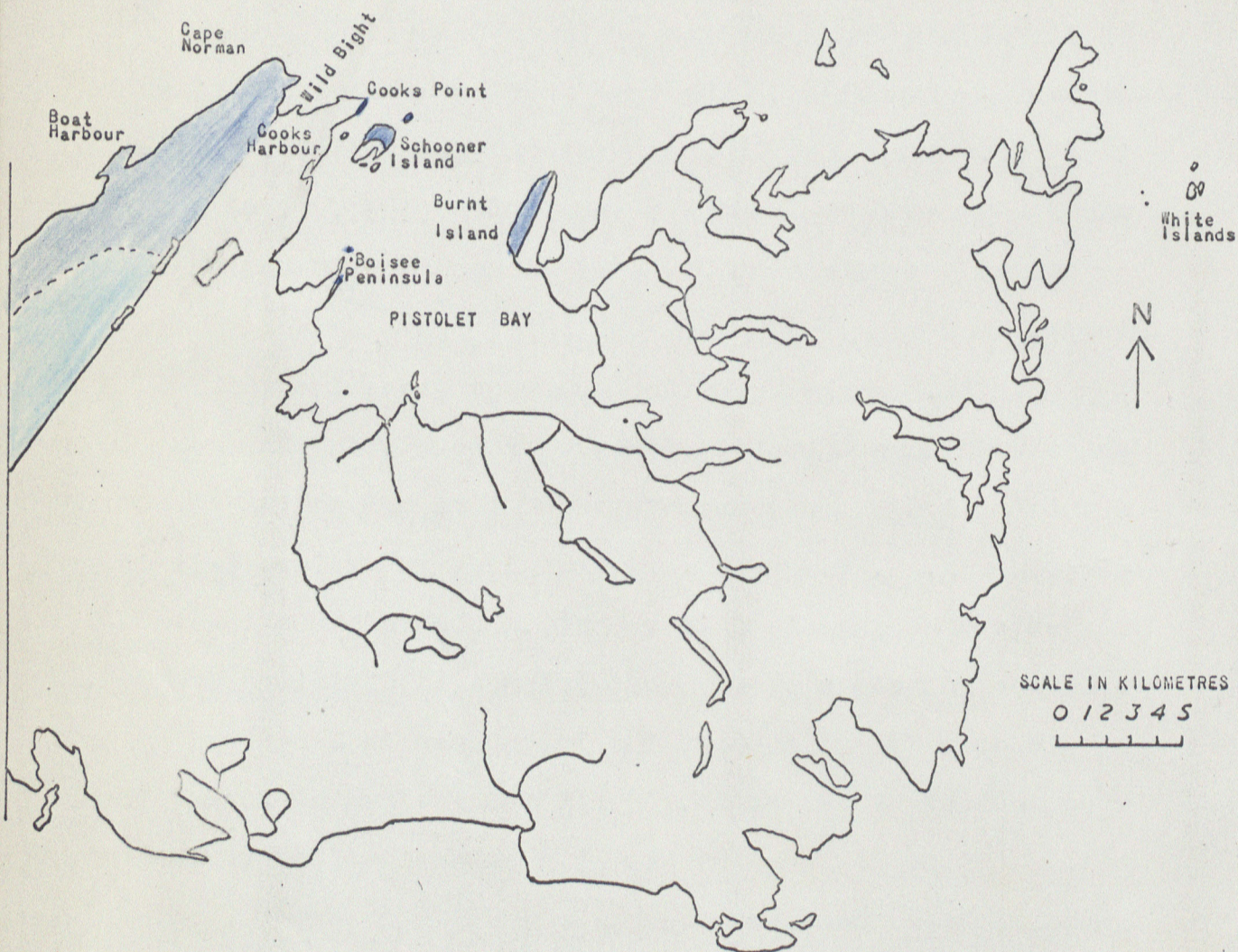
The St. George Formation outcrops along the west coast from Cape Norman southward for 65 km. Richardson (in Logan 1863) considered these beds to belong to divisions E, F, G, and H (only the last two outcrop within the area discussed in this report). Richardson allocated the beds on Schooner and Burnt Islands to divisions H and I.

Cooper (1937) thought the limestones in Hare Bay were equivalent to the St. George and Table Head formations but in the areas where his and the author's maps overlap no St. George beds are found.

Kindle (1945) collected fossils from all but one of the outcrop areas of the St. George Formation.

The largest outcrop of the St. George Formation is in a belt about 3 km wide along the west coast. (Fig. 4). Outcrops of about 3 sq. km are also found on Schooner and Burnt Islands. Smaller exposures occur on Boisee Island and Peninsula and a thin fault slice on the eastern side of Cooks Point.

PISTOLET BAY AREA



Distribution of the St. George Formation

Well exposed



Poorly exposed



Fig. 4

The St. George Formation is best exposed between Cape Norman and Boat Harbour where about 100 m of beds outcrop. Although neither the top nor the base is seen here, the beds are thought to belong to the upper part of the St. George Formation because of lithological similarities with the upper part of the type section.

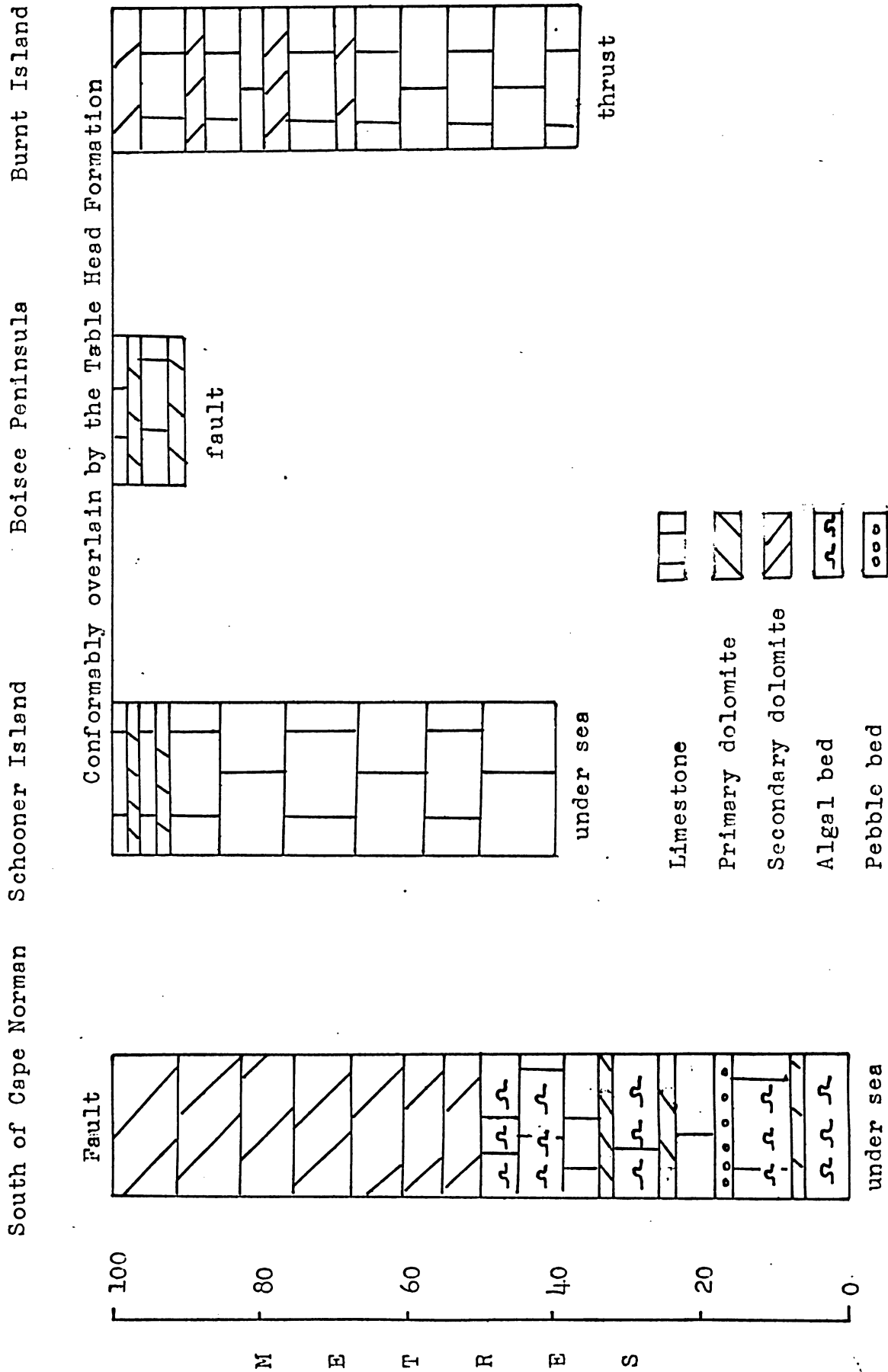
The lower 50 m are mainly grey weathering medium grey limestone but a few cream weathering dolomite beds are present. The limestone is mostly micrite, calcilutite and calcisiltite with scattered fossils, but there are a few lenses of biomicrite, and calcirudite and calcarenite are also present. The beds of the lower part are characterised by abundant algal structures (Plate 4). Intraclast breccias are common and desiccation cracks occur in some of the beds.

The upper 50 m of the St. George Formation on the west coast has been dolomitised. The junction between dolomitised and non-dolomitised beds is irregular and does not follow any stratigraphic horizon. The dolomite beds are brown weathering and have a saccaroidal texture and feel. Vugs, often lined with white crystals of dolomite are common.

All the other exposures which have yielded lower Ordovician fossils (except a small slice near Cooks Point) are visibly overlain by the Table Head Formation

Fig. 5

SECTIONS OF THE ST. GEORGE FORMATION



and thus definitely belong to the uppermost part of St. George Formation. The exposures on Boisee Peninsula and on Boisee and Schooner Islands consist of light grey limestone, indistinguishable from that of the Table Head Formation, followed by about 10 m of interbedded creamy weathering dolomite and grey limestone. The highest dolomite bed is arbitrarily taken as the top of the St. George Formation. The junction is gradational and there is no sign of a disconformity, although elsewhere in Newfoundland the St. George and Table Head formations are separated by disconformity.

No dolomite beds are present on Burnt Island but the limestones in which Kindle (1945, p.5) found Lower Ordovician trilobites are white weathering at the bottom and mottled, slightly dolomitised at the top whereas the overlying beds of the Table Head Formation in which Middle Ordovician fossils occur are grey weathering dark limestone. Kindle thinks the junction is a disconformity but the junction appears to the author to be conformable.

The calculated thickness of the beds on Burnt Island is 65m.

Paleontology

Fossils are abundant in the limestones of the St. George Formation on the west coast but they are rare elsewhere in this formation. Only partial outlines of fossils can be found in the dolomitized beds. Trilobites are common and tend to occur abundantly in lenses. Bathyuriscus timon Billings is present in large numbers but only the thorax and pygidium can be found. Cross sections of cephalopods are common but the fossils are difficult to extract.

Stromatolites are common along the west coast. They usually occur in colonies with individual stromatolites about 75 cm in diameter and 50 cm high.

All fossils collected by the author are now at the University of Ottawa with the exception of the conodonts which are in the possession of C.R. Barnes at the University of Waterloo.

Kindle (1946) recorded the following fossils from the St. George Formation.

Bathyuriscus timon (Billings)

Bathyurellus marginatus (Billings)

fraternus (Billings)

glandicephalus (Whitfield)

Bobbocephalus sp.

Gignopeltis rara (Billings)

Illaenus fraternus (Billings)

Niobe sp.

Onchonotus globosus (Billings)

Petigurus nero (Billings)

The author found

Bathyuriscus timon (Billings)

Illaenus fraternus (Billings)

Petigurus nero (Billings)

Other fossils found by the author and identified by H. Whittington

Murchisonia simulatrix (Billings)

Ophileta sp.

several cephalopods both straight and coiled.

These fossils suggest a Lower Ordovician age for the St. George Formation.

The following conodonts, found in the outcrop of the St. George Formation on the west coast just north of Board Harbour, were identified by C.R. Barnes.

Acodus oneontensis Furnish

sp.

Acontiodus staufferi Furnish

n. sp.

Distacodus sp. aff. D. stola Lindström

Drepanodus arcuatus Pander

concavus (Branson and Mehl)

homocurvatus Lindström

pandus (Branson and Mehl)

parallelus Branson and Mehl

simplex Branson and Mehl

sp.

Oepikodus sp. cf. O. equidentatus Ethington and Clark

Scandodus n. sp.

Scolopodus cortuniformis Branson and Mehl

filosus Ethington and Clark

quadriplicatus Branson and Mehl

sp. cf. S. triangularis Ethington and Clark

n. sp.

sp.

Ulrichodina n. sp.

sp.

This conodont assemblage suggests an upper Lower Ordovician age for the beds on the west coast. (Barnes personal communication).

Age and correlation

The beds described above contain lower Ordovician fossils and may thus be correlated with the St. George Formation. The Table Head Formation conformably overlies the St. George Formation thus reaffirming the Lower Ordovician age of the beds and suggesting that these probably correspond to the upper part of the St. George Formation. The beds at and south of Cape Norman are also thought to belong to the upper part of the St. George Formation because of the conodonts found in them.

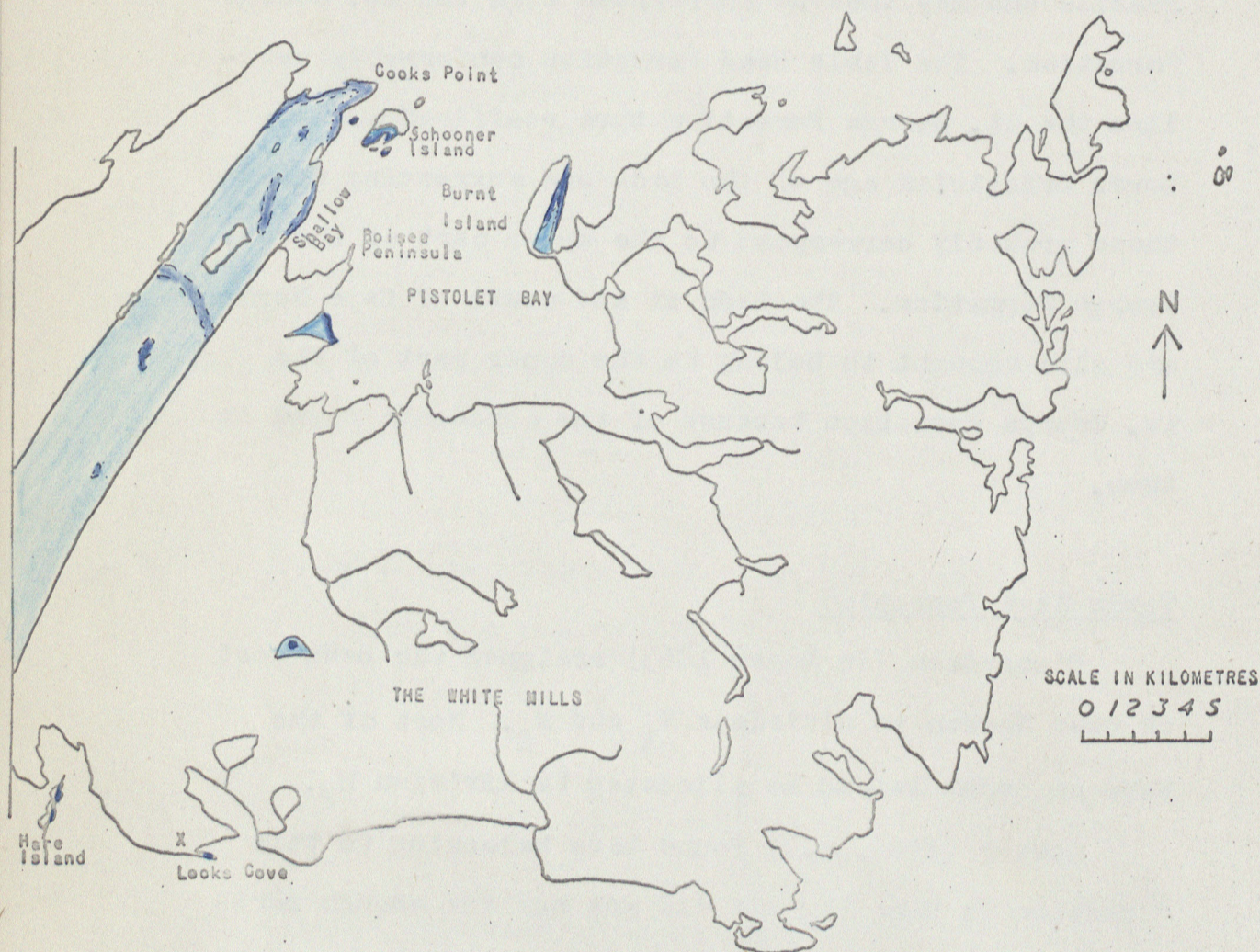
Table Head Formation

Richardson (in Logan 1863) assigned the beds east of Cape Norman to divisions N_1 and N_2 . Most of the beds on Burnt Island he allocated to division M_2 .

Cooper (1937, p.7) found beds belonging to this formation in Hare Bay but did not map far enough north to encounter them in Pistolet Bay. He noted the small patches of limestone on Hare Island, at Locks Cove and north of Howe Harbour. These he placed in his Hare Island Limestone which he correlated with the Table Head Formation.

Kindle (1945) collected fossils from many of the limestones in Pistolet Bay and thus separated those beds of Lower Ordovician age, (St. George Formation) from those of Middle Ordovician age (Table Head Formation).

PISTOLET BAY AREA



Distribution of the Table Head Formation

Well exposed
 Poorly exposed

Fig. 6

The Table Head Formation outcrops in a belt running southwest from Cooks Point, and on Schooner and Burnt Islands (Fig. 6). Smaller exposures are found on Boisee Peninsula, Hare Island, Locks Cove and north of Howe Harbour. Gillis (1965) thinks there are exposures of the Table Head Formation near Quirpon.

Wherever exposed, the beds of the Table Head Formation are fine grained, blue grey or tan limestone which weathers blue grey. The beds on Cooks Point, and the northern parts of Schooner and Burnt Islands weather to a hackly surface whereas those further south weather to a smooth surface along the coast. Inland the formation weathers to an angular gravel. The bedding is commonly massive and in many places lacks visible stratification. The remains of algal mats are locally the only indication of the bedding. Intraclasts were noted only at one place and no sedimentary structures were seen.

Shale lenses occur with the limestone in Wild Bight and just to the south of Cooks Harbour. The two in Wild Bight are calcareous and very fossiliferous whereas those south of Cooks Harbour are not. It is thought that these shale lenses indicate that the beds in which they are found belong to the uppermost part of the Table Head Formation because shale beds overlies the formation in this area and because in the type section the beds become more argillaceous higher in the section.

The base of the formation rests conformably on the St. George Formation and is visible on Schooner and Burnt Islands and on Boisee Peninsula. The top of the Table Head Formation is disconformably overlain by the shales of the Goose Tickle Formation. This contact can be seen on the southern part of Schooner and Burnt Islands and on the west side of Pistolet Bay (Plate 5). The bedding in both formations is parallel but the shale fills cracks in the limestone.

The section of the formation on Burnt Island is 30 m thick but faulting makes this figure unreliable. A similar thickness is found on Schooner Island where the beds are also much faulted. In both places the lower and upper contacts of the formation are seen. An apparently greater thickness is present between Wild Bight and Cooks Point but the succession lacks stratigraphic control, the bedding is poorly marked and there are numerous faults.

It is often impossible to distinguish Table Head beds from those of the St. George Formation in small outcrops without the aid of fossils. The Table Head beds lack dolomite and shallow water features. The presence of shale lenses suggest that beds belong to the Table Head Formation.

Paleontology

Fossils are rare in the Table Head Formation except in the two calcareous shale lenses in Wild Bight where they are plentiful. Fossils are relatively abundant along the road to St. Anthony just west of the junction with the Cooks Harbour road.

Kindle (1965, p.7) reported the following trilobites from the Table Head Formation.

<u>Agnostus</u>	Billings
<u>Anisopetus glacialis</u>	Billings
<u>Apothophyla aurora</u>	Billings
<u>Illaeus consumilis</u>	Billings
<u>Pseudonera barrandei</u>	Billings
<u>Nileus scrutator</u>	Billings
<u>Rabergia schlotheimi</u>	Billings
<u>Raphiophorus semicostatus</u>	Billings
<u>Telephus americanus</u>	Billings
<u>Triarthrus fisheri</u>	Billings

The author found the following fossils which were identified by H. Whittington.

<u>Agnostus</u> sp.	
<u>Illaeus fraternus</u>	Billings
<u>Nileus scrutator</u>	Billings
<u>Triarthrus fisheri</u>	Billings

The following fossils were also found and identified by the author

<u>Strophomena</u> cf <u>auroa</u>	Billings
<u>Pleurothis</u> of <u>convexa</u>	Cooper
<u>Orthis</u> <u>delicatula</u>	Cooper
<u>Murchisonia</u> <u>augusta</u>	Billings

Ostracods were found in material which is lithologically identical to the Table Head limestone in the limestone breccias in Pistolet Bay.

These were identified by M. Copeland as

Eoleperditia sp.

Age and correlation

The fossils named above indicate a Middle Ordovician age for the beds which thus belong to the Table Head Formation. The fossils in the Goose Tickle Formation are lower Middle Ordovician and this means that the beds of the Table Head Formation must also be lower Middle Ordovician.

The Table Head Formation in Pistolet Bay consists of massive limestone with rare shale lenses. This is best correlated with the lower division of the Table Head in the type section. This division of the type section is massive limestone but contains no shale lenses. The middle and upper divisions of the Table Head Formation in the type section are respectively interbedded shales and limestones and black carbonaceous shales. No interbedded shales and limestones are found in Pistolet Bay.

The lower division in the type section is 250 m thick whereas the limestone in Pistolet Bay is apparently only 30 m thick. This is probably due to the limestone being laterally replaced by shale of the Goose Tickle Formation, (see p.29).

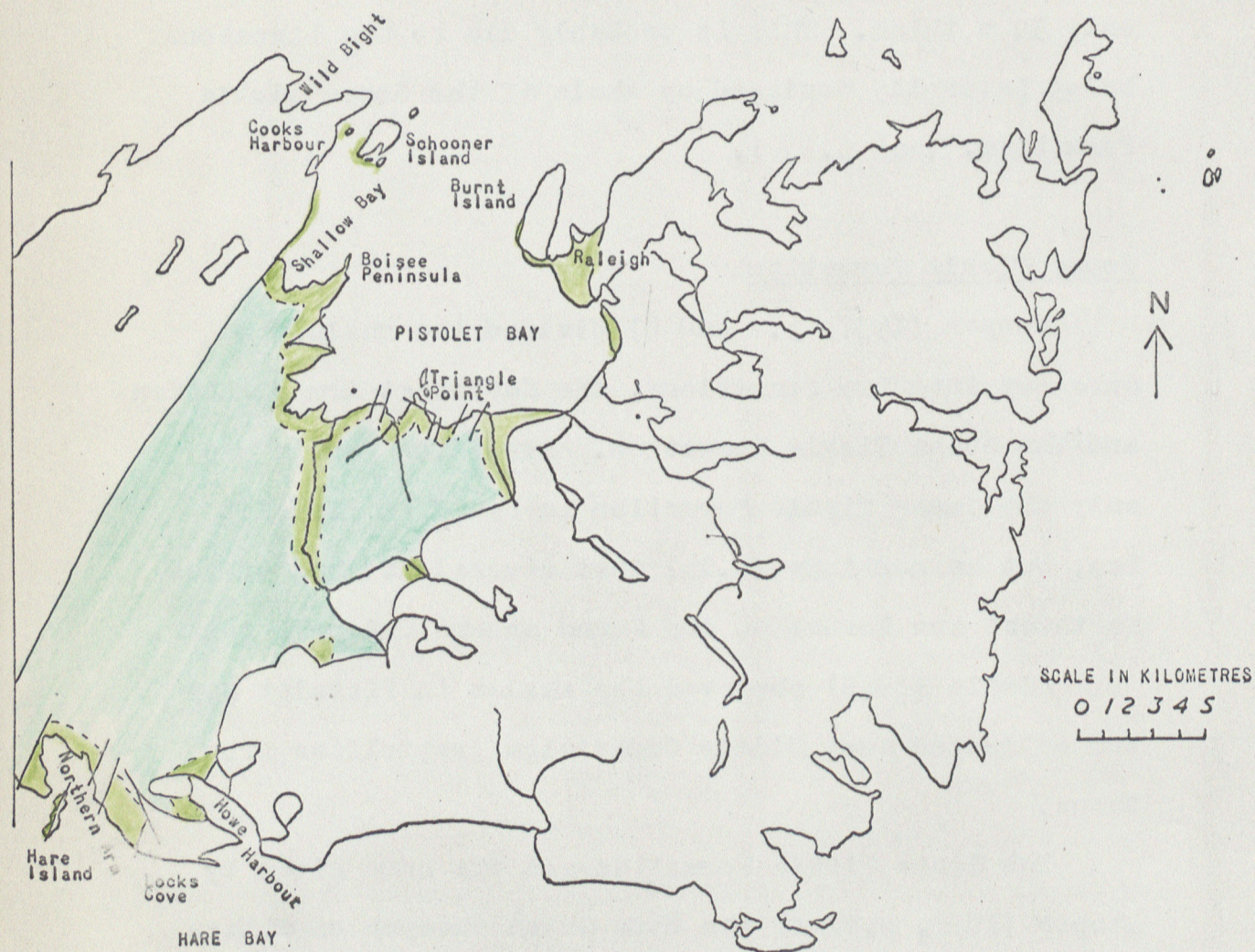
Goose Tickle Formation

Cooper (1937, p.7 and 8) divided the shales in Hare Bay into two formations, the Northwest Arm Formation and the Goose Tickle Formation. According to his map only the Goose Tickle Formation is found in Pistolet Bay, but he mentions (p.14) that several patches of the Northwest Arm Formation are found around Triangle Point.

Kindle (1945) observed the shales in Pistolet Bay and collected some Middle Ordovician graptolites from there.

The Goose Tickle Formation was the name given by Cooper (1937, p.8) to the beds which outcrop on either side of Goose Tickle in the western part of Hare Bay, just south of the area covered by this report. The beds in the type section lie disconformably on the Table Head limestone, and consist mainly of grey, brown, layered shale, with graded and convolute bedding. A limestone breccia (limestone clasts set in a shale matrix) is found a few metres above the base, and near the top is a conglomerate of black and green shale pebbles. Stratigraphically higher beds are covered by the sea but the

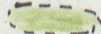
PISTOLET BAY AREA



Distribution of the Goose Tickle Formation

Fig. 7

OUTCROP



AREA UNDERLAIN BY GOOSE TICKLE OR
NORTHWEST ARM FM.

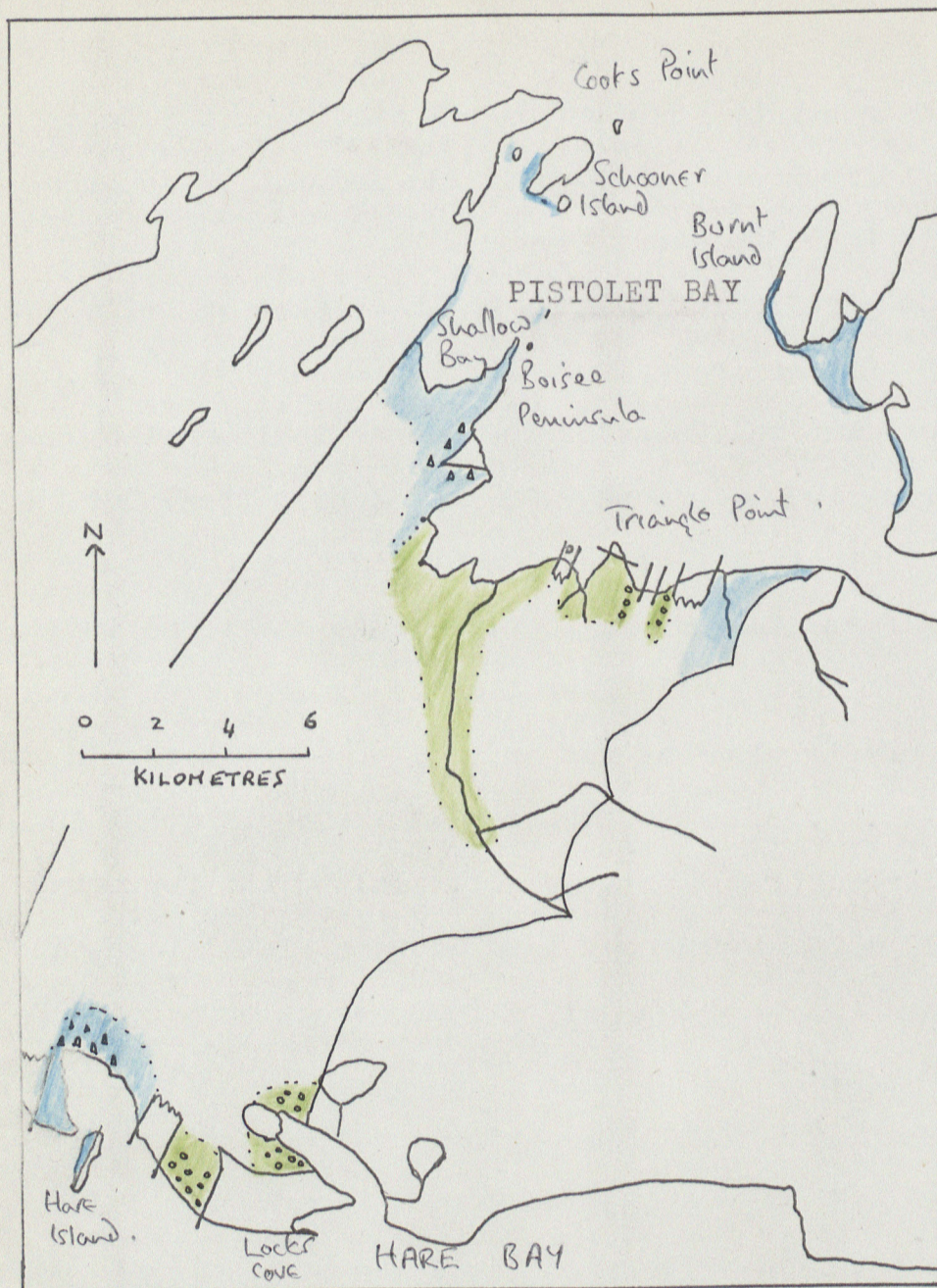


same beds can be found along the strike on the west side of West Brook and on Goose Tickle Point. These beds contain thin limestone layers.

Cooper did not measure the type section but about 1000 m of beds are exposed there. Cooper (1937, p.8) measured the thickness of the Goose Tickle shales exposed in Spring Arm and found 2000 feet (650 metres) but the upper contact is faulted. He stated that the Goose Tickle Formation may be 5000 feet (1600 metres) thick.

The Goose Tickle Formation is exposed along the shore of Pistolet Bay and on some of the islands in the bay (Fig.7). The beds outcrop on the south coast in Howe Harbour and Northern Arm. Inland the formation underlies the low marshy land between Pistolet Bay and Northern Arm in which only a few poor exposures are found in streams.

The Goose Tickle Formation rests disconformably on the Table Head Formation on Burnt and Schooner Islands (Plate 5). The shale fills crevices in the limestone but rests without angular discordance on the pitted surface. The lowest 3 m or so are calcareous argillite with alternating light and dark laminae but no bedding plane fissility. Above this comes a considerable thickness of greywacke and shale (Plate 6). These rocks



Conglomerate beds.....	
Mostly shale.....	
Limestone breccia.....	
Shale and greywacke.....	

FACIES OF THE GOOSE TICKLE FORMATION

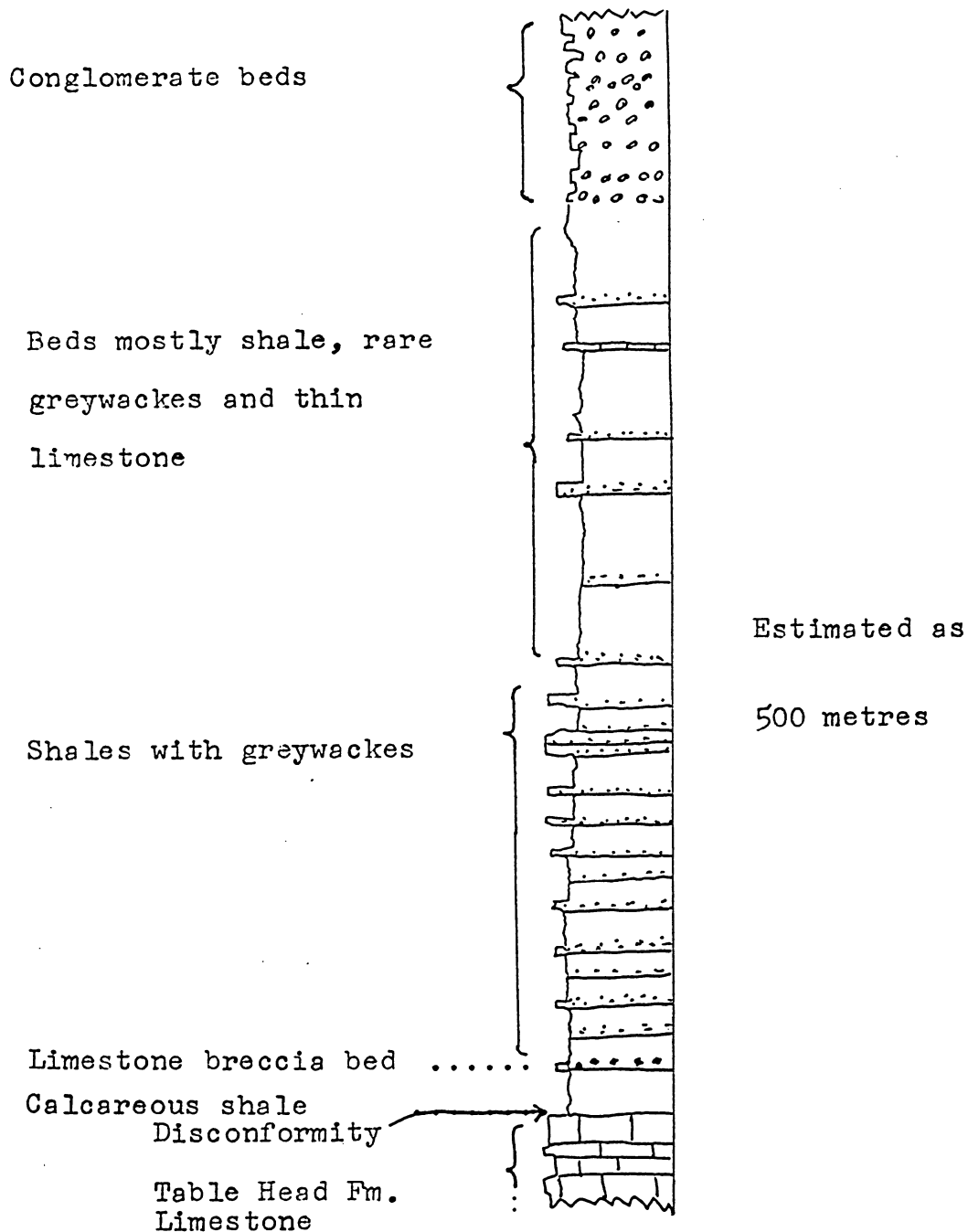
are grey on fresh surfaces and grey brown on weathered surfaces due to the presence of ankerite. The greywacke beds vary in thickness from 10 to 50 cm. These become rarer higher in the section and the shales become more calcareous. Ripple drift and convolute bedding are common.

A limestone breccia bed is found at several localities about 20 m from the bottom of the formation but it does not form a continuous horizon (Plates 31-33).

A few thin limestone beds are present within the shale in the middle part of the formation. At the top of the formation shales and interbedded conglomerates occur (Plate 34). The conglomerates have rounded clasts of black and green shale, the same lithology as that found in the Northwest Arm Formation, and angular blocks of limestone. The matrix of the shale is grey calcareous shale similar to the shale of the beds separating the conglomerates.

The total thickness of the formation is estimated as 500 m but it may be twice that. Higher beds of the formation are overlain by the thrust Maiden Point Formation or lie below the sea.

Higher beds not exposed



COMPOSITE SECTION OF
THE GOOSE TICKLE FORMATION

Fig. 9

Paleontology

Graptolites are easy to find in the Goose Tickle Formation though cleavage makes it difficult to obtain complete specimens. Segments of orthocerids were found in the breccias along with some ostracods. Kindle (personal communication) found the following graptolites, which were identified by H. Johnson.

Climacograptus antennarius

Climacograptus cf bicornis

Dicellograptus sp.

Didymograptus sagitticaulis

extensus ?

Glossograptus ciliatus

Isograptus caduceus

Nemagraptus sp.

Kay (personal communication) found the following graptolites which were identified by J. Riva.

Climacograptus antiquus var. lineatus Elles and Wood

Didymograptus cf nicholson Lapworth

Glossograptus cilliatus Eamons

The author found the following:

Climacograptus antiquus var bursifer ^x Lapworth

Dicellograptus sp.

Dictynema sp.

Didymograptus cf nitidus Lapworth

Didymograptus cf hirundo Lapworth

cf spinosus

Glossograptus echinatus Eamons

Phyllograptus anna

Illiciformis Hall

typus

Tetragraptus quadribrachiatus ^x Hall

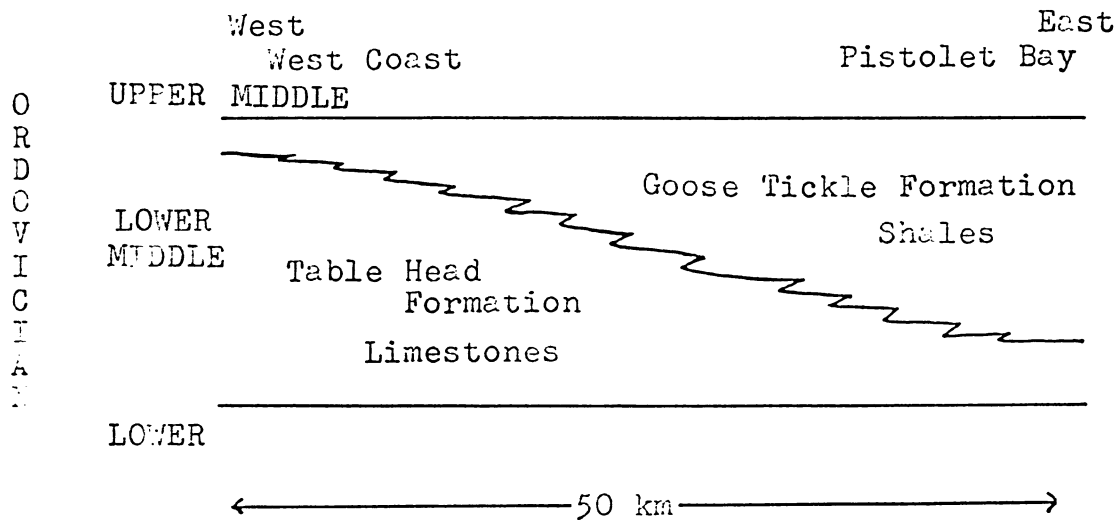
x Identified by L.M. Cumming, others
identified by the author.

Ostracods

Eoleperditia sp. Identified by M. Copeland.

The arthropod Caryocaris curvilata^{Gurley} was found by the author in several places. The only other fossils found were an inarticulate brachiopod and a section of a crinoid stem.

These fossils indicate a lower Middle Ordovician age for the Goose Tickle Formation.



Stratigraphic relationship of Table Head and Goose Tickle Formations

Fig. 10

Age and stratigraphic position

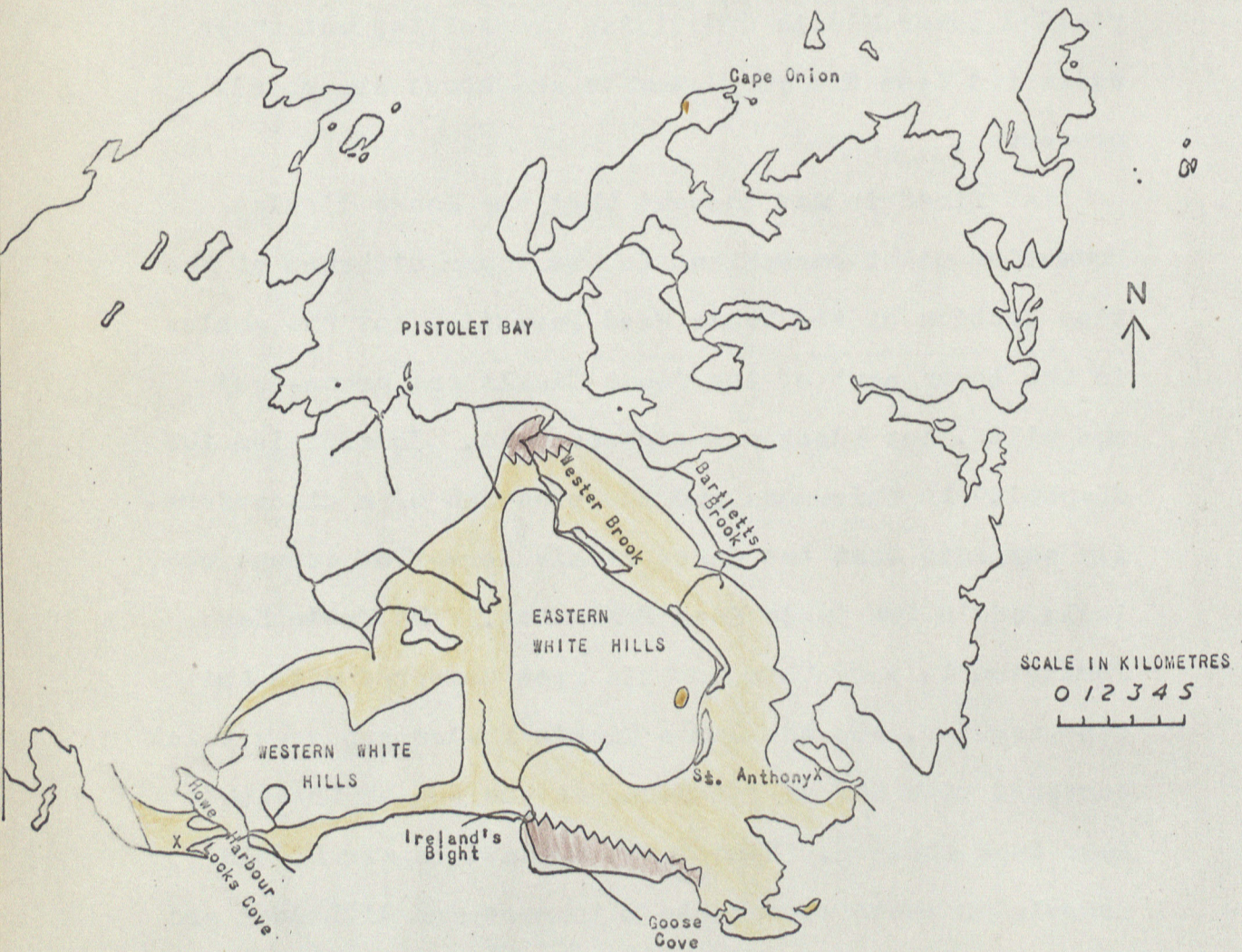
All parts of the Goose Tickle Formation have yielded lower Middle Ordovician graptolites but those collected from the conglomerate and above are poorly preserved.

At first it was thought that the Goose Tickle Formation might correspond to the Upper Division of the type section of the Table Head Formation but the shales in the lower part of the Goose Tickle are brown-grey and silty, not black and carbonaceous. In addition the disparity in thickness and the presence of a disconformity suggests that the Goose Tickle Formation cannot be included in the Table Head Formation. The Table Head Formation is very thin in this area compared with the type section, and the Goose Tickle shales are very thick compared with the shales found at the top of the Table Head type section. Since both formations are Middle Ordovician these changes in thickness and lithology are best explained by a facies change from west to east. The area of shale deposition moved westward (Fig. 10).

Correlation

The Englee Formation in Canada Bay (Betz 1939) is probably equivalent to the Goose Tickle but it has more limestone and fewer greywacke beds than the type section at Goose Tickle. At Port au Port in Southwestern Newfoundland shales with siltstones lie conformably on the Table Head limestone, and a limestone breccia is found within these shales not far from the base (Table 2).

PISTOLET BAY AREA



Distribution of the Goose Cove Formation

- AMPHIBOLITES
- SLIGHTLY METAMORPHOSED VOLCANIC BEDS

Fig.11

Allochthonous Sequence
Goose Cove Formation

Cooper (1937, p. 24) referred to the rocks which surround the White Hills as the Goose Cove Schist. Because they outcrop around the White Hills Ultrabasic intrusion Cooper concluded that they form an aureole to this intrusion and are in sedimentary contact with the Maiden Point Formation. The author has changed the name to Goose Cove Formation and does not refer to them as schists because many of the rocks are gneissose or only slightly metamorphosed volcanic beds. The gneissose and schistose rocks are amphibolites.

The best exposures of the amphibolites are found along the cliffs west and north of Goose Cove and in some road cuttings in that area (Fig. 11). A small fault-bounded outcrop of contorted amphibolite is found on the east side of Cape Onion Peninsula.

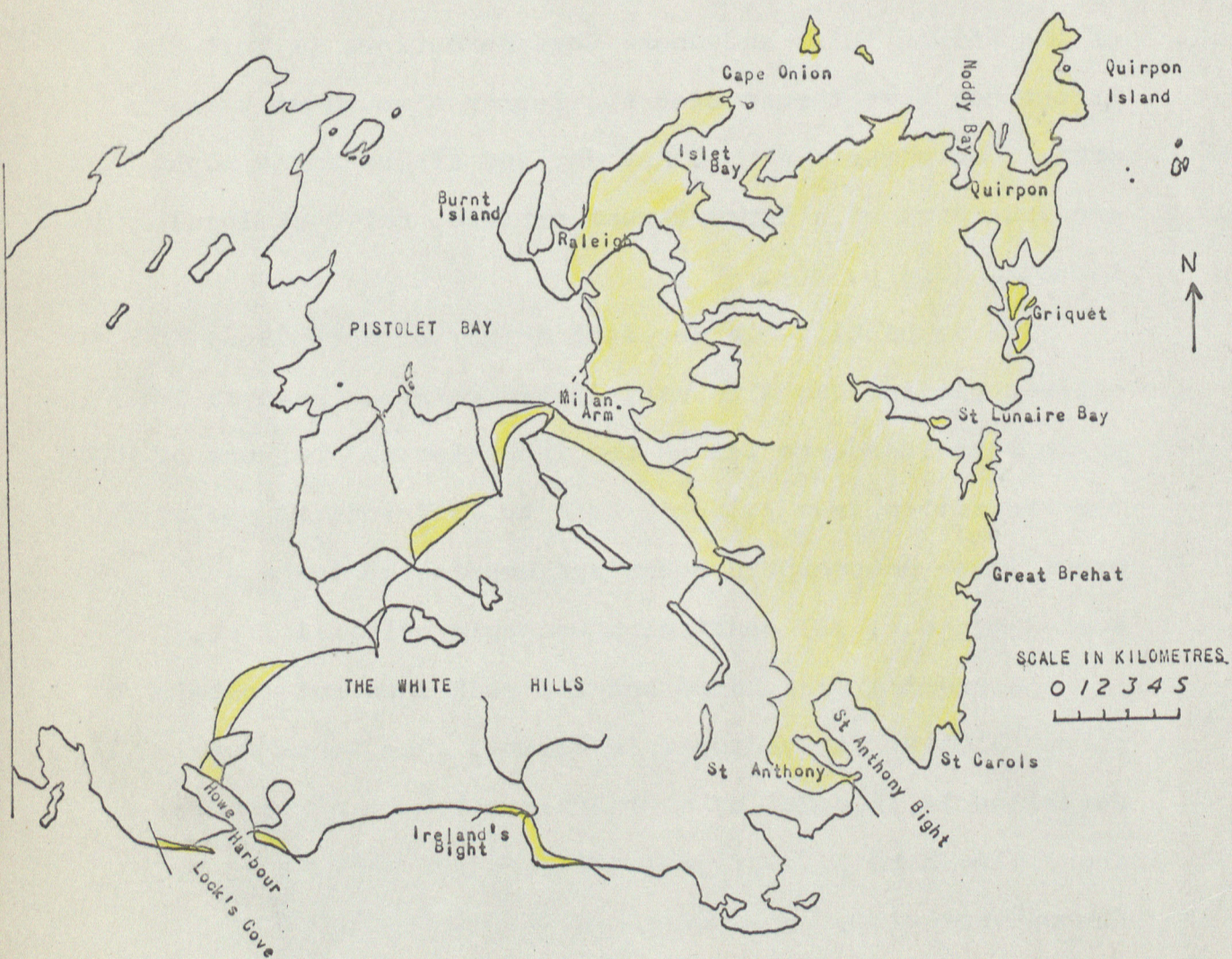
The beds of the formation adjacent to the ultrabasic intrusion are gneissose but away from it they grade into schistose rocks and then slightly metamorphosed volcanic beds. The gneissose rock has a salt and pepper appearance and is massive. Slightly altered volcanic beds clearly showing original pillow structures occur between Ireland's Bight and Goose Cove. Shale laminae are present in the volcanic and schistose rocks.

The amphibolite has been visibly thrust over the Maiden Point Formation at Ireland's Bight and St. Anthony, and the only satisfactory explanation of the relationship of the Maiden Point and Goose Cove Formations is that the latter has been thrust over the former throughout this area. The thrusts at St. Anthony and at Ireland's Bight are thus part of a large thrust surface, not just local thrusts, (See p. 86).

The amphibolite is composed mainly of hornblende and altered plagioclase with very little quartz. Because the grain size increases toward the intrusion and because of the transition from volcanic beds to schistose to gneissose rocks these metamorphic rocks are considered to be an aureole (see p. 72) confirming Cooper's original idea.

No fossils were found and the rock does not contain enough biotite for radiometric dating. The Goose Cove Formation is intruded by peridotite which is similar to those elsewhere in Newfoundland which are thought to be Lower Ordovician. The nearest radiometrically dated intrusion is in Gaspé and this has lowermost Ordovician age (p. 35). This suggests that the Goose Cove Formation is Lower Ordovician or older.

PISTOLET BAY AREA



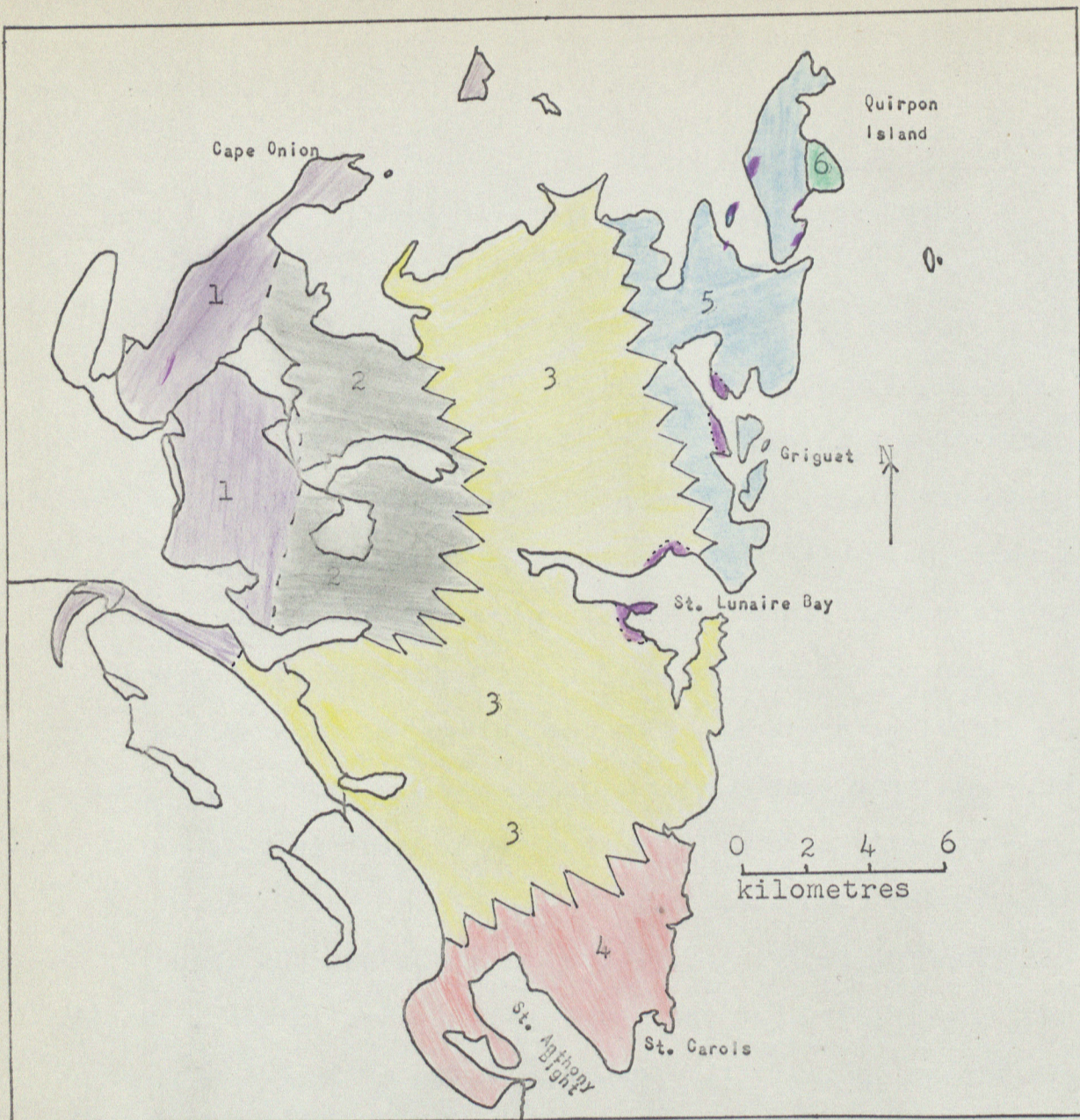
Distribution of the Maiden Point Formation

Maiden Point Formation

Coarse greywackes and slates in Hare Bay were called the Maiden Point Sandstone by Cooper (1937, p.9). The type section at Maiden Point on the south side of Hare Bay was estimated by Cooper as 6000 ft (2000 m) and consists of coarse grained greywacke which weathers grey green and black, and grey shale, lava, and tuffs. No fossils have been found in the type section. Because the formation contains less than 50% sandstone the author has changed the name to Maiden Point Formation. The beds in Pistolet Bay ascribed to the Maiden Point Formation have the same coarse greywacke as the type section. However, more volcanic beds and limestone are present in this area than in the type section.

The Maiden Point Formation occupies all the area east of Pistolet Bay and southwards to St. Anthony. Small patches of the formation outcrop on the northwest side of the White Hills and the formation can be seen underlying thrust volcanic rocks and gneiss on the north shore of Hare Bay, (see Fig. 12).

The Maiden Point Formation is composed of slate, greywacke, and volcanic rocks with minor amounts of limestone and mica schist. The lowest beds of the formation outcrop on the east side of Cape Onion Peninsula, in Milan Arm, and on the east side of the White Hills, and have all been thrust over the underlying Goose Tickle Formation.



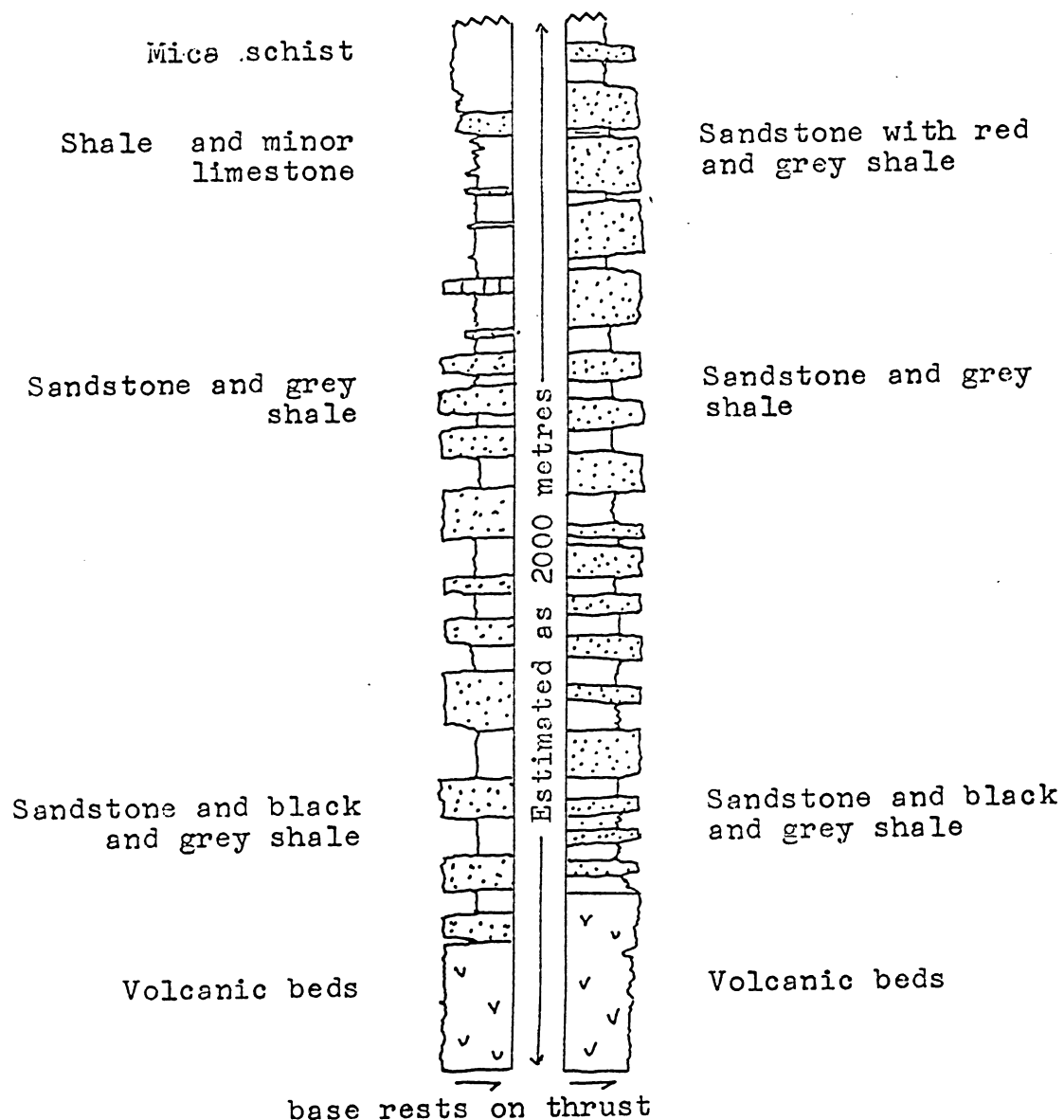
- | | |
|---|---------------------------------|
| 6 | Greenschist |
| 5 | Shale and minor limestone |
| 4 | Sandstone, red and grey shale |
| 3 | Sandstone, and grey shale |
| 2 | Sandstone, black and grey shale |
| 1 | Volcanic beds |

LITHOLOGIES
OF THE MAIDEN POINT FORMATION

These lowest beds are a series of lava flows, pillow lavas, agglomerates, tuffs, and interbedded sandstone and shale. The lava flows vary in thickness from less than a metre to more than 10 m. They are highly chloritised and it is difficult to distinguish any of the original minerals. Spectacular pillows can be seen in the cliffs on Cape Onion Peninsula (Plate 9). The agglomerates (Plate 12) consist of round lumps of volcanic material in contact with one another, set in a matrix of crystalline calcite. Many of the beds in this part of the formation are soft green material which may originally have been lava or tuff. Of the beds here the least altered are the agglomerates, but they are too fine grained for identification by optical methods. The other rocks are all so altered that they may well be described as greenstones. Thin sections of the lava flows contain fragments of devitrified glass, and calcite amygdales and much opaque material. It is thought that these flows were acid. Others which were basic or intermediate contain plagioclase relicts in a mass of chlorite. The tuffs are a mass of fine grained crystals, probably quartz and feldspar but which are too small and too altered for certain identification. Thin veins of secondary calcite cut the tuffs.

Cape Onion to Quirpon

Wester Brook to St. Anthony



COLUMNAR SECTIONS OF
THE MAIDEN POINT FORMATION

Fig.14

The volcanic beds diminish and slates and greywackes increase eastwards and upwards in the formation, (the enveloping surface of the folds dips gently eastward) The slates immediately above the volcanic beds are grey and black and contain much pyrite but higher in the section the black slates disappear. Red and grey slates occur around St. Anthony (Fig. 13). The greywackes usually occur in beds about 1 m thick and are commonly coarse. The lowest layers of some of the beds have pebbles 3 cm long and the beds are often graded. The slates and greywackes are interbedded with minor amounts of volcanic material.

The greywacke beds are relatively common south of St. Lunaire Bay, especially round St. Anthony Bight Where they comprise about 75% of the total, but they are rare on the northeast. There the beds are mostly slate with thin limestone beds. A 20 m argillaceous limestone bed crops out in Noddy Bay and a thinner one south of Griquet. Breccia beds of plates of limestone occur on Quirpon Island. These are probably intraformational breccias, the clasts being derived from some of the thin limestone beds. Volcanic beds occur within the slate, the largest outcrop areas are shown on Fig. 13.

It has been suggested (Gillis, 1965) that the shale and limestone belong to the Table Head and Goose Tickle formations but that the associated volcanic and greywacke beds belong to the Maiden Point

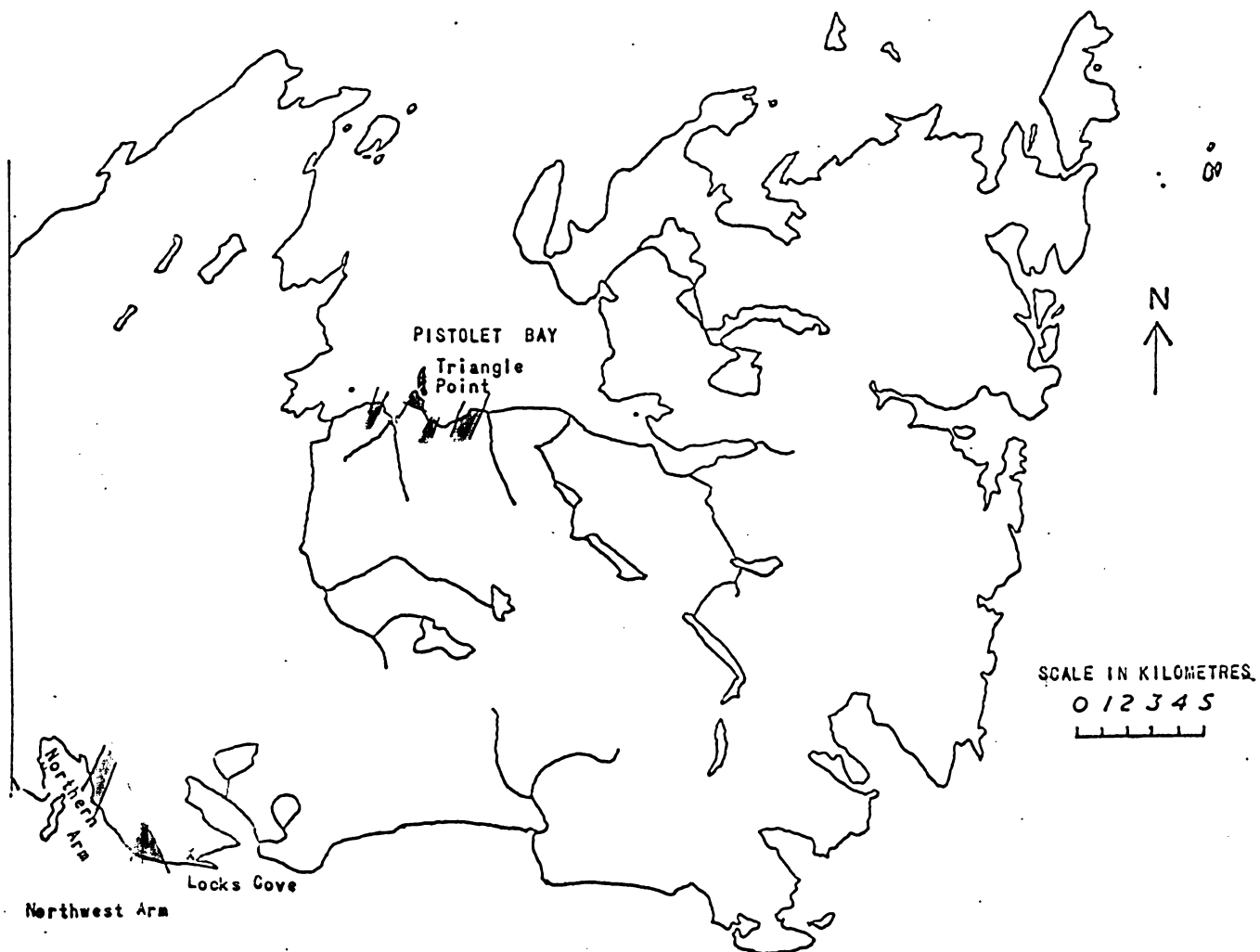
Formation and that they are separated by a thrust. The author agrees that some of the lithologies, the slate and limestone, resemble those in the Goose Tickle and Table Head formations, although the limestone is more argillaceous than in the Table Head Formation and the contacts between the shale and limestone are gradational over greater distances, and the greywacke beds in the slate are coarser than those in the Goose Tickle Formation but not as coarse as those in the Maiden Point Formation. The author thinks that volcanic beds and coarse greywackes are interbedded with the slate and limestone and sees no evidence for a thrust separating them. A better explanation is that the slate and limestone belong to a finer grained facies of the Maiden Point Formation.

On the eastern part of Quirpon Island the slates grade into phyllites and then to mica schist.

Age and Correlation

No fossils have been found in this formation in spite of intensive searching. The formation is thought to be Lower Ordovician or older because it is intruded by peridotite (on Milan Arm and Quirpon Island). Peridotites elsewhere in Newfoundland have intruded Lower but not Middle Ordovician strata (Williams Personal communication). The nearest radiometrically dated intrusion, Mount Albert gave a lowermost Ordovician age (MacGregor, 1963). This suggests that the Maiden Point Formation must be Lower Ordovician or older.

PISTOLET BAY AREA



Distribution of the Northwest Arm Formation

Betz (1939) mapped similar beds in Canada Bay and called them the Canada Head Formation. This formation outcrops along the east coast between Canada Head and Hare Bay (see Fig. 33).

The Botwood Group is somewhat similar to the Maiden Point Formation but contains more red beds and much more current bedding. The only other beds which are similar are some of the greywacke sandstones found in the Humber Arm near Cornerbrook. These are thought to be Cambrian by Stevens who has worked in the area (personal communication).

Northwest Arm Formation

Cooper (1937, p. 8) gave the name Northwest Arm Formation to a succession in Hare Bay and Pistolet Bay characterised by a great diversity of lithology: shale, sandstone, limestone, and chert. The type section is in Northwest Arm in Hare Bay, where about 160 m of highly deformed beds are exposed. The base and top are faulted against the Table Head limestone and the Goose Tickle shale. Only cleavage can be seen in the shale of the Northwest Arm Formation but bedding planes are shown by the intercalated beds of sandstone and the lines of boudins. No fossils have been found in the type section. Cooper (1937, p. 8) concluded that both the Northwest Arm and the Goose Tickle Formations

lie conformably above the Table Head Formation and this led him to think that the Northwest Arm Formation was a local facies of the Goose Tickle Formation.

The formation crops out in three places on the north side of Hare Bay and in four places in Pistolet Bay (Fig. 15). All outcrop areas are faulted or thought to be faulted against the Goose Tickle Formation. Because of the occurrence both to the north and south, and because the strike of the beds is NE it is probable that beds of this formation underlie parts of the lowlying area between Pistolet Bay and Northern Arm.

The outcrops of the Northwest Arm Formation in Pistolet Bay and Hare Bay suggest that the formation can be separated into members, a lower one with abundant calcareous sandstone and an upper one consisting mainly of ^hsale (Plates 7 and 8). The lower member is characterised by its highly deformed assemblage of limestone, sandstone, chert and shale and is found in the western exposures in Pistolet Bay and Hare Bay. The sandstone beds vary from several centimetres to a metre in thickness, and some are greywackes whereas others are almost calcarenites. These beds are considerably folded and sole structures indicate that many of the beds are upside down. Faulting and boudinage are also present and it is unusual to be

able to trace a bed for more than a few metres. Chert occurs in a wide variety of colours; green, brown, dark red, grey, or black. The lack of internal structures suggests an inorganic origin for the chert.

Black and green shales occur between the more competent beds of sandstone and chert. The colouring of these shales is patchy and beds of one colour can only be traced for a short distance. The shale content of the formation increases upwards in the section and in the upper member, exposed in the eastern patches of the formation in Pistolet and Hare Bays, are a few thin limestone beds, no sandstone beds. The beds in the upper member appear to be less deformed than those in the lower member but this is probably because no competent beds are present to show the bedding.

Cooper estimated the thickness of the Northwest Arm Formation to be 500 ft (160 m) but, as he noted, this figure is unreliable because of folding and faulting. The writer considers this figure is probably an over-estimate for the lower member is only about 30 m thick and the upper one probably not much thicker. It is suggested that 70 m is a more accurate estimate of the thickness of the Northwest Arm Formation.

Age and stratigraphic position

Fossils are not abundant in the Northwest Arm Formation. None were found in Hare Bay but all four patches of this formation in Pistolet Bay yielded graptolites of Lower Ordovician age. The most rewarding graptolite locality is west of Triangle Point where the sea is nearest the road. The only fossils found were:

Staurograptus dichotomus

Dictyonema cf flabelliforme

Both members of the Northwest Arm Formation have yielded graptolites indicating a Lower Ordovician age. The Northwest Arm Formation cannot lie stratigraphically above the St. George Formation because this position is occupied by the Middle Ordovician Table Head Formation close to the outcrop of the Northwest Arm Formation. Nor can it lie within the St. George Formation because no beds similar to it can be seen even where there are complete sections of the St. George Formation. The lowest part of the St. George Formation is Cambrian so it is also impossible for the Northwest Arm Formation to lie below the St. George Formation. The beds of the two formations are too dissimilar to be local facies equivalents (see p.61). The most reasonable explanation is that the two formations were deposited at the same time but not as near one another as they are now (see p.98).

Correlation

Similar beds were noted by Rodgers (personal communication) just north of Port au Port. R. Stevens (personal communication) mapped chaotic black and green shales near Corner Brook. At both these localities the Northwest Arm type beds are associated with beds like the Maiden Point Formation. Hawley (1957) described beds very similar to the Northwest Arm Formation, from the Champlain Valley, New England. They are Lower Ordovician and have been thrust over Middle Ordovician shales and greywackes similar to the Goose Tickle Formation.

SEDIMENTOLOGY AND PALEO-ENVIRONMENT

The facies developed in the Northern Appalachians have long linear outcrop patterns, always with the same spatial arrangement. The shallow water limestone is found in the west, followed eastward by shale and greywacke (deposited in deeper water) and still further east by shale, greywacke, and volcanic beds. This has led to the idea that the beds were deposited in a linear depression trending approximately SW (Kay 1942).

The sedimentology of the formations in the Pistolet Bay area is described below and it will be seen that the beds in this region have the same facies and facies distribution and are thus thought to have been deposited in a continuation of the Appalachian trough.

This study of the sedimentology of the beds also shows that the facies of some of the beds are very dissimilar and are unlikely to have been laid down as close together as they are now found. The source area, modes of transport and deposition of the sediments are also discussed.

St. George Formation

The St. George Formation in this area consists of limestone interbedded with fine grained dolomite in the lower part and coarse grained dolomite in the upper part. In places the limestone and fine grained dolomite are interbedded in very thin laminae, commonly less than 5 mm thick. Current bedding can be seen on a very small scale with alternate laminae of limestone and dolomite, which shows that the dolomite must be primary or pene-contemporary^{ar}. Penecontemporary^{ar} dolomite can form in the supra-tidal zone under tropical conditions (Shinn 1965; Illing 1965).

The grains of limestone and dolomite are lutite, silt-, and sand-size in the lower part of the formation. Beds with small clasts of limestone and dolomite set in a matrix of dolomite are not uncommon. The clasts are usually 2 cm or less in diameter but one bed contains imbricated clasts 5 cm long. The direction of imbrication is variable.

Ripple marks and desiccation cracks (Plate 24) are present south of Cape Norman and current bedding was seen in calcarenite near the end of Boisee Peninsula.

Hollow chert pebbles have been found at one horizon but the bed is only one pebble thick and the pebbles are not usually in contact. The pebbles are roughly aligned in a NE - SW direction, are mostly 2 cm long and consist of chert and limestone. The pebbles are often indented and cross sections show a concentric structure. They are thought to have grown as concretions in the limestone and to have been subsequently eroded out, rolled into their present position and incorporated again into the limestone.

Many of the beds of the St. George Formation show evidence of having been disturbed by organisms. Worm borings and trails in the beds are emphasized by selective dolomitization in which the trails and burrowed material are dolomitized but the host rock is not.

The beds contain algal structures as much as one metre high (Plate 4). Horizons with smaller algal structures about 30 cm are common. The limestone filling the gaps between individual algae is commonly rich in fossils, looking as though the fossil debris had collected in the hollows between the living algae.

Lenses of limestone rich in fossil fragments occur in several places. The fossils are typical shallow water forms; trilobites, brachiopods and gastropods.(p. 17)

The beds of the upper part of the St. George Formation on the west coast and to a lesser extent on Burnt Island have undergone several post depositional changes; they have been dolomitised (definitely secondary, not penecontemporary^{ar}) to coarse grained dolomite, and chert has replaced some of the dolomite.

Environment of deposition

The presence of algal structures indicates that the water was shallow because modern algae require light for growth. Many modern algae live on tidal flats and it is on the landward side of tidal flats that penecontemporaneous dolomite has been found.

Fine grained dolomite might well have been formed in such an area but desiccation cracks are not as common as would be expected. The intraformational breccias might be due to extra high tides sweeping together flakes which had formed through the desiccation of the supra-tidal flat sediments. The author considers that the St. George Formation was probably deposited in tidal and supra-tidal flats.

Table Head Formation

This formation is massive or bedded in uniform units about 30 cm thick. The limestone of the Table Head Formation is more argillaceous than that in the St. George Formation and the amount of argillaceous material increases upwards causing the limestones to become darker in colour. This is well demonstrated in the section on Burnt Island.

The only sedimentary structure is "algal banding" which appears on the rock surface as a series of discontinuous wavy lines. They are thought to be the remains of algal mats.

Shale lenses are found at the top of the Table Head Formation. Two of these are highly calcareous and very fossiliferous. Several limestone clasts about 15 cm long occur in the limestone above the calcareous lenses and these are the only signs of current activity in the Table Head Formation in this area.

This formation lacks the shallow water features common in the St. George Formation. There is very little evidence of current activity and the massive nature of the beds suggests that the limestone accumulated continuously in a quiet environment, probably below wave base.

Goose Tickle Formation

The Goose Tickle Formation consists mostly of shale and greywacke but limestone breccia is found near the base of the formation and conglomerate near the top.

The shale varies in colour from dark to light grey, commonly brownish due to the weathering of ankerite. Interbedded with these shales are greywackes, usually between 5 and 30 cm thick which are continuous and show no sign of depositional thinning. Many of the greywacke beds are graded but it is rare to find complete gradation from sandstone to shale.

The thicker units of greywacke generally exhibit convolute bedding (Plate 30). The convolutions are restricted to one sedimentary unit, which is convoluted throughout its length, the overlying and underlying beds being unaffected. The anticlines of the convolutions are overturned toward the south. Because of low relief in the exposures of the Goose Tickle Formation most of the under surfaces are hidden but where the latter are exposed small flutes are abundant (Plate 29). All the flutes indicate that the currents moved toward the southwest. Ripple drift cross bedding present in many of the greywacke beds always indicates movement to the

southwest. Other structures typical of turbidity current deposits which are found in these beds are load casts, flames (Walton 1956) and sandstone balls (Plate 28).

Most of the sedimentary structures described above are commonly found in turbidites and it is concluded that these beds were deposited by such currents.

Paleoecology

The lack of benthonic fossils suggests that the depositional surface of the Goose Tickle Formation was hostile to life. The dark colour of the shale indicates that the water was anaerobic.

Graptolites are common in these beds in shales and greywackes. In the shales they lie on the bedding planes, some planes have abundant graptolites whereas others are devoid or almost devoid of them. The irregular distribution of graptolite remains may be explained by recurrent mass mortality possibly due to convective overturn bringing up poisonous waters from the sea bed (Brongsma-Sanders 1948). Alternatively, the irregular graptolite distribution may be caused by variation in the rate of sedimentation.

In greywackes, the graptolites are distributed preferentially throughout the bed and at various angles, but are aligned

in a down current direction. The graptolites in one example were plotted on a rose diagram and the mean direction was to the SW. These graptolites must have been deposited by the turbidity current that laid down the surrounding sediments.

Fragile graptolites such as Dicellograptus are common in the shales but rare in greywackes in which climacograptids are common. The dicellograptids are without their floats in the greywackes though they are connected to them when found in the shales. The lithological association of the graptolite types may be because the two types lived in separate areas and the climacograptids were brought into the area by the turbidity currents or because the more fragile graptolites were destroyed by the motion of the turbidity currents and only the more robust types survived the journey.

The writer prefers the latter explanation because a few thin dicellograptid fragments occur in the turbidites and climacograptids are found in the shales.

A lens shaped breccia with angular clasts of limestone set in a matrix of calcareous shale crops out

on Boisee Peninsula and in Northern Arm, and lies about 10 m stratigraphically above the base of the Goose Tickle Formation. The breccia is considered to have originated by the collapse of limestone recently deposited on the western side of the trough. The material was transported by turbidity currents to its present position, (see appendix for more detailed description and discussion). The presence of this breccia shows the tectonic instability of the trough.

Near the top of the Goose Tickle Formation is a series of conglomerates whose clasts, set in a matrix of grey shale are black and green shale very similar to the shale of the Northwest Arm Formation, and angular fragments of limestone. The beds are, like the breccia, thought to be the deposits of turbidity currents and to indicate the continuing instability of the trough. Unlike the breccia the conglomerates are thought to have been derived from contemporary erosion of the Northwest Arm Formation to the east.

Current directions

Sedimentary structures observed in the Goose Tickle Formation indicate that the currents came from the NNE along the axis of the trough (see Fig. 17). It is most

likely that much of the sediment was derived from the sides of the trough in which case the currents travelled down the sides before turning along its axis. Because the carbonate shelf area existed to the west it is most probable that the greywackes and shales were derived from the eastern side. On the other hand clasts forming the limestone breccias are identical with the shelf beds and almost certainly came from them. The black and green shale pebbles in the conglomerates cannot have come from the erosion of underlying beds exposed in a geanticlinal ridge within the trough because the Goose Tickle Formation is underlain by the Table Head Formation not by the Northwest Arm Formation, beds which would not yield these sort of pebbles. A more satisfactory explanation is that they came from the erosion of rocks within a gravity slide advancing from the west (see p.98).

Environment of deposition

The beds of the formation bear no evidence of a shallow water origin. No depth can be given for the depositional surface but the carbonaceous nature of the shales suggests it was below wave base. The basin which the breccia and conglomerates suggest was unstable was

elongated NNE-SSW, sloped gently to the SSW and was bounded on the west by an area of carbonate deposition from which the limestone clasts were derived and on the east by the Northwest Arm Formation from which the conglomerates clasts came. Turbidity currents carried sands and mud into the area from the NNE.

Maiden Point Formation

The Maiden Point Formation consists of greywacke, shale and volcanic beds. Well developed pillow lavas are found only in the north of the area and the centre of eruption is therefore thought to lie further to the north. Pillow structures indicate that the lavas were extruded under water.

Many of the agglomerates have a matrix of crystalline calcite with grain size up to 3 mm. The coarse texture cannot be due to the metamorphism because fine grained limestone beds are found nearby, nor can it be due to the hot volcanic material sinking into a bed of lime mud because the proportion of clasts to matrix does not vary from top to bottom and because the clasts are all in contact with each other. Baird (1953 p.8) attributed similar coarsely crystalline limestones to the warming of sea water by the introduction of the volcanic material. However the change

in solubility of calcium carbonate in water with temperature is small (Levin 1956, p. 248). The writer suggests that the heat of the clasts caused the evaporation of the calcium carbonate rich water into which they fell. The agglomerate pieces fell to the bottom of the water and most of the evaporation was from the water between the clasts of the agglomerate. As the water in the gaps evaporated cooler water from above would take its place. The water deposited calcite as it was evaporated.

Sandstones

Most of the sandstone beds are grey green but a few red sandstones outcrop in St. Anthony Bight. The greenish colour is caused by a chloritic matrix and the red by ferric oxide. Before diagenesis constituent grains appear to have been sub-angular but many of them now have sutured or corroded edges. They vary in size up to 3 cm.

The grains are mostly quartz, but plagioclase, mica, iron ore, and rock fragments are also present. Quartz grains commonly show undulatory extinction and many are polycrystalline. No quartz overgrowths were seen. The plagioclase content varies considerably; neither

orthoclase nor microcline were observed. Plagioclase is too altered to allow accurate determination of composition.

The mica is light coloured and is probably either sericite or muscovite. Tourmaline, zircon, and rutile are the only heavy minerals present.

Many shale flakes, mostly between 1 and 3 cm long but some up to 30 cm in length were seen in the sandstones. They usually occur at a definite horizon a few centimetres above the base of the bed, and are identical in lithology to the shale beds in the formation and are probably intraformational.

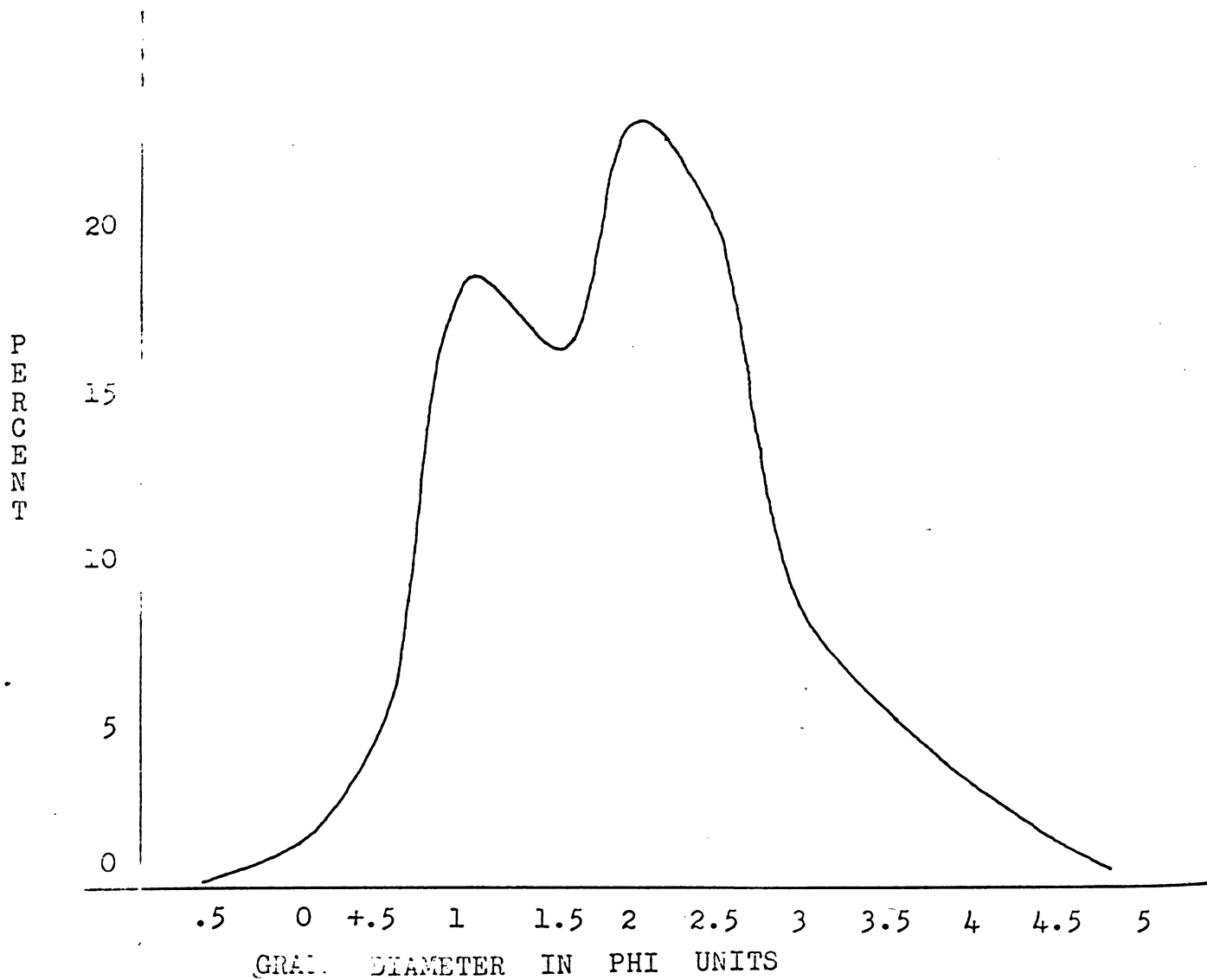
A few other rock fragments were found in thin sections but their size and extent of alteration prevent determination in most cases. However the following rock types have been identified:

- coarse acidic igneous rock
- feldspar porphyry
- fine grained acid volcanic rock
- metaquartzite
- orthoquartzite

A small amount of altered glass is present and oolites were seen in one thin section. Small amounts of calcite occur in many of the thin sections examined.

GRAIN SIZE FREQUENCY CURVE OF MAIDEN POINT SANDSTONE

based on 1200 measurements in six samples



Some of the calcite fragments are the same size as the quartz grains and may well be detrital. Pyrite occurs as small euhedral crystals and as irregular lumps, commonly being ringed with iron oxides.

200 grain diameters were measured in each of six thin sections of the Maiden Point sandstones. All the samples have a bimodal size distribution with peaks at 1.0 and 2.0 phi (0.5 and 0.25 mm). The peaks are not separated enough to represent clasts and matrix and they are not due to the grains of different minerals because quartz is the only abundant non-matrix mineral. The two peaks probably represent quartz grains derived from two different sources, a hypothesis that is reinforced by the petrology of the rock fragments, which suggest that the material came from igneous and metamorphic terrains.

The matrix, arbitrarily designated as all material less than 0.2 mm, consists mostly of fine fragments of quartz and a green flakey mineral, optically determined as clinochlore.

The average composition of the sandstone determined from grain counts of 200 grains in each of six thin sections is:

Quartz	50%
Matrix	40%
Rock fragments	6%
Plagioclase	2%
Other	2%

This would be classified by Pettijohn (1957, p.292) as a lithic greywacke, but he does not mention what he classifies as matrix.

The soles of many of the greywacke beds are uneven but because of the amount of distortion in the underlying shale it is rarely possible to show that the unevenness is caused by sole marks. Load casts were seen just north of St. Carols and just north of Bartletts Brook on the road to Griquet. Some flutes were observed near St. Carols indicating a southward moving paleo-current.

Graded bedding (Plates 35 and 36) is present in many of the greywacke beds. The best graded sequences occur in Milan Arm where one bed grades upward from 1 cm pebbles to shale, although more commonly the beds grade from very coarse sandstone to siltstone. The upper part of some of the sandstone units is laminated parallel to the bedding and contains much mica.

Very minor slumps, each involving only one thin bed were found in St. Anthony Bight (Plate 39).

Channels, usually 5 to 10 cm deep but occasionally 30 cm deep, are common in the Maiden Point Formation. They are filled with coarse, friable, current bedded sandstone. The channels are best displayed just north of Bartletts Pond but examples can also be found in St. Anthony Bight.

In this formation current bedding occurs only in the channel fillings. The angle of foresets dip about 25° and for the most part indicates that the paleocurrents came from the west (Fig. 18).

Mode of deposition of the sandstones

The following data is relevant.

- 1) The sandstones are interbedded with agglomerates, tuffs and pillow lavas but very little volcanic material is found in the sandstone beds themselves. This suggests that the sandstone was brought in rapidly from outside.
- 2) Sedimentary structures other than graded bedding are rare.
- 3) The sandstones are immature.
- 4) The sandstones have less matrix than the average greywacke.

The lack of current bedding makes a fluvial origin unlikely and a littoral environment of deposition is also improbable because the sandstone is poorly sorted and the grains angular. The explanation best fitting the evidence is that they are turbidites. The reported lack of bottom structures may be because few undersides are visible and because tectonic

deformation has made the detection of bottom structures difficult. Bouma has shown that a lack of internal sedimentary structures is usual in the coarse division of a turbidite (Bouma 1962).

If these beds are turbidites, it is necessary to explain the low matrix-clast ratio. Modern deposits which have been attributed to turbidity currents or have been formed by experimental turbidity currents have a low matrix-clast ratio (Ericson et al. 1951; Kuenen and Migliorini 1950). Paleozoic turbidites have a much higher matrix-clast ratio, which Cummins (1962) attributes to the alteration of unstable minerals to clay or clay-like substances. It is possible that the Maiden Point Formation contained only a small proportion of unstable minerals when it was deposited and thus only a small amount of matrix has subsequently been formed.

Slates

Slates in the Maiden Point Formation are mainly grey but black slates are found at the base and red ones at the top of the formation. The black colour is thought to be due to carbon content, which suggests that the beds were deposited in an anaerobic environment. Pyrite commonly accompanies the black slate in the lower part of the formation but is absent from the upper part,

and provides further evidence of an increase in the oxidation potential during deposition of the formation.

Limestones

Limestone is found in the Maiden Point Formation both as discrete beds and as scattered clasts. The limestone beds range in thickness from a few centimetres to tens of metres and consist of very argillaceous limestone. Thin limestone beds occur in groups interbedded with shale. Tabular limestone clasts found in the formation on Quirpon Island are a few centimetres long and are mostly probably intraformational in origin. A lone boulder of limestone 30 cm in diameter was found in contorted slate in Milan Arm.

Current directions

The ^{orientation of the} long axes of quartz pebbles at the base of one bed in the Maiden Point Formation gives a single distinct peak showing a NE-SW paleocurrent trend. Shale blebs examined are elongated north-south and flutes suggest a paleocurrent moving SW.

Source and depositional environment

The feldspar, large mica flakes and the polycrystalline quartz suggest a source area containing acid plutonic and metamorphic rocks.

The occasional precipitation of limestone suggests that beds were laid down in shallow water, on the other hand the lack of sorting in the sandstone suggests that the depositional site was below wave base. The change in colour of the shales and the disappearance of pyrite towards the top of the formation suggest that the water, at first reducing, latter became oxidizing. Turbidity currents, moving toward the south brought greywackes into the area and volcanic material also was sometimes laid down.

Northwest Arm Formation

This formation contains a great variety of lithologies; sandstones, black and green shales, chert and limestone. The green shales are not tuffaceous

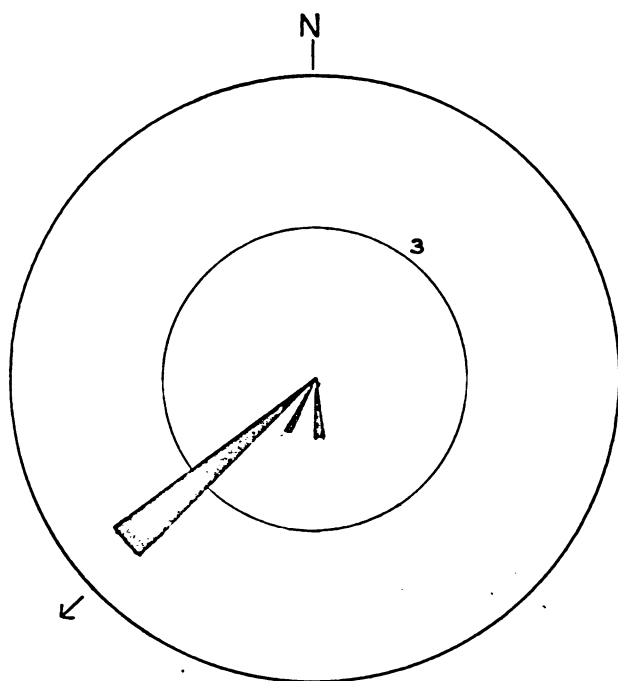
The sandstone is coarse and consists of quartz and minor plagioclase and calcite grains set in a clay matrix. The quartz grains are subangular and have sutured contacts and commonly show strained extinction. Tourmaline, zircon and rutile are also present. Pyrite nodules occur in the sandstone. The sandstone beds are much thicker than those in the Goose Tickle Formation and the grain size is also larger. Ripple drift cross bedding is more prominent in the sandstones of this formation than in those of the Goose Tickle Formation. Some of the ripple drift

Environment of deposition

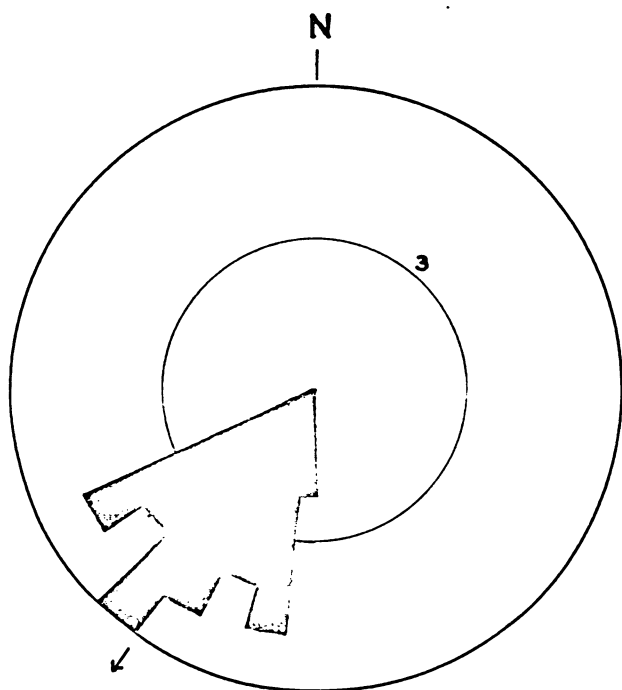
The pyrite and the black colour of most of the shales suggest that the depositional environment was anaerobic. The presence of graptolites indicates that the area of deposition was open to the sea and the flutes and grooves suggest that the currents moved from the NNE and that the area of deposition was elongated NNE-SSW.

The problem presented by the Northwest Arm Formation

The Northwest Arm Formation presents a problem in that its fossils indicate it is coeval with the St. George Formation yet it belongs to a very different facies. The St. George Formation consists of shallow water limestone and dolomite without any shale lenses whereas the Northwest Arm Formation is mostly shale and greywacke. The fossils in both formations fit the environment and show no evidence of resedimentation. It has been suggested that the depositional areas of the St. George and Northwest Arm formations were separated by a fault. The situation would be similar to the Craven Area in England where shallow water limestones accumulated on the upthrown side of a fault and black shales on the downthrown side (Parkinson 1957). Objections to this suggestion would be a) no continuous fault has been found b) if a fault existed one would



Current directions in the
Goose Tickle Formation
taken from 7 measurements
of flutes



Current directions in the
Goose Tickle Formation
taken from 31 measurements
of ripple drift bedding

Current azimuths

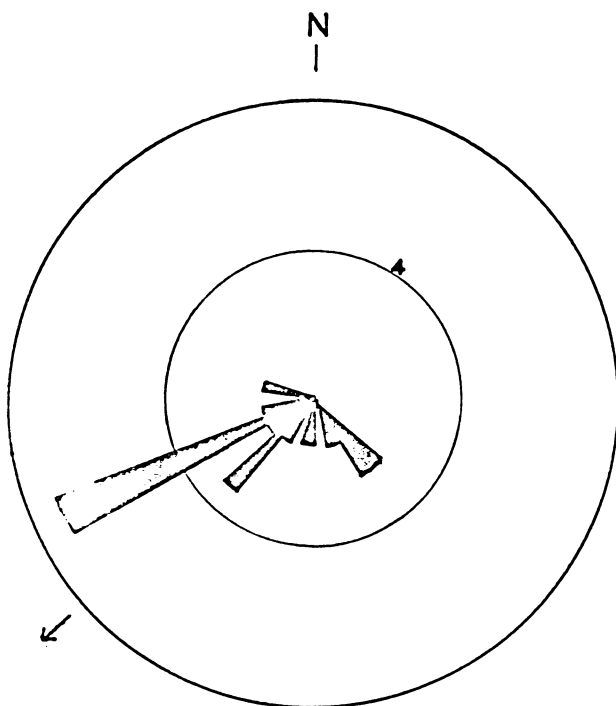
Fig. 17

expect to find limestone lumps in the shale below but there are no sedimentary limestone breccias in the Northwest Arm Formation c) St. George limestone is found on three sides of the outcrop of the Northwest Arm Formation so there is no linear separation of the formations. Another hypothesis is that the shales accumulated in a basin surrounded by the St. George Formation. If this were so more interfingering of the facies would be expected. Further evidence against this hypothesis is the fact that the St. George Formation contains only minor chert whereas it is relatively abundant in the Northwest Arm Formation.

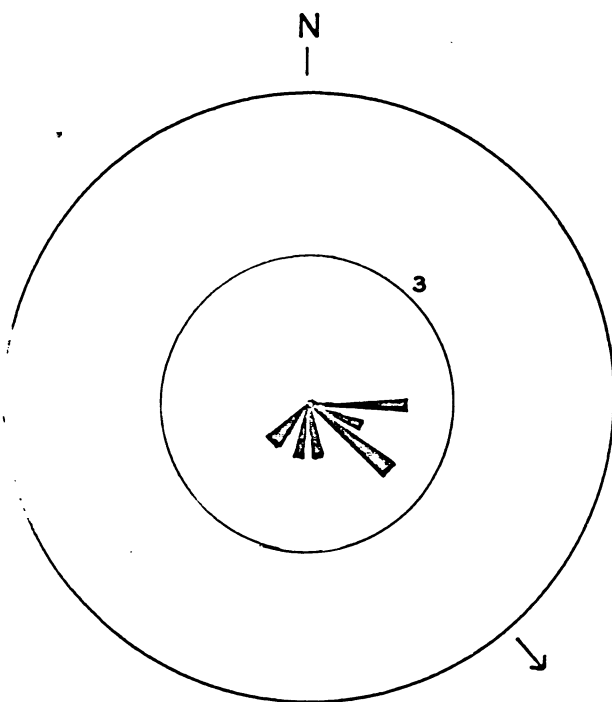
The most plausible explanation is that the Northwest Arm Formation accumulated elsewhere and was subsequently moved in to its present position by gravity sliding (see p.98).

Summary of current directions

Sedimentary structures in the Goose Tickle Formation indicate that the currents flowed toward the SSW. Similar current directions were found in the Northwest Arm Formation. The orientation of pebbles in the St. George Formation is the same but may indicate currents flowing at right angles to that direction because the pebbles were probably rolled.



Current directions in the
Northwest Arm Formation
Taken from 21 measurements
of flutes



Current directions in the
Maiden Point Formation.
Taken from 9 sets of
cross-bedding

Current azimuths

This is the usual but unexplained pattern of currents in geosynclines, directions on the shelf at right angles to those in the basin (Potter and Pettijohn 1963, p.241). The paleocurrent directions found between Hare Bay and Canada Harbour also fit the pattern outlined above.

The paleocurrents in the autochthonous Goose Tickle Formation flowed towards the present position of the Long Range. This suggests that the Long Range was not topographically higher than the depositional surface of the Goose Tickle Formation when it was being laid down, (see Fig. 31).

Sedimentological conclusions

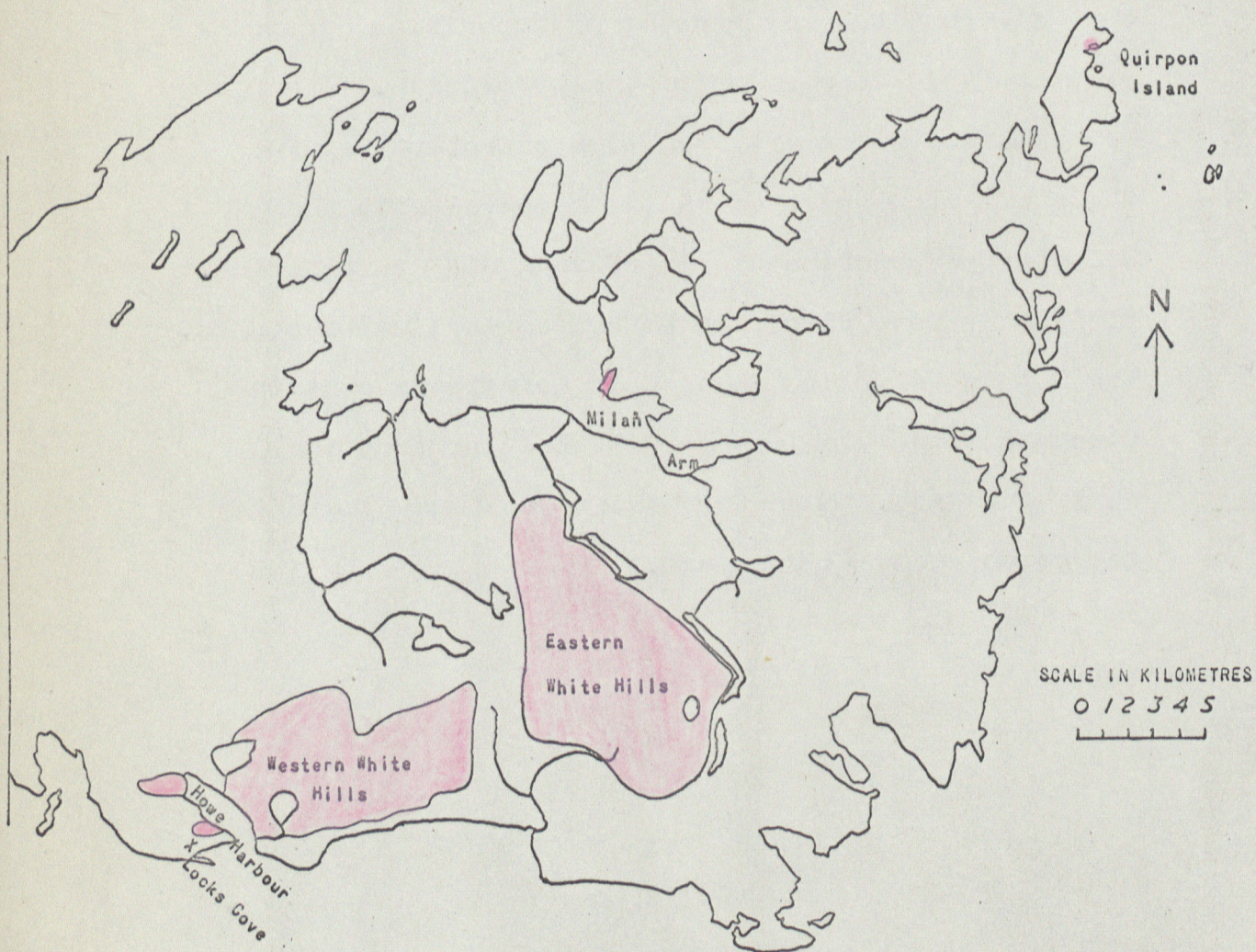
The beds of the St. George Formation were deposited above wave base whereas those of the succeeding Table Head Formation were laid down below it. The beds of the Goose Tickle Formation were definitely deposited below wave base and probably further below it than the Table Head Formation because of the turbidites which Kuenen (1964) has interpreted as deep water deposits. These formations must all belong to one sequence as they have sedimentary contacts between them.

The beds of the Bradore Formation are quartz sandstones, typical of a shelf sequence and are therefore thought to belong to the shelf sequence.

The overall aspect of the shelf sequence suggests that the environment of deposition became progressively deeper during the Ordovician.

The Northwest Arm Formation cannot belong to the shelf sequence because it is coeval with the St. George Formation and is of very different facies. It is therefore placed in the eugeosynclinal sequence. The Maiden Point and Goose Cove Formations contain volcanic beds which are totally lacking from the shelf sequence, these formations are thus placed in the eugeosynclinal sequence.

PISTOLET BAY AREA



Distribution of the ultrabasic masses

IGNEOUS INTRUSIONS

Gabbro

Gabbro intrudes the Maiden Point Formation in four places in this area; near St. Anthony, south of Milan Arm, in Pistolet Bay, and in the mouth of Howe Harbour. Field evidence suggests to the author that the intrusions are small stocks, and not sills as reported by Cooper (1937, p.22). At two localities they are overridden by the Ireland's Bight thrust.

The gabbro consists essentially of titanite and altered plagioclase, with accessory apatite, ilmenite, and secondary chlorite.

Dikes

A few diabase dikes cut the lower part of the Maiden Point Formation. One of these dikes, considered representative of them all, contains plagioclase, clinopyroxene, and orthopyroxene all partially altered to chlorite.

Ultrabasic bodies

^t
Serpentinised peridotites occur in several parts of the Pistolet Bay area, with the largest masses forming

the White Hills (Fig. 19). These masses are characterised by the bright orange surface colouration resulting from weathering.

Cooper (1937, p.20) was the first to map the peridotite of the White Hills.

The most complete account of the mineralogy of this intrusion is supplied by Shepherd (1962) in a report of the Patino Mining Company. He found that most of the intrusion is a porphyritic augite serpentinite with augite phenocrysts forming 15 to 25 per cent of the rock. Variations in the concentration of pyroxene produce a marked layering. The augite is altered locally to tremolite and chlorite and is set in a matrix of tremolite and dark green serpentine. Thin veins of serpentinitised peridotite are found locally in the centre of the peridotite bodies. Shepherd observed that massive serpentinite occurs around the margin of the intrusion and at the base, a dense serpentinite includes partially digested fragments of country rock. The author of this thesis also found hornblende composed of brown hornblende, biotite and magnetite. Only serpentinite outcrops in Milan Arm and on Quirpon Island.

Thickness of the White Hills intrusions

Cooper (1937, p.11) suggested that the White Hills peridotites were thin bodies which had been thrust, together with their aureole over the underlying sediments. The following points support his suggestion that the ultrabasic rocks are thin bodies:

- 1) The base of the peridotite approximately follows the contour lines.
- 2) The distribution of magnetic highs (Patino Mining Company, personal communication) associated with the peridotites corresponds with the topographic highs.

These two points together suggest that peridotite lies only beneath the area where it outcrops and not elsewhere.

- 3) Ireland's Brook cuts through the peridotite into the metamorphic rocks below.
- 4) Gneiss is found in the centre of an anticline in the Eastern White Hills.
- 5) The peridotite does not cause a gravity anomaly (D. Weaver personal communication).
- 6) Negative magnetic values are found all around the margin of the intrusion.
- 7) Amphibolite near the peridotite dips towards it at small angles.

Because the peridotite does not cause a gravity anomaly it cannot be more than 1500 m thick (personal communication D. Weaver). Point no. 6 indicates that the dip of the base is low. The peridotite must therefore be sheet-like in form. The field relations of the peridotite to the surrounding metamorphic rocks suggest a probable thickness of 200 m and a nearly horizontal base. The extent of the metamorphic aureole to the southeast also suggests that the lower surface is approximately flat. The outermost portion of the aureole is too far from the intrusion (7 km) to have been metamorphosed by it unless it originally extended over it.

This suggests that the peridotite may be interpreted as a sill or the basal part of a thicker intrusion.

The evidence presented leaves two possible interpretations, a) the peridotite is in place but has a neck too thin to produce a gravity anomaly or b) the peridotite has been separated from its roots.

At the north end of Howe Harbour the peridotite overlies unmetamorphosed shale which would have been metamorphosed had the peridotite been intruded in its present position. Elsewhere it is underlain by metamorphosed volcanic beds on three sides of which there is good evidence for thrusts (see p.86). The author therefore agrees with the suggestion of Cooper (1937, p. 13) that the peridotite and its metamorphic aureole form a thrust slice.

Age of the intrusions

No samples found by the author in this region contained sufficient biotite for radiometric dating and no other method for directly dating the intrusion is available. Some indirect evidence is however available. The nearest radiometrically dated ultrabasic intrusion is at Mount Albert in Gaspé which is dated as 495 m.y. This is earliest Ordovician according to the time scale published by the Geological Society of London (1964). The peridotites in Newfoundland are undated, they cut Lower Ordovician but not Middle Ordovician strata. The peridotite is accordingly considered to be Lower Ordovician.

Gabbro cuts the Maiden Point Formation and is truncated by the Ireland's Bight thrust. Its intrusion must therefore be later than the deposition of the Maiden Point Formation and prior to the thrusting. The relationship of the gabbro to the peridotite is unknown but the two rock types are commonly associated in other parts of the world and it is probable that they are both part of the same igneous cycle and may thus have been intruded at about the same time.

THE METAMORPHIC AUREOLE

Attention is here confined to the beds in the White Hills because the slates and other low grade rocks of the Maiden Point Formation are fully described in other chapters.

The ultrabasic intrusion is almost completely surrounded by a metamorphic aureole grading from hornblende gneiss at the contact to a slightly metamorphosed volcanic rocks farthest from it. This aureole is about 150 m thick if the peridotite is assumed to have a horizontal base (p. 68).

The most common mineral assemblage in the rocks of the inner part of the aureole is: amphibole (70%), altered plagioclase (25%), and quartz (5%), often with accessory sphene, spatite and iron ore. The other common assemblage is biotite, garnet and quartz in approximately equal amounts. This latter assemblage occurs only as thin layers within the first. The mineralogy suggests that the original rock was a basic tuff with thin laminæ of shale. The beds furthest from the intrusion are chloritised volcanic rocks with some black shale.

The problem posed by the aureole

Most peridotites and serpentinites have very thin metamorphic aureoles, this peridotite does not. Because many peridotites have thin aureoles it has been thought that

peridotites were intruded at relatively low temperatures. Many peridotites were intruded into rocks which had already undergone, or were later to undergo regional metamorphism and structural deformation which occluded whatever contact metamorphism there was. Elsewhere retrogressive metamorphism has obscured the original aureole. Many peridotites have been serpentised, a process which allows them to be structurally intruded without metamorphosing the new host rock, rather like salt and gypsum. Thus peridotites are unlikely to retain an aureole in an identifiable condition.

Several peridotites with extensive aureoles have been described recently. These are present at the Bay of Islands (Smith 1958), Mount Albert (MacGregor 1963), Tinaquillo (MacKenzie 1960), Blue River (Wolve, 1964), Lizard (Green 1964), and the Red Hills New Zealand (Challis 1965). The intrusions have contact aureoles of respectively 150, 450, 600, 120, (not given) and 230 metres thick. The White Hills intrusion is 150 m thick.

Several changes in mineralogy have been noted between the inside and outside of the above mentioned aureoles but of these only one was noted in the White Hills aureole.

Plagioclase in the rocks of the aureole surrounding the White Hills intrusion is mostly too altered to permit determination of composition by optical methods. Three determinations however indicate increasing anorthite content toward the intrusion, as do the plagioclases in other peridotite aureoles.

Both the colour and intensity of absorbtion^p in the amphiboles are highly variable and cannot be related to the distance from the intrusion. No diopside, prehnite, or calcite was found in the rocks closest to the intrusion, and no change in the proportion of garnet was observed. The average grain size increases from 0.01 cm at the margin to 0.1 cm near the peridotite, a change not recorded in other peridotite aureoles.

It seems likely that the metamorphism of these rocks was caused by the intrusion because of the gradation between the chloritized volcanic rocks away from the peridotite and the hornblende gneiss near it.

STRUCTURE

History of investigation

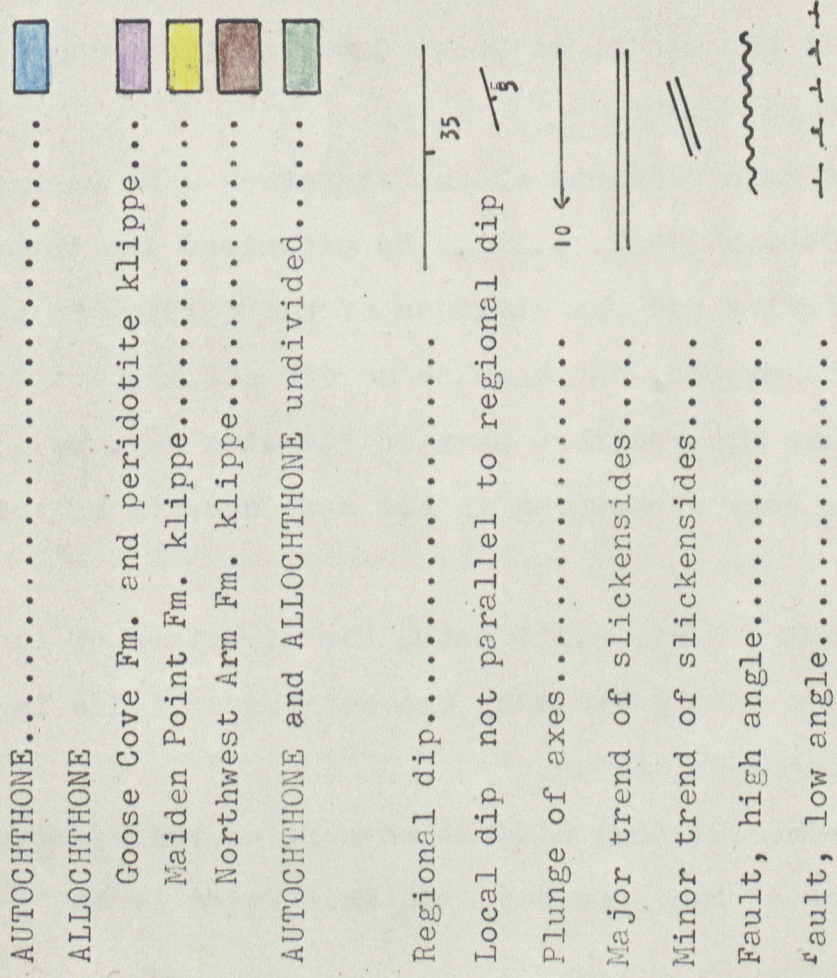
Richardson (in Logan 1803, p.876) reported three normal faults and one thrust in Pistolet Bay. Murray (Murray and Howley 1881, p.26) mentioned the contorted nature of the schist at Goose Cove and the thrust on Hare Island (op. cit. p.23).

The main elements of the structure were worked out by Cooper (1937, p.11). He described the thrusts, normal faults and the attitude of the folding in the region he mapped, but because he did not map further north than the southern part of Pistolet Bay, he did not describe many structures in the area covered by this report.

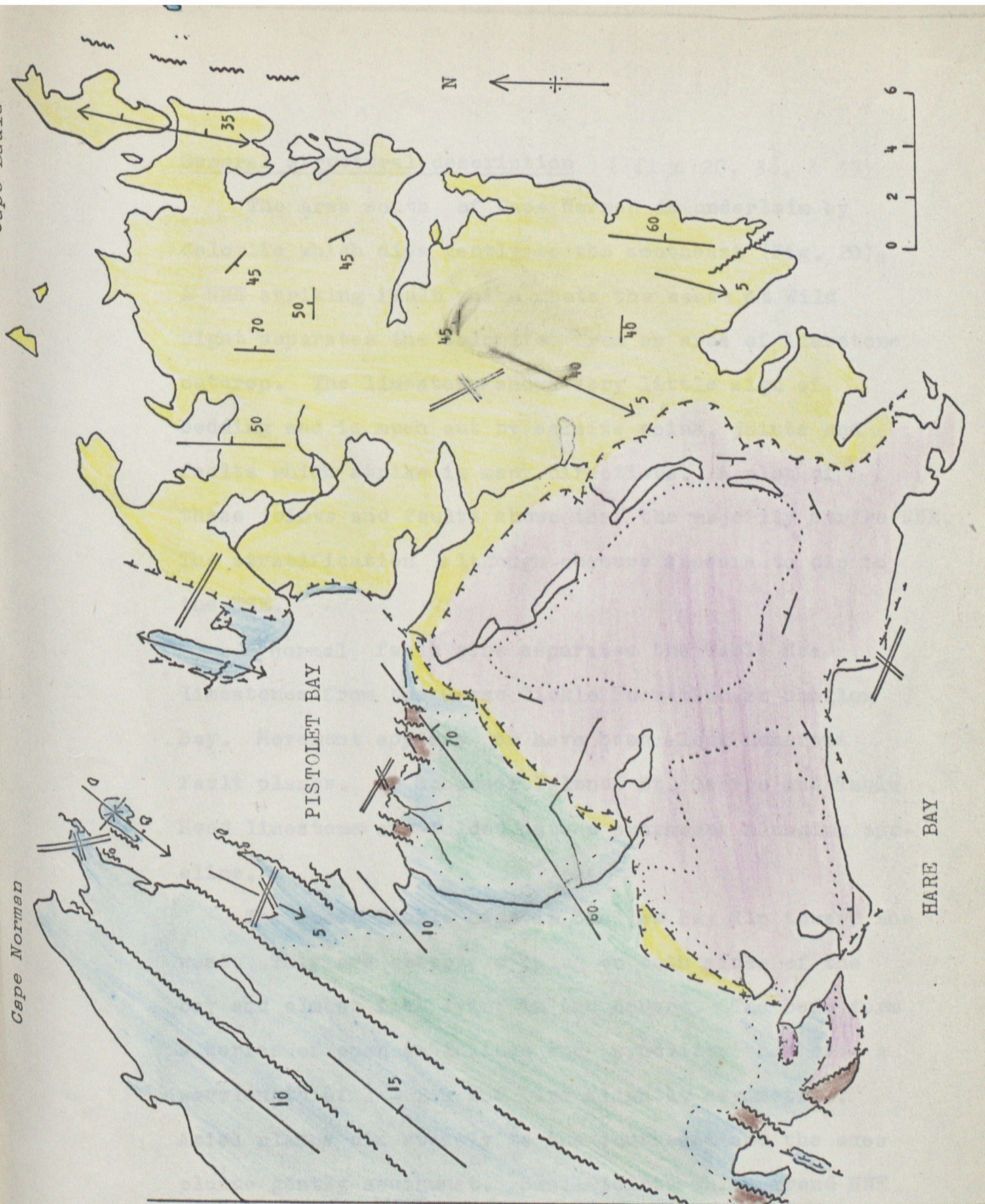
Kindle (1945, p.11) noted the structure of the limestones and shales and the overturned folds in the Maiden Point Formation.

Shepherd (1962) made no comment on the general structure of the area but mentioned folds in the peridotite.

PISTOLET BAY AREA STRUCTURE



Cape Norman



General structural description (figs 20, 36, & 37)

The area south of Cape Norman is underlain by dolomite which dips gently to the southeast (Fig. 20). A NNE striking fault which meets the coast at Wild Bight separates the dolomite from an area of limestone outcrop. The limestone shows very little sign of bedding and is much cut by calcite veins, joints and faults which strike in many directions. A plot of these joints and faults shows that the majority strike NNE. The stratification although obscure appears to dip to the ESE.

A normal fault zone separates the Table Head limestones from the Goose Tickle Formation in Shallow Bay. Movement appears to have been along numerous fault planes. On Schooner Island St. George and Table Head limestones are folded into a southwest plunging syncline.

The Goose Tickle beds in Shallow Bay dip toward the west. They are steeply dipping on both sides of the bay and almost flat lying in the centre. The beds form a series of open anticlines and synclines that have a wavelength of 1 - 2 m and are slightly asymmetric. Axial planes dip steeply to the southeast and the axes plunge gently southwest. Small joints which trend NNE cut the beds every 20 cm or so. Slickensides in this bay are common and trend NW (Fig. 22).

On Boisee Peninsula the Goose Tickle shales are again separated from Table Head limestones to the west by a normal fault but because the overall dip is to the southeast the shales outcrop further southeast in Pistolet Bay. The shales in Pistolet Bay have an average dip of 30° to the southeast; some asymmetric folds with axial planes dipping steeply southeast are present. The axes of folds plunge gently both northward and southward. The cleavage dips steeply to the southeast. Subvertical joints striking NNE occur every few centimetres and slickensides trending NW cross many nearly horizontal surfaces. Near Triangle Point normal faults striking NNE bring beds of the Northwest Arm Formation to the surface at several places. The frequency of calcite veins increases toward the east.

The limestones of Burnt Island are thrust westward over shales but because of the eastward dip the shales reappear on the east side of the island (Fig. 37, cross section A - B).

On the east side of Pistolet Bay, volcanic beds of the Maiden Point Formation are thrust over the shales. Little internal structure can be seen in the

volcanic beds except that they dip eastwards.

Slickensides on surfaces are common and are highly variable in direction. Rose diagrams of these show a preferred orientation toward the NW (Fig. 23J).

To the east of the volcanic beds, sandstones are mostly folded into anticlines and synclines with wavelengths of about 30 m and amplitudes of 10 m. The folds are slightly inclined with steep limbs lying on the west side of anticlines (Fig. 37 cross-sections). Nearly flat lying isoclinal folds are apparent in two places in St. Anthony Bight.

Locally the cleavage is less steep than the bedding and the beds are overturned. The dips in the Maiden Point Formation are dominantly east or south. Slickensides have a preferred orientation to the NW quadrant (Fig. 24).

The White Islands are formed of rocks of a different lithology, quartzites, from the greywackes and shales on the mainland and a fault with downthrow to the west is thought to separate them. The quartzites of the White Islands have a constant dip of 50° eastward. The cleavage which dips eastward at 75° is well developed in the sandstones on the western part of the islands but is much less pronounced in the east.

To the south of Pistolet Bay lies a large thrust sheet of peridotite and its metamorphic aureole. This has been thrust westward (see p.86 for discussion) over the Goose Tickle and Maiden Point Formations. The peridotite is folded in gentle anticlines and synclines with axes trending NNE (Fig. 37, cross section E-F). One anticline brings gneiss to the surface in the middle of the peridotite. The peridotite has well developed sheet jointing near the base (Shepherd personal communication), which might have been caused by the thrusting.

Shales exposed in Howe Harbour and along the coast west of Locks Cove dip eastwards at 30° to 60° . Several faults separate small outcrops of Northwest Arm Formation from the Goose Tickle Formation. Limestone of the Table Head Formation is thrust westward over the shales on Hare Island.

Folds and associated structures

Goose Tickle Formation

The beds of this formation are gently folded although most of the beds dip toward the southeast. Most of the folds have low dipping limbs, and axial planes that dip steeply to the southeast. Overturned

folds occur singly and the beds on either side have low dips. The folds plunge gently SSW. No evidence was seen for isoclinal folds but the lack of top and bottom criteria in parts of the section make it impossible to disprove.

The cleavage in the Goose Tickle Formation dips steeply to the east or southeast parallel to the axial planes of the folds. In the argillites it is a planar slaty cleavage. The argillites break more easily along the cleavage than the bedding but the sandstones and siltstones fracture ^hconcoidally or along the bedding planes.

The Goose Tickle shales are cut by calcite veins. These increase toward the eastern side of Pistolet Bay. Most of the veins cut obliquely northward across the bedding. A large number of these veins are found just south of Raleigh where one large vein up to one metre wide is accompanied by many smaller ones arranged en echelon.

Northwest Arm Formation

The sandstone beds of the Northwest Arm Formation are faulted and contorted (Plates 18 and 19). They have commonly been deformed so that the only remnants of the beds are lines of sandstone blocks in a matrix of shale.

At first appearance these look like blocks which have fallen into the shale as it was being deposited. However, the blocks are aligned and flute and groove marks in each block in a line have the same orientation thus indicating that the blocks once formed a continuous sedimentary deposit which was subsequently disrupted. The lines of blocks cannot be followed for more than a few metres because of abundant faulting. Folds in the beds can be seen in some places, but in others they are only known to be present because of the sole markings. The folds in the Northwest Arm Formation are isoclinal or nearly so. The axes of the folds tend to lie on a plane dipping steeply ESE (see Fig. 25B). The axes of many of the smaller folds plunge down the dip of this plane. They open to the north and to the south in about equal proportions. At several exposures of the Northwest Arm Formation only black and green shales are present. The cleavage makes these beds look like a simple succession but wherever a thin sandstone band occurs it is folded and discontinuous thus suggesting strongly that the enclosing beds are also folded and faulted.

In general the cleavage is steeply dipping toward the southeast. No planar cleavage is found in the

Northwest Arm Formation. The shales break into lozenge-shaped flakes and the cleavage is a series of interweaving curves. The flakes of shale have shiny surfaces possibly caused by slight movement of the flakes against one another. This type of cleavage has been called reticulate cleavage by Crook (1964). The cleavage is deflected round the blocks of more competent material in the shales and the shale is thickened in the hinge areas of folds, thus suggesting plastic flowage. Where the competent beds have not been broken they are bent into acute folds which show no sign of cleavage.

It seems as though the shales were mobile and the sandstones were in a state in which they could be acutely folded without developing cleavage or fracture, or could be squeezed into boudins. This suggests that the beds were still largely unconsolidated when deformed. The lozenge shaped fragments into which the shale breaks reminds one of the argille scagliose ^(Maxwell 1959) although the lozenges in the Pistolet Bay beds are much thicker.

Structural comparison of the Goose Tickle and Northwest Arm formations

The internal structure of the Northwest Arm Formation is very different from the surrounding Goose Tickle Formation. These structural differences cannot be attributed to differences in lithology for both are shales with some sandstone beds.

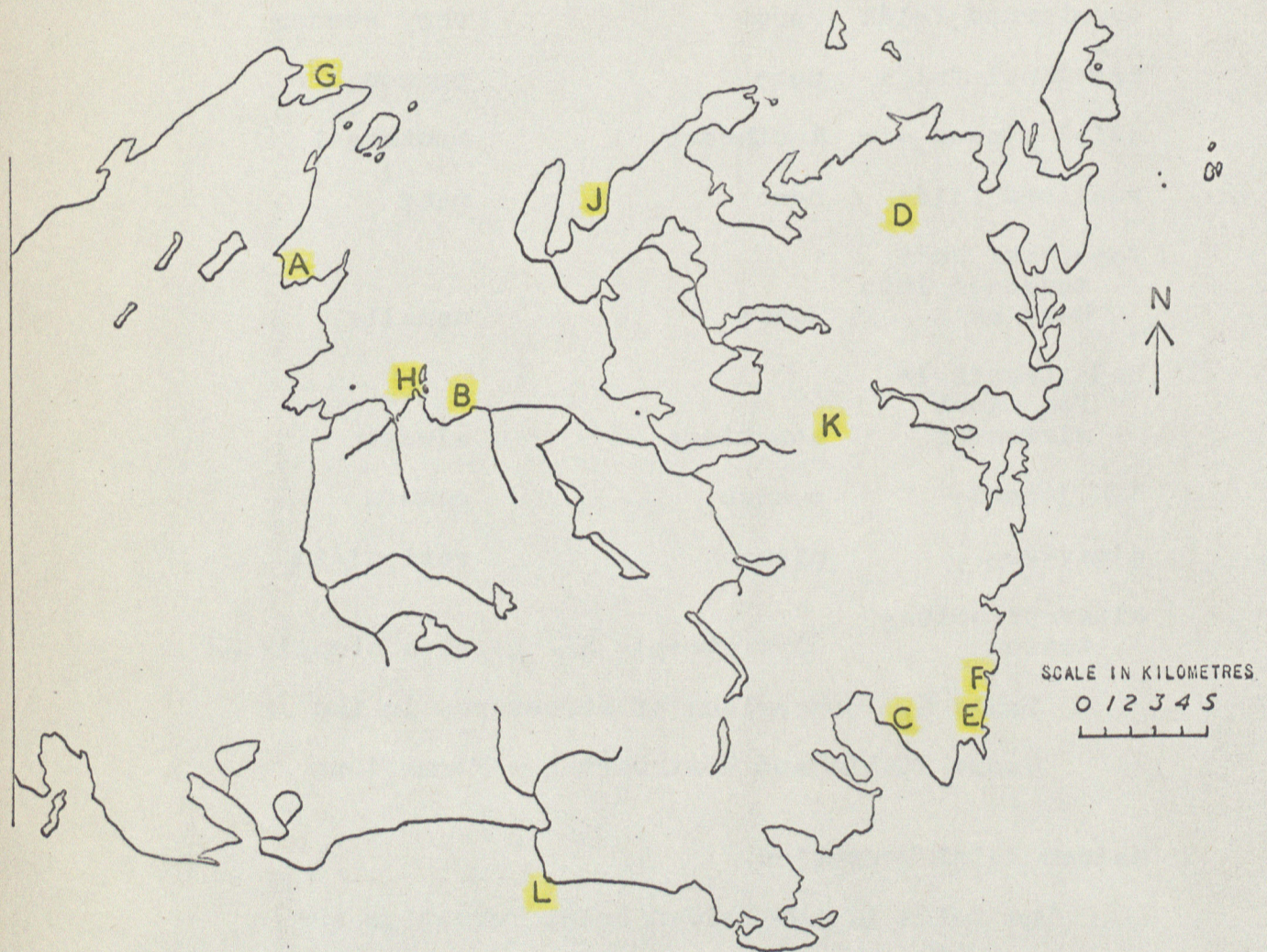
<u>Structure</u>	<u>Goose Tickle Fm.</u>	<u>Northwest Arm Fm.</u>
Folds	not very common	very common
overturned folds	rare	very common
isoclinal folds	none	common
axial planes dip	southeast	southeast
reclined folds	none	many
Competent beds squeezed into boudins	never	usually
beds traceable for short distances	sometimes	always
NNE joints	common	common
cleavage	planar	reticulate
cleavage orien- tation	dips steeply SE	dips steeply SE

Table 4. Comparison of structures in the
Goose Tickle and Northwest Arm Formations

Maiden Point Formation

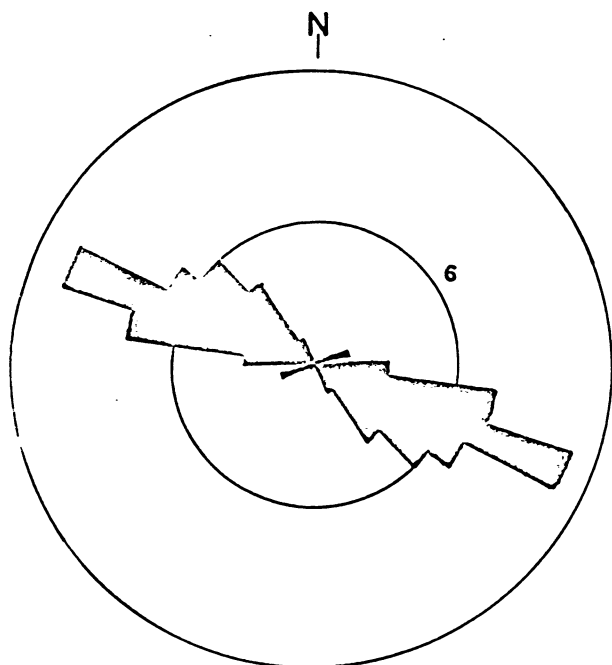
The folds in the Maiden Point Formation are usually asymmetric with longer and more gently dipping limbs on the east side of the anticlines. The axial planes dip steeply ESE in most places. The axes of folds in the Maiden Point Formation were plotted on an equal area net. It was found that the axes generally plunge to the SSE (Fig. 26) but the distribution of fold axes in the northern part of the area appeared to be random. The majority of folds have limbs dipping at less than 40° but

PISTOLET BAY AREA

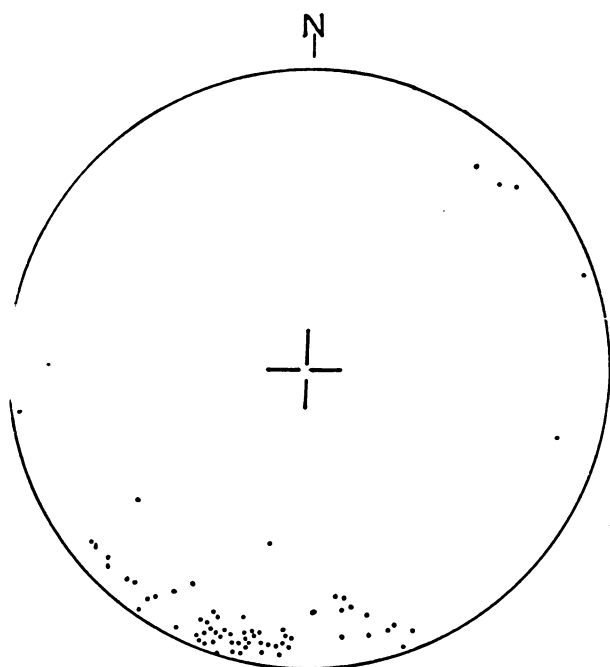


Locations where measurements were made on fold axes
and slickensides

Fig. 21



A
Trends of slickensides
41 measurements

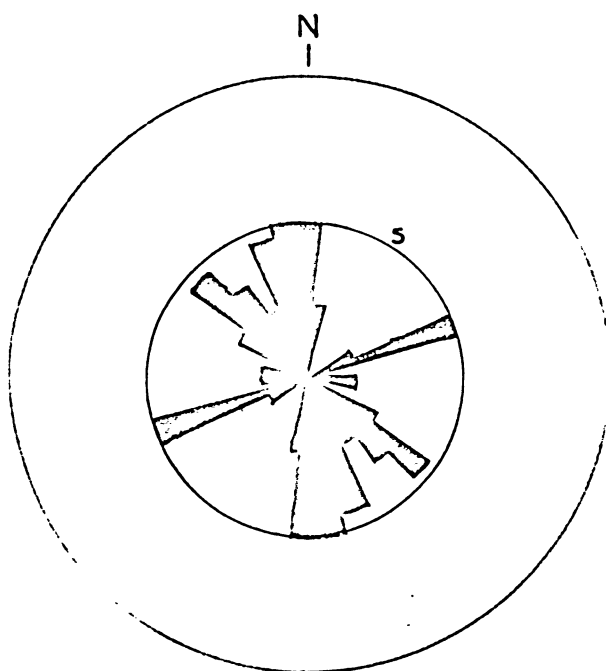


A
Orientation of fold axes
71 measurements

Lower hemisphere equal area
projection.

Relationship of slickensides to fold axes
in Shallow Bay

Fig. 22



G

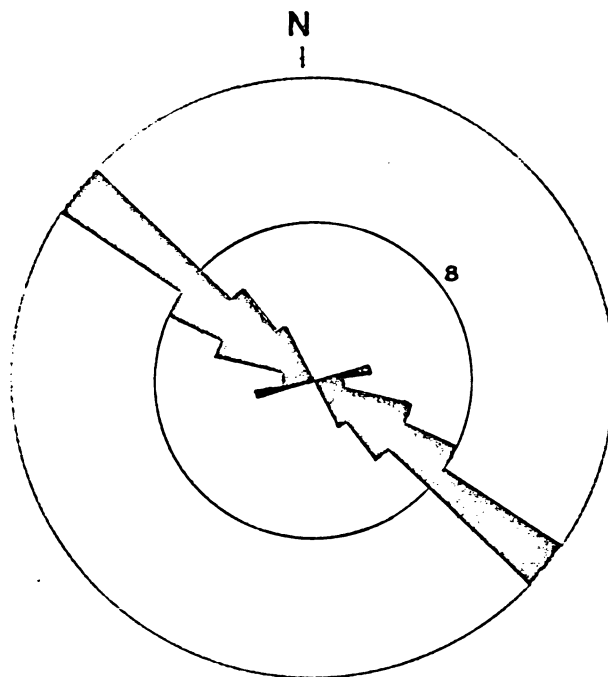
Table Head Formation between
Cook's Point and Wild Bight

36 measurements

H

Triangle Point

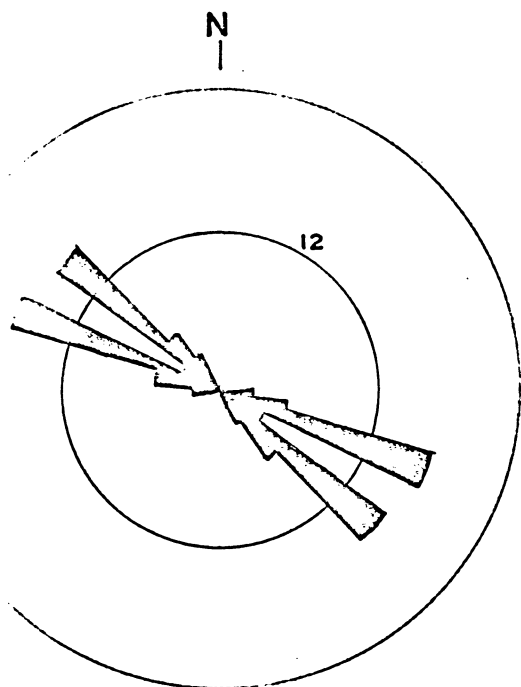
44 measurements



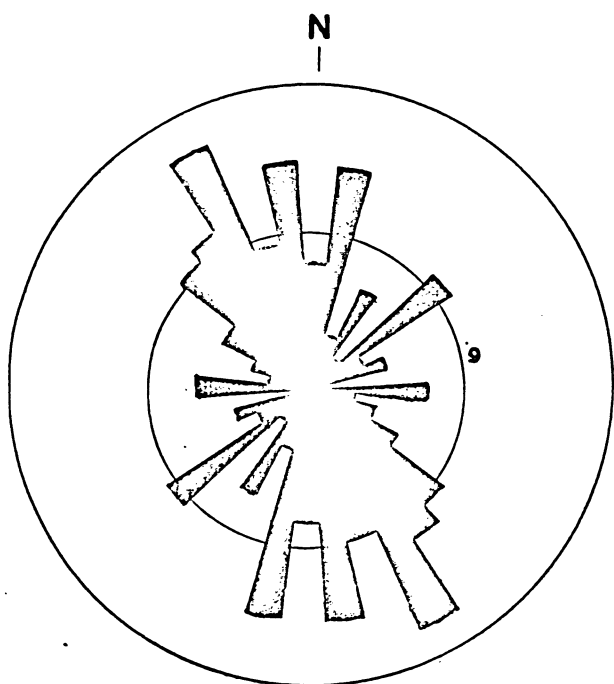
J

North of Raleigh

53 measurements



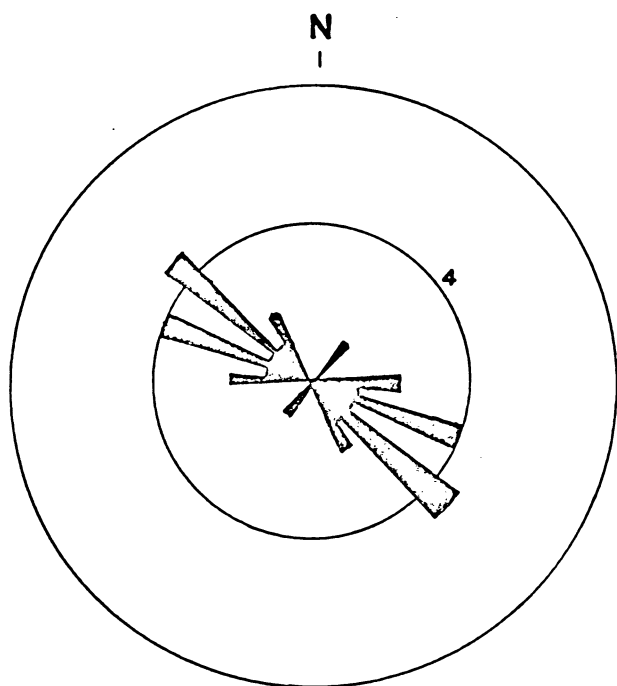
Trends of Slickensides



K

Along the road to Griquet

118 measurements



L

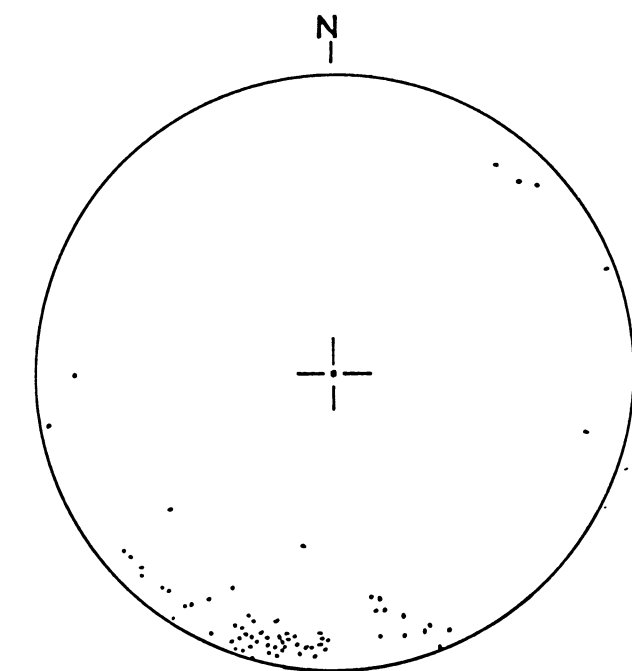
Ireland's Bight

19 measurements

Trends of Slickensides

Fig. 24

Orientation of Fold Axes

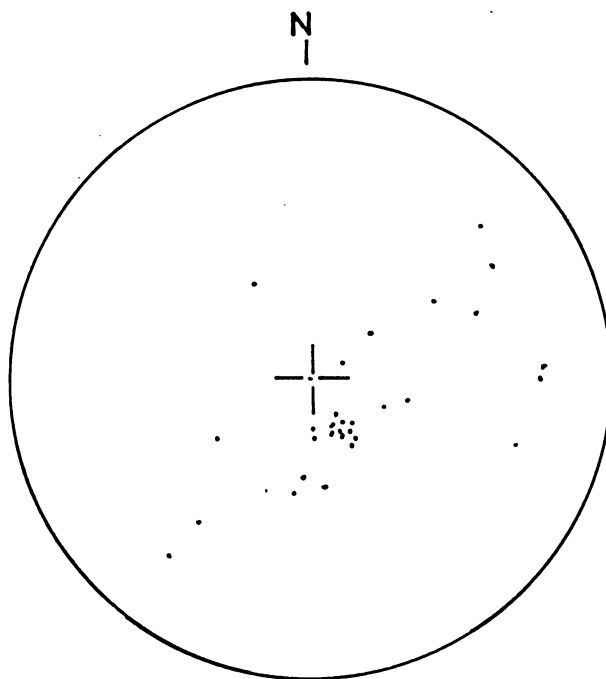


A

The Goose Tickle Formation in
Shallow Bay

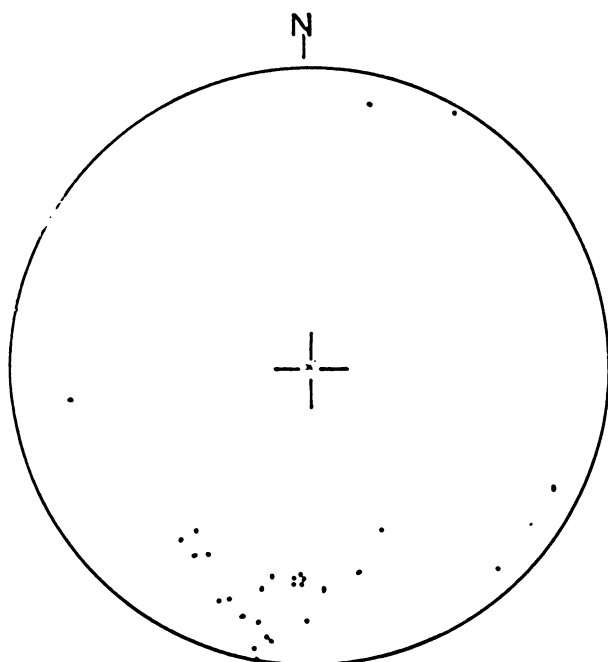
75 measurements

B
The Northwest Arm Formation
east of Triangle Point
31 measurements



C

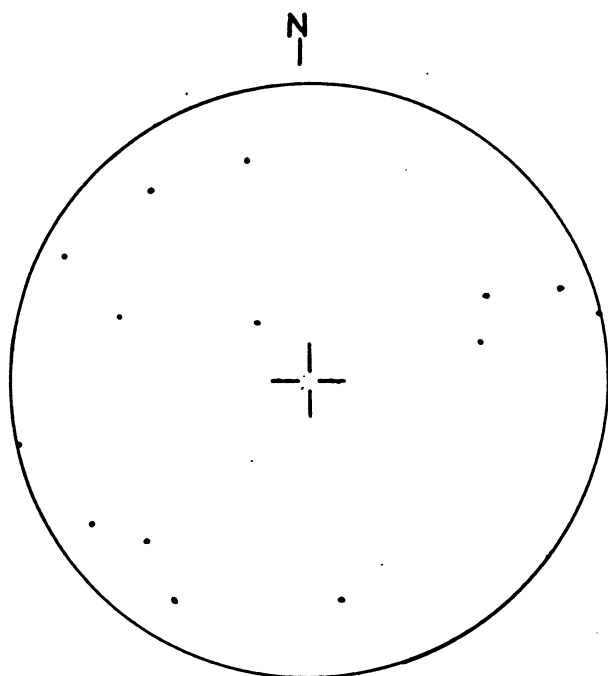
The Maiden Point Formation
just north of St. Anthony Bight
30 measurements



Lower hemisphere equal area
projections

Fig. 25

Orientation of fold axes in the Maiden Point Formation



D

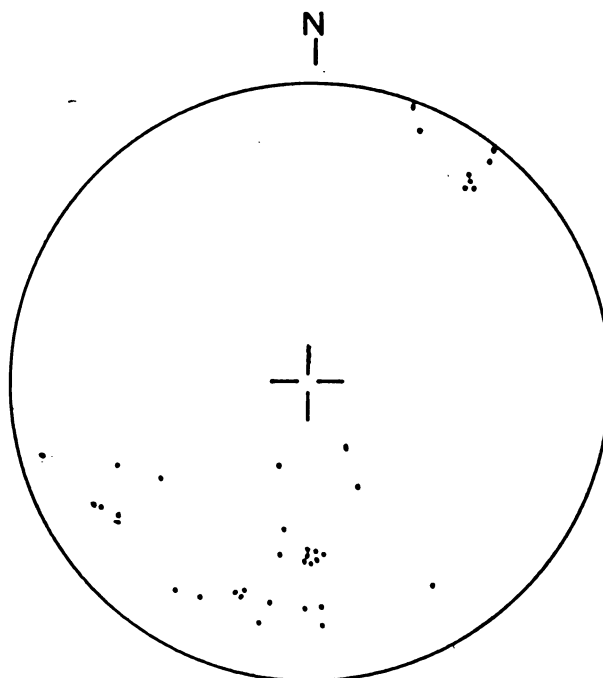
Southwest of Noddy Bay

14 measurements

E

Bay between Square Bay and St Carols

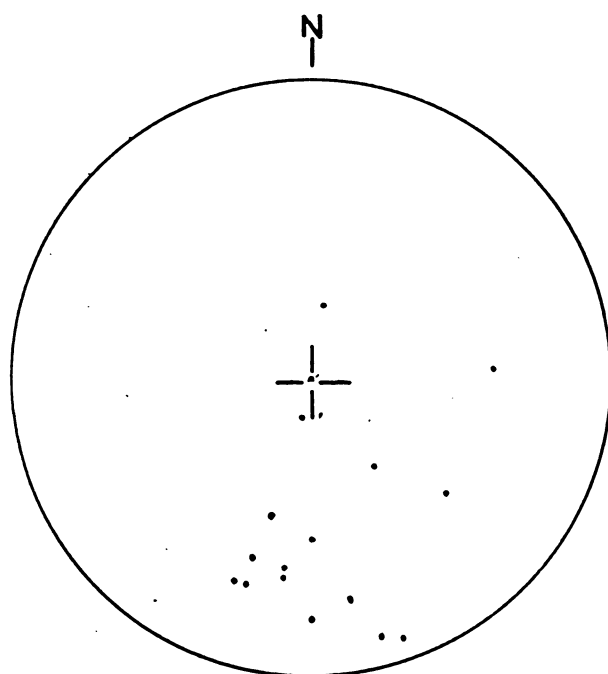
35 measurements



F

Square Bay

15 measurements



Lower hemisphere equal area
projections

in some places the limbs are steeper or overturned. The two best exposed overturned folds are in St. Anthony Bight (Plates 20 - 22). Both folds have horizontal fold axes trending ESE and the beds are overturned toward the north. This is at right angles to the normal trend. A plot of poles of limbs of folds in this formation shows no indication that the steeper beds are associated with more easterly trending axes. The beds for 350 m west of one of these folds are overturned but the dips change so that no great thickness of beds are necessarily involved. The dip of the cleavage is constantly shallow in that area. The eastern overturned fold consists of a pile of isoclinal recumbent folds resting on top of one another, (Plate 21). Isoclinal folds may be more common than recorded because the hinge areas are infrequently seen, and top and bottom criteria are often missing. The majority of beds in this area dip ESE or WNW and the folds plunge to the SSW but there are some beds, including those in the overturned folds in St. Anthony Bight which strike at right angles to the regional trend. These are thought to be the limbs of cross folds.

The cleavage in the Maiden Point Formation is planar and dips in the same SE direction as that of the Goose Tickle Formation although it often dips less steeply. A change in the dip of the cleavage

can be seen where it passes through graded beds; slaty cleavage in argillites is replaced by fracture cleavage in the coarser beds.

Mechanism of Folding

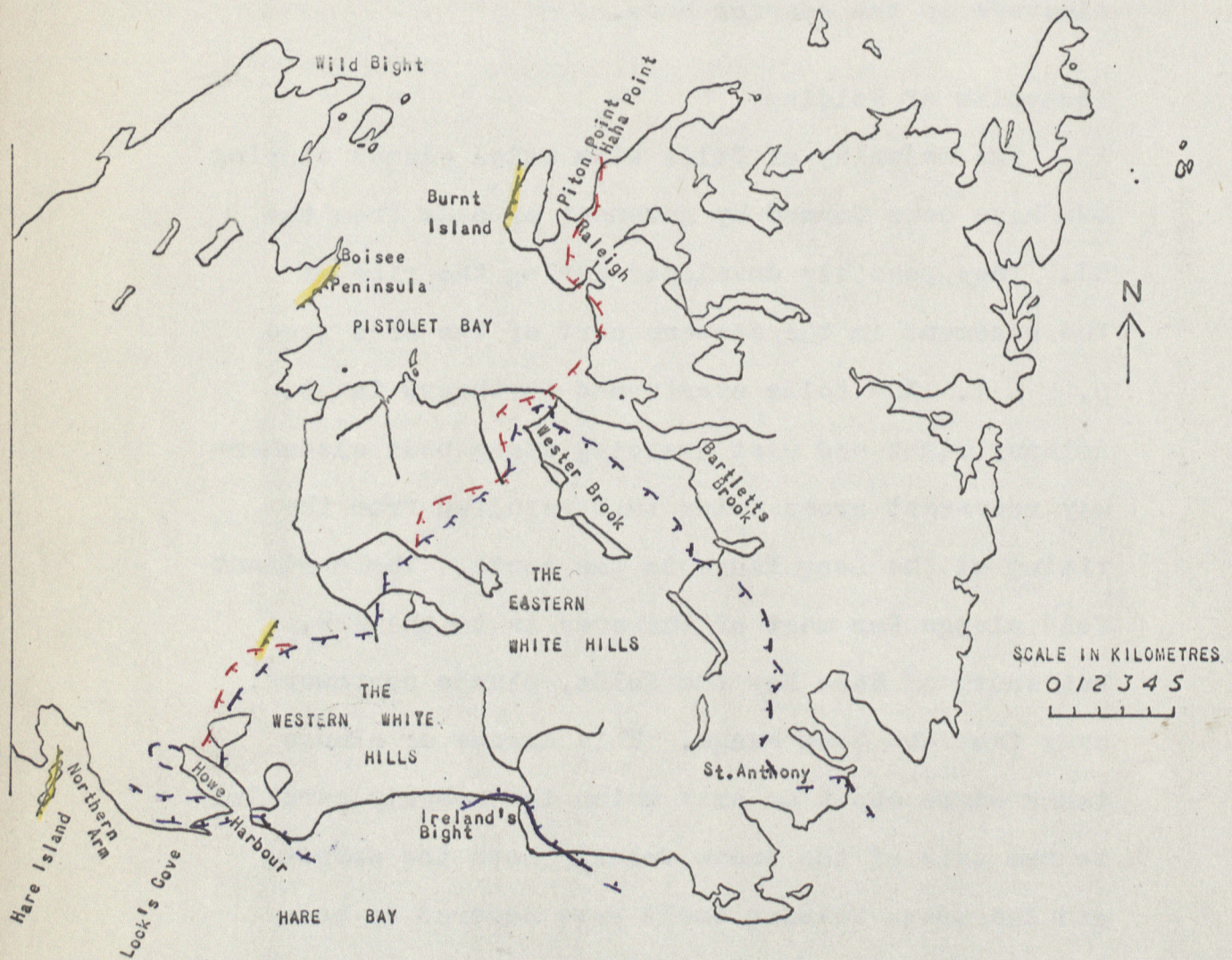
The majority of folds with axial planes dipping ESE have been formed by movement of beds from the SE. They possibly developed during the rise of the basement in the eastern part of the area (see p. 100). The folds overturned northward in St. Anthony Bight and east trending steep beds elsewhere may represent cross folds that resulted from the rising of the Long Range to the south. The dominant fold plunge for most of the area is to the SSW, but south of Hare Bay the folds, plunge northward, away from the Long Range. This change of plunge takes place about an axis which is probably parallel to the axis of the cross folds. Both the warping and the cross folding could have occurred by beds slipping off the uplifted surface of the Long Range.

Thrusts

The word "thrust" is used below for low angle dislocations without any inference to their mode of origin.

Two major thrusts are found in this area.

PISTOLET BAY AREA



Distribution of Thrusts

HARE BAY THRUST..... T T T

RALEIGH THRUST..... T T T

MINOR THRUSTS..... T T T

The lowest is here named the Raleigh thrust because it is best exposed near the village of that name. As a result of this thrust the Maiden Point Formation overlies the Goose Tickle Formation. The second major thrust, named the Hare Bay thrust by Cooper, (1937, p. 15) brings the metamorphic aureole of the peridotite over the Maiden Point Formation.

Raleigh Thrust

The volcanic member of the Maiden Point Formation rests directly on the Goose Tickle Formation in a number of exposures northeast of Raleigh. The bedding and cleavage in the shales dip steeply toward the southeast, but just below the assumed thrust plane they are deflected northwest to a nearly horizontal position. The volcanic strata on the other hand dip gently to the south east, (Plates 14 and 15).

Near the junction both the volcanic rocks and the shales are more chloritised than elsewhere. The shales and volcanic beds are separated by a distinct undulating surface, the thrust plane, with an overall dip of 2 or 3 degrees to the south east. Where they outcrop the shales beneath the thrust are commonly eroded leaving the volcanic beds overhanging. Only at one locality was it completely clear that the bedding in the shales

is cut off at the contact.

South of Raleigh a single exposure of the thrust can be seen on the east side of Pistolet Bay. Here the lower surface of the volcanic beds dips east at 50° and has slickensides trending down dip. Usually outcrops of the shale and volcanic beds are separated by covered ground.

Volcanic beds of the Maiden Point Formation lie above the shales of the Goose Tickle Formation on the southeast shore of Pistolet Bay. The contact is obscure and the units are separated by about 100 m of muddy shore without outcrop. The junction although not seen can be traced diagonally up the wooded hills south of the road just west of Wester Brook. The shales dip at 30° to 60° to the southeast. No evidence of isoclinal folding was seen but because of a lack of top and bottom criteria this could not be ruled out. The volcanic beds dip to the southeast at 10° to 20° and are apparently unfolded. The inland exposures are poor and the outcrops scattered.

To sum up, the features of the assumed thrust and adjacent beds plane are as follows:

- 1) Strike of the beds on both sides are the same but the shales dip more steeply than the volcanic beds. The shales are folded whereas the volcanic beds are not.

- 2) The bedding in shales is cut off at the junction.
- 3) The cleavage and bedding in the shales are flattened just below the junction.
- 4) The plane separating the lithologies is undulating.
- 5) The type of shale underlying the volcanic beds varies.
- 6) Slickensides are present in the beds above and below the junction.

These features can only be explained by considering their contact to be thrust.

The trends of slickensides and the dip of the axial planes of folds suggest that the beds moved to the northwest. If this were the case then, assuming the front of the thrust is at right angles to the direction of movement, the minimum distance of transport of the thrust sheet is the distance between the most northwestern outcrop of the Maiden Point Formation and the most southeastern exposure of the Goose Tickle Formation when projected onto a northwest trending line. This distance is four kilometres. Facies differences suggest that the actual distance of movement is probably much greater (see p. 99).

Hare Bay Thrust

This thrust was well described by Cooper, (1937, p. 15). The writer has seen it clearly exposed

along the northern shore of Hare Bay and at St. Anthony.

Slightly metamorphosed volcanic beds^{of the Goose Cove Formation} rest upon upturned beds of Maiden Point Formation at Ireland's Bight. The volcanic beds are almost horizontal but the shales and sandstones of the Maiden Point Formation dip at about 45° to the southeast. The beds of the Maiden Point Formation are bent toward the northwest just below the contact and are truncated. The metamorphic beds rest on the Maiden Point Formation on both sides of Howe Harbour.

At Fishing Point metamorphic rocks rest upon the sandstone and gabbro of the Maiden Point Formation. The beds of the Maiden Point Formation are certainly cut off below the contact here and the lowest beds of the Goose Cove Formation are contorted.

This junction, although not exposed elsewhere, shows up well in the topography. The schist forms higher ground than the sandstones and shales and an escarpment marks their junction. A number of streams cross this junction but in each case at least 8 m of covered ground separates the highest exposure of sandstone and the lowest of schist. Where the metavolcanic beds rest upon the volcanic member of the Maiden Point it is difficult to draw a boundary. The metamorphic beds lie directly

upon Goose Tickle shales in the central and southern parts of the plain south of Pistolet Bay.

Summary of Data on the Contact

- 1) The Maiden Point beds are truncated at the contact.
- 2) The Goose Cove beds rest upon Goose Tickle shales in the west, the volcanic member of the Maiden Point in the central part, and on the sandstones and slates of the Maiden Point in the east.
- 3) The bedding in the Maiden Point Formation dips at 30° to 50° whereas it is 5° to 10° in the Goose Cove Formation. Both have approximately the same strike.
- 4) Most of the rocks below the contact are sandstones and slates whereas those above are metamorphosed volcanic rocks with rare slate laminae.
- 5) Gabbro intrusions are cut off at the contact and do not penetrate the Goose Cove rocks.
- 6) No gradation in lithologies is seen near the contact.
- 7) The lowest beds of the metamorphic rocks are contorted.
- 8) The plane of contact is not always parallel to the bedding of the metamorphic rocks and sometimes cuts across it.

The evidence presented above can only be satisfactorily explained by a thrust.

If the metamorphic aureole and peridotite are considered to have been thrust into their present position then their relationship to the other rocks becomes much clearer. The thrust rises stratigraphically across the metamorphic rocks (Section E-F Fig. 37). This explains why the peridotite rests on the Goose Tickle Formation in Howe Harbour and gneiss on the Goose Tickle Formation just south of there. Further southeast the gneiss is underlain by less highly metamorphosed rocks and these increase in thickness in that direction.

The alignment of movement on the thrust is given by the orientation of the slickensides. These invariably show maximum alignment in the northeast quadrant (Fig. 23 and 24). Where slickensides azimuths and orientation of fold axes were measured in the same area the peaks of the plots appear to be at right angles to one another (see Fig. 22). This suggests a genetic connection between the slickensides and the folds. Most of the folds have axes trending NNE and axial planes dipping ESE. This indicates that during folding the upper beds moved NW relative to the lower ones. It is thus concluded that the direction of movement of the thrust was from the SE.

The minimum distance the thrust sheet has moved

is the distance between the most northwesterly portion of the thrust sheet and the most southeastern outcrop of the underlying beds (Maiden Point Formation), some 23 km.

Other thrusts

The St. George Formation has been thrust over the Goose Tickle Formation on the west side of Burnt Island. The beds of the Goose Tickle Formation are strongly folded just below the thrust (Plate 17). The eastern limbs of the anticlines are nearly horizontal and the western ones nearly vertical. Axial planes dip at about 40° ESE and axes are approximately horizontal. Both the amplitude and the inclination of the folds decreases away from the thrust. The limestone immediately above it is massive and without obvious bedding but higher up it shows dips inclined gently to the east. The actual contact is obscured but the shales and siltstones dip below the limestones. No breccia or striations were seen. The plane of the thrust which is very uneven with undulations of as much as 15° has a general dip of 5° to 10° to the ESE.

The shales which outcrop on the western side of Hare Island are covered by massive Table Head limestone on the eastern side. The junction is a thrust which runs along the length of the island and

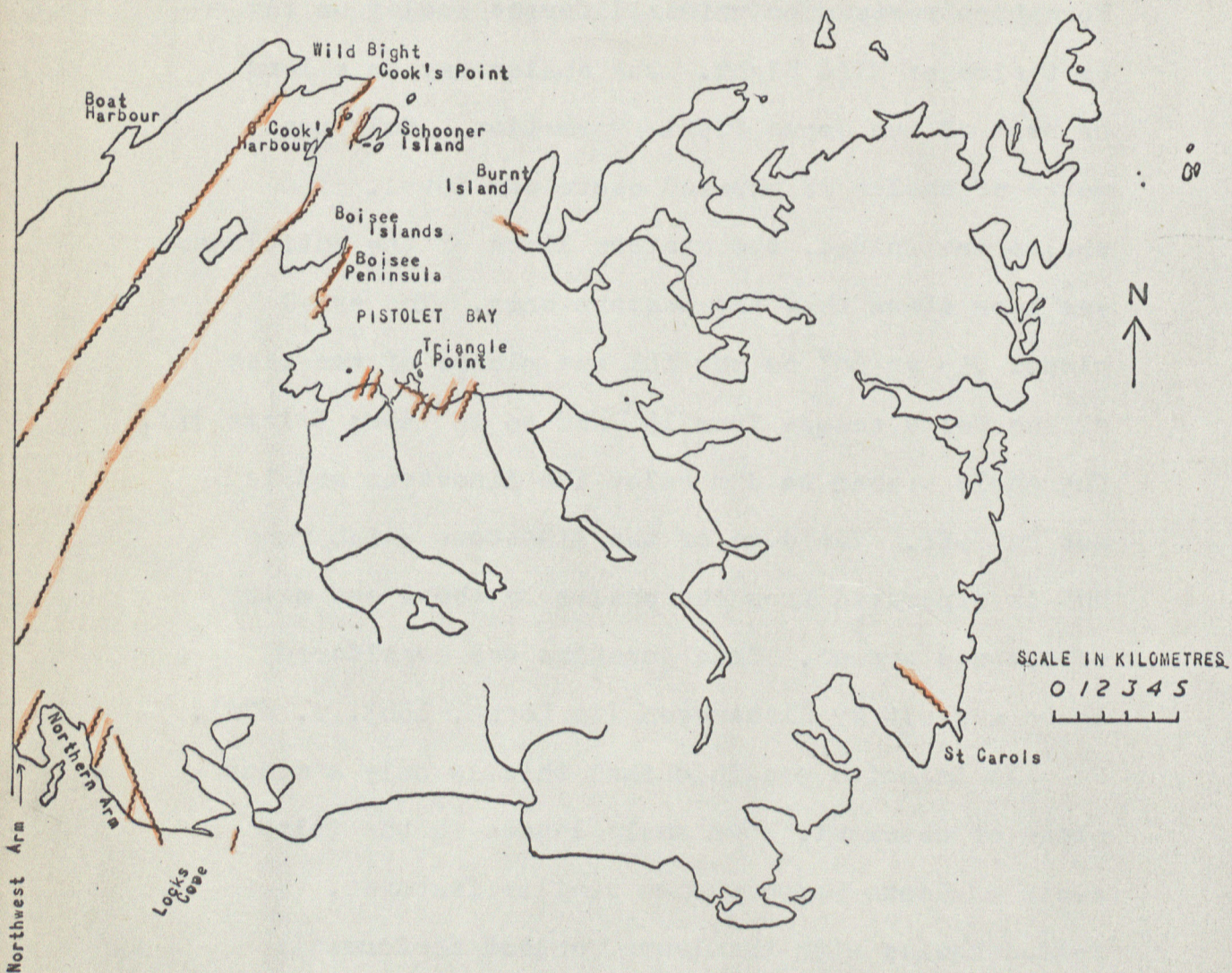
was mapped by Cooper (1937, map).

Massive limestone belonging to the Table Head Formation rests upon unfossiliferous shales on the east side of Wild Bight. The shales may be a lens or part of the Goose Tickle Formation. Only one metre of shales is exposed above sea level. The shales are folded, the eastern limbs of the anticlines are less steep than the western ones. The axial planes dip at 60° to the ESE and plunge of the axes of the folds change from 15° NNE to 15° SSW; (Plate 16). The shale appears to dip below the limestone and is not cut off. The edge of the limestone which runs NNE is separated from the shales by about one metre of covered ground. This junction was considered to be a fault by Richardson (in Logan, 1863, p. 872).

It is quite possible that this is only a minor plane of movement. Two shale lenses in the inlet south of Cooks Harbour show similar features, folded shales with the lower contact conformable and the upper one obscured. The shale lens at the mouth of this inlet has been very much distorted. The siltstone beds have been broken into boudins.

Many of the contacts between the Northwest Arm and Goose Tickle Formations are obscured and could be low or high angle faults.

PISTOLET BAY AREA



Distribution of Normal Faults

Normal and Other Faults

Normal Faults, NNE Striking (Fig. 28)

NNE striking normal faults largely control the present distribution of formations. Many of these are inferred because they bring one lithology against another, and probably many remain undetected because they do not. Several of these NNE striking faults are shown on the map and of these two are important, the Wild Bight Fault and the Shallow Bay Fault.

The junction of the St. George and the Table Head Formations can be traced southward for 12 km from Wild Bight. Overall the strike of the two formations is parallel but in detail this is not so. A fault between the formations is exposed on the shore in the centre of Wild Bight. The beds of the St. George are bent downwards and those of the Table Head upwards immediately adjacent to the fault but where the cross-section C - D ^{Fig. 37} crosses the fault the dips suggest that, on a scale of tens of metres the fault movement has changed the dips in the opposite sense, as though the fault had moved up on the east side. This is reverse drag which may be considered as an alternative mechanism to antithetic faulting for occupying the space left by a normal fault

whose fracture plane is curved (see Hamblin, 1965). Changes in lithology of the fragments in the trace of the fault suggest that several fault slices are present. The fault dies out to the southwest of the area.

The fault between the shales and limestones on the west side of the bay is best seen a few metres to the east of a small island south of Cooks Harbour. Massive limestone forms most of the island but at low tide shales can be seen on its eastern side. These are much contorted near the fault. The limestones and shales are separated by about one metre of covered ground. The amount of throw is unknown but it cannot be greater than the combined thickness of the Table Head and lower part of the Goose Tickle Formation. The west side has moved upwards. The fault can be traced inland because of the limestone forms an escarpment.

NW Striking Faults (Fig. 28)

Several normal faults striking NW were discovered and are marked on the map (Fig. 36). One which is clearly exposed at Triangle Point separates Northwest Arm Formation from Goose Tickle Formation. The NW striking fault at Locks Cove cuts the Goose Cove and Northwest Arm Formations and must therefore be post thrusting. A fault striking in the same direction

cuts the thrust on Burnt Island. The fault marked on the map near St. Carols can be seen as a lineament on the air photographs but cannot be detected on the ground although the proportion of shale to greywacke increases north of it.

Age of Normal Faults

Normal faults cut Middle Ordovician beds so the most recent movement must be post Middle Ordovician. A large fault which may be normal or strike-slip, runs along the east coast of the Great Northern Peninsula and has had at least three periods of movement (Baird 1966) Pre-Horton, pre-Windsor and pre-Westphalian.

Joints

Vertical joints trending NNE are a feature of the St. George and Table Head limestones where the beds have not been greatly disturbed. The beds near Cooks Point and in the northern part of Schooner Island have joints striking in many directions but plots indicate a maximum orientation NNE - SSW. The Goose Tickle and North West Arm shales are cut by innumerable joints trending in the same direction. They are spaced every few centimetres. Joints in this direction were not seen in the Maiden Point or Goose Cove Formations or in the peridotite but some were seen on the air-photographs of the areas underlain by these beds.

Dikes trending NNE occur in the Long Range

(Clifford and Baird, 1962). It is not known whether these were injected at the same time as the formation of the NNE trending normal faults^{and joints}, but they suggest the same stress system - maximum tension at right angles to their trend.

Other Faults

The Cabot fault which is thought (Wilson, 1961) to have a large strike slip displacement runs along the east coast of the Great Northern Peninsula. Because of the proximity of this fault the author expected to find some evidence of strike slip faulting in the Pistolet Bay area. Fold patterns and slickensides were examined with this in mind. No evidence of strike-slip faulting is seen in the fold pattern. Five of the six plots of slickensides have a minor peak lying between west and southwest (Figs. 23 and 24). Not only do these not trend in quite the right direction but also they are only found on near horizontal surfaces not on NNE striking vertical faces as would be expected if they had been caused by strike slip faulting.

Sequence of Structural Events

Some structural events in the area can be related to one another and can be placed in sequence, but others are more elusive. The broad movements

reflected in the sedimentology have been discussed at the end of the section on sedimentology.

The folding in the Northwest Arm Formation is very different from that in the adjacent Goose Tickle Formation although the lithologies are similar. This suggests the beds were folded before they were thrust into their present position. The thrusts cut across the folded strata beneath them and are therefore thought to be later than the major phase of folding. The SSW plunge of the beds and the cross folding affects all the formations and is thus likely to have occurred after the beds were thrust into their present positions.

Joints in the area are always vertical, even across folded beds. This suggests folding preceded the formation of the joints. Normal faults strike NNE, are parallel to the joints and probably originated at the same time. The upper thrust sheet is cut by a NW trending fault west of Locks Cove and the smaller Burnt Island thrust is also cut by a normal fault with that trend. The NW trending faults are therefore later than the thrusts. Joints trending NNE and NW can be seen on the air photographs to cut all the lithologies, allochthonous or not. The relation of the NNE and NW trending faults is unknown because they were never observed to intersect.

The order of events is:

- 1) Folding
- 2) Thrusting
- 3) Normal faulting and formation of joints
- 4) Movement causing plunge of fold axes and cross folds

It is thought that the allochthonon moved into its present position by gravity sliding (p. 98). If this is so then the folding in the allochthonous beds took place immediately before the formation of the thrusts in this area.

ORIGIN AND MOVEMENT OF THE ALLOCHTHON

Several lines of evidence have been presented that suggest that of some of the beds are not at their original sites of deposition. If this is so it is important to find out where these beds were originally deposited, and how and when they moved to their present site.

The author thinks that the Northwest Arm Formation is allochthonous because:

- 1) The St. George and Northwest Arm Formations are of contemporaneous but very different facies not likely to have been deposited as close together as they are now (see p. 61).
- 2) The structural differences between the Northwest Arm Formation and the surrounding Goose Tickle Formation are not attributable to differing lithologies (p. 80).

It is more difficult to prove that the Maiden Point and Goose Cove Formations are allochthonous because no direct evidence of their age has been obtained, but they are thought to be Lower Ordovician or older. (see p. 35) The Maiden Point and Goose Cove Formations both belong to a eugeosynclinal facies, whereas all the known Cambrian and Ordovician rocks in this region, except those of the Northwest Arm Formation are shelf or miogeosynclinal sediments.

The marked facies differences and the major thrusts underlying both formations suggest that they have moved a considerable distance.

Mechanism of Movement

Hubbert and Rubey (1959) have solved one of the major problems posed by thrusting and gravity sliding - that of friction. Their studies show that when water pressure approaches the pressure due to the overlying weight of rock the friction is very considerably reduced. They state that this is most likely to happen in rocks such as unconsolidated shales and sandstones with high porosity and low permeability.

The Northwest Arm Formation consists of sandstones and shales which while they were unlithified could have reduced friction due to the water trapped in the pores. The base of the Maiden Point Formation consists at least in part of volcanic rocks. Although this lithology does not seem to be satisfactory for the operation of Hubbert and Rubey's mechanism, gravity sliding in volcanic beds is well known (examples in North 1964). The lower part of the upper thrust sheet is serpentinite near the front and metamorphosed volcanic beds behind it. Serpentine has acted as a lubricant in many examples of gravity gliding, (Kozary in North 1964).

A gravity survey over the St. Anthony region

showed that a sharp change in gravity occurs in the eastern half of this area, (personal communication, Weaver). This may well indicate that the basement rises toward the east and this could be the slope which caused the gravity sliding. The present slope of the thrust planes may be due to beds piling up at the bottom of the slope (see Fig. 34 - 8). Gravity sliding is preferable to thrusting due to horizontal compression because a gravity slide would move under its own weight and no forces would need to be transmitted long distances within the sheet. Thus the only force acting on each particle is its own weight and that of particles vertically above it.

DeSitter (1964, p. 254) puts forward the following criteria for distinguishing gravity sliding from thrusting due to horizontal compression:

- 1) An appropriate slope should exist.

Results from a gravity survey may be interpreted to indicate that the basement rises to the east (D. Weaver, personal communication)

- 2) A downward plunge at the rear is characteristic of thrusts due to compression and an upward curve would be expected for a gravity slide.

The rear end is not seen in this area

- 3) A thrust sheet due to horizontal compression has no inverted limb; the inverted position

of a large mass is strong evidence for gravity sliding.

No large masses are inverted in this area.

- 4) Chaotic structure and isolated slabs in an incompetent matrix are valuable evidence for gravity sliding; a thrust mass should be coherent and competent.

The structure is chaotic in places and isolated slabs in a weak matrix are found in the Northwest Arm Formation.

- 5) In small scale gravity sliding the folds are discontinuous and have no relation with the surrounding trends; the opposite is true of thrusting due to horizontal compression.

The folds in the Northwest Arm Formation are discontinuous.

It can be seen that, except for the presence of inverted masses, all these criteria for gravity sliding are satisfied by the beds of the Northwest Arm Formation.

The Northwest Arm beds are chaotic and are thought to have arrived by gravity sliding, associated with other more competent beds. The situation is similar in the classical area for gravity sliding, the Appennines (Maxwell, 1959), and also in Turkey, and Ortesini (McRighi, 1964). In both these areas all the allochthonous beds are thought to have slid under gravity.

Probably all the allochthonous beds in the Pistolet Bay area have also arrived by gravity sliding.

The Goose Cove and Maiden Point Formations moved as relatively coherent bodies. This type of movement is classed by North (1964) as compressional glide. The Northwest Arm Formation on the other hand is much more chaotic than the Goose Cove Formation but not as chaotic as the argille scaliuse (Maxwell, 1959). The pattern of deformed rocks appears to be similar to that found by Kozary in Cuba, (in North 1964) and is called chaotic glide by North.

One feature that might suggest horizontal compression rather than gravity sliding of the Maiden Point Formation is that in this formation folds become tighter to the east. A "push" from the rear could result in this arrangement. However the prevalence of tighter folds toward the east is because the beds on the east coast are mostly slates which form sharper folds than the thick bedded sandstones. The folds in the few sandstone beds in the east are no more acute than similar beds in the west.

The metamorphism of the beds east of Quirpon Island may have been caused by another ultrabasic intrusion or by regional metamorphism not related to gravity sliding.

A further reason why gravity sliding is considered a more satisfactory mechanism than horizontal com-

pression for the Pistolet Bay area is the analogy with the southern klippe. Rodgers and Neale (1963, p. 726) state

"One might suggest that they (the klippe rocks) are merely remnants of a great thrust sheet that was once continuous over the whole area of the Great Northern Peninsula and extended to the south and east as far as the source area, having been pushed laterally from here by tangential orogenic forces. If, however, one attempts to restore the materials of so vast a thrust sheet to their original position, the amount of shortening in the source area becomes extreme."

Although no such argument can be produced from the Pistolet Bay area, the strong resemblance to the geology of the west coast suggests that if the beds there were moved by gravity then a similar mechanism was operative in Pistolet Bay.

Original Distribution and Order of Arrival

The allochthonous beds occur in three separate sheets. The sheet containing the Goose Cove Amphibolites and peridotite intrusion lies above the Maiden Point sheet, but the relation of the sheet containing the Northwest Arm Formation to the other sheets is unknown.

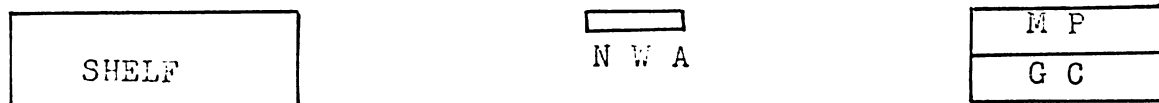
The beds of the Northwest Arm sheet are inter-

mediate in facies between the limestone and shale shelf sequence and the beds of the volcanic and clastic Maiden Point sheet; they are clastic rocks with only a little limestone and no volcanic beds. Their source should therefore lie somewhere between the source of the Maiden Point sheet and the unmoved shelf sequence.

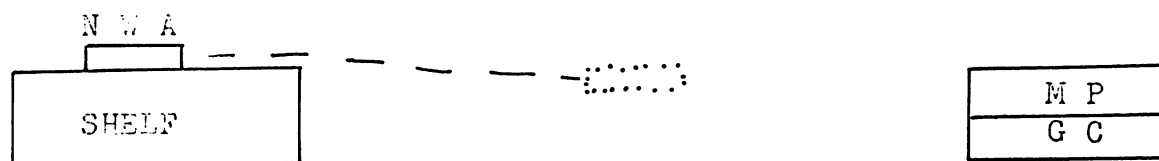
The Goose Cove sheet has been thrust over the Maiden Point sheet and must therefore have arrived later. The succession in the source area was thus the reverse of the one now preserved. As the Goose Cove Formation originally lay below the Maiden Point Formation it is possible that the volcanic beds at the base of the Maiden Point Formation belong to the same unit as those beds (volcanic before metamorphism) which form the Goose Cove Formation. The original distribution was perhaps:

West		East
Shelf Sequence	Northwest Arm Fm.	Maiden Point Fm.
		Goose Cove Fm.

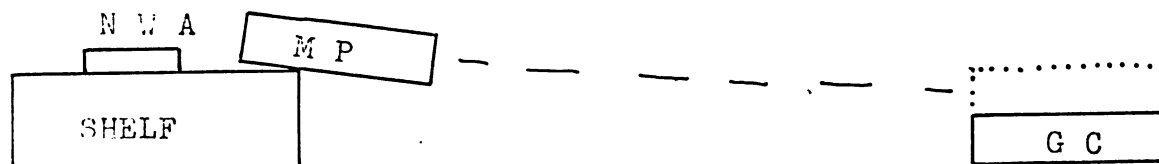
Pebbles of the Northwest Arm Formation are found in the upper part of the Goose Tickle Formation, whereas it contains no fragments of the Maiden Point or Goose Cove amphibolites or peridotite. Because of this it is thought that the Northwest Arm sheet moved during the Goose Tickle sedimentation and before the Maiden Point sheet. This gives the



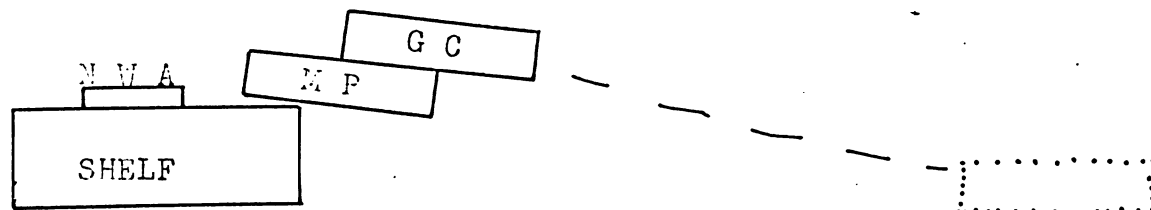
Original distribution



Stage 1 Northwest Arm sheet slides onto Goose Tickle Formation



Stage 2 Maiden Point sheet slides onto Goose Tickle Formation



Stage 3 Goose Cove sheet slides onto Maiden Point sheet

ORDER OF MOVEMENT OF ALLOCHTHONOUS BEDS

Fig. 29

following order of

- 1) Northwest Arm sheet glides onto Goose Tickle Formation
- 2) Maiden Point sheet glides onto Goose Tickle Formation
- 3) Goose Cove sheet with peridotite glides onto Maiden Point sheet.

See Fig. 29.

Source Area

The northwest - southeast alignment of slicken-sides and the northwest inclination of the folds suggest that the source area for the sheets lies to the southeast of their present positions. The minimum displacements of the sheets as worked out from the outcrop distribution are

Northwest Arm sheet	8 km
Maiden Point sheet	4 km
Goose Cove sheet	23 km

but the marked facies differences suggest a much greater distance of movement.

The probably source of the allochthonous beds in the Pistolet Bay area lies to the southeast beneath the sea at the present time. Nevertheless some idea of the lithologies likely to be found there can be obtained by studying the beds on the northeast coast of Newfoundland which strike toward the source

area (Fig. 30).

Ideally rocks in the source area of the Maiden Point and Goose Cove sheets should contain the following lithologies or their metamorphic equivalents:

Coarse sandstone without abundant current bedding

Black, grey, and red slate

Agglomerates, tuffs, and pillow lavas

Peridotite intrusions

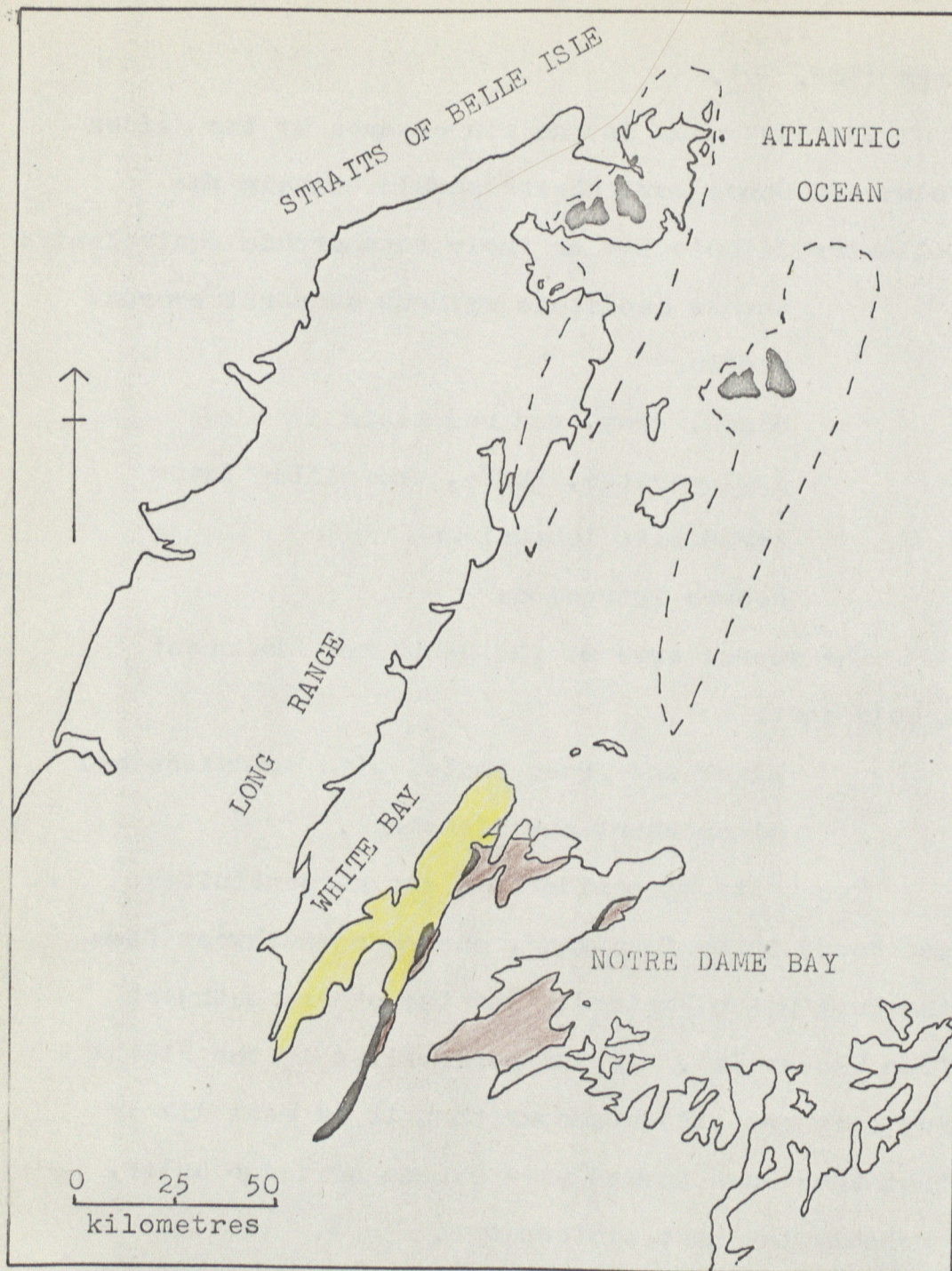
Gabbro intrusions

The source area of the Northwest Arm sheet should contain:

black and green shales with sandstone and minor chert and limestone.

Two belts of peridotites and serpentinites are found in Newfoundland, one runs southwest from the Burlington Peninsula and the other southwest from Gander Bay. If the peridotites in the Pistolet Bay area are allochthonous then it is most likely that they once formed part of one of these belts, probably the most western one.

Certain beds can be ruled out as possible source rocks. No beds of Carboniferous age are in the least similar to the klippe beds. The Silurian Botwood group consists mainly of thick sandstone beds but these are commonly cross bedded. All except the lower beds of the Exploits Bay



Fleur de Lys Group.....

Baie Verte Group.....

Ultrabasic rocks.....

ORIGINAL POSITION OF THE KLIPPE

The klippe has been moved backward along the direction given by the slickensides to a position where the White Hills Ultrabasic masses are aligned with those on the northeast coast

and Gander Lake groups have been dated as Middle Ordovician or younger by graptolites. The beds of the klippe are thought to be Cambrian and no beds of known Cambrian age found in the White Bay - Notre Dame Bay area have much similarity with the beds in the allochthon. The Fleur de Lys Baie Verte beds which are no younger than Middle Ordovician and probably no older than late Precambrian are the closest in lithology to the allochthonous rocks in the Pistolet Bay area (Fig. 30).

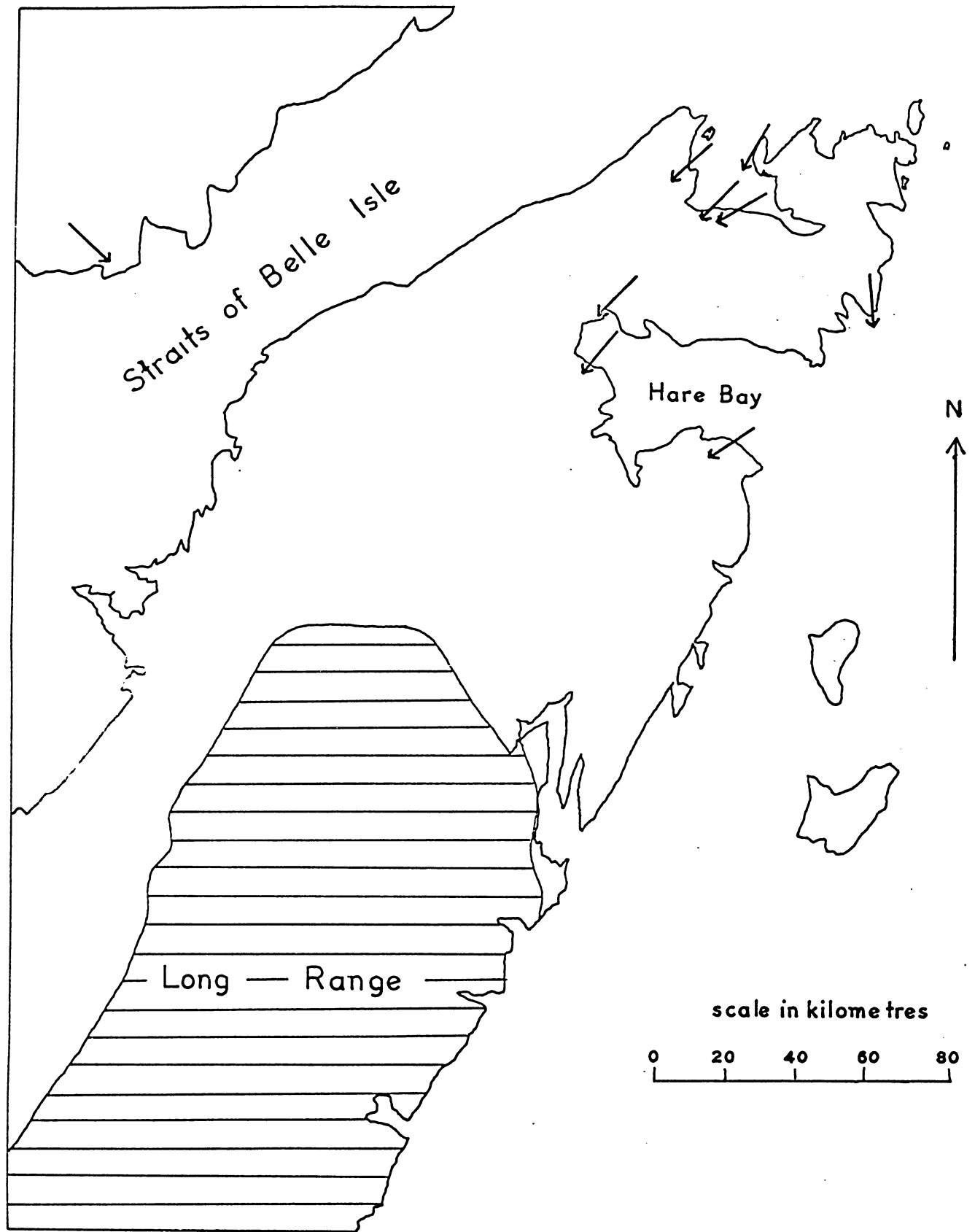
The Fleur de Lys rocks are schists and gneisses composed of quartz, plagioclase, biotite and muscovite. Graphitic schist and marble are found within the gneisses, and hornblende gneiss and beds of marble are found in the upper part of the succession. Before metamorphism these beds were probably greywacke sandstones with interbeds of shale and limestone, and in the upper part limestone and basic volcanic beds and sandstone (Williams, 1964, p. 1144). This sequence is similar to the Maiden Point Formation in the northern part of the Pistolet Bay area.

The beds of the Fleur de Lys Group are conformably overlain by the Baie Verte Group which consists of sericitized volcanic beds (Williams, 1964, p. 1147) that may well be equivalent to the Goose Cove Formation. Ultrabasic rocks occur in many places along the boundary between the Fleur de Lys and Baie Verte Groups.

P.M. Clifford in a lecture to the Geological survey of Canada in 1966 suggested that the Fleur de Lys group underwent deep seated metamorphism before the deposition of the Baie Verte Group. If so, the source area for the Goose Cove beds might lie within the upper part of the Fleur de Lys group; but in this case the metamorphism can not have taken place before the Middle Ordovician when the gravity sliding occurred. From the above it is apparent that suitable rocks for the Maiden Point and Goose Cove sheets could exist in the proposed source area of the allochthon, but no suitable source rocks for the Northwest Arm Formation have been found. It is of course possible that no rocks of the appropriate type now exist in the source area as they could have all slid out of that area.

Date of movement

No certain evidence has been discovered for dating the arrival of the klippen in Pistolet Bay. However it is thought that the conglomerate at the top of the Goose Tickle Formation (Middle Ordovician) was derived from the erosion of the Northwest Arm Formation as it was sliding into its present position. If this is so then the movement took place in the Middle Ordovician. Certainly its arrival can not have been before the deposition of the uppermost beds of the Goose Tickle Formation. Rodgers (1965) reported that the Long Point Formation (Middle Ordovician) rests



Relationship of Cambrian and Ordovician Current
Directions and the Long Range

unconformably on the allochthonous Humber Arm Formation in western Newfoundland. This suggests that the klippen in that area must have arrived before the end of the Middle Ordovician and thus corroborates the evidence from Pistolet Bay.

The Long Range - A Possible Obstacle

Although the presence of the Long Range in its present position relative to the surrounding beds would not hinder the movement of the klippe in the Pistolet Bay area it would certainly have been in the path of the west coast klippe.

The currents which deposited the Goose Tickle Formation moved straight towards the present position of the Long Range (Fig. 31). This suggests that the Long Range gneisses were lower than the depositional surface of the Goose Tickle Formation during the Middle Ordovician. Some of the rise of the Long Range took place during the Mississippian as shown by the occurrence of Precambrian boulders in conglomerates of this age (Baird, 1957). It is therefore thought that the range has moved upwards relative to the adjacent strata since the Middle Ordovician and probably since the emplacement of the klippen.

An extension of the Cabot Fault, which is thought (Wilson, 1962) to have a large lateral displacement

lies just off the east coast of the Great Northern Peninsula. The actual displacement on this fault is unknown but Wilson believes it to be sinistral. This means that the source area now lies further northeast than originally. However this does not affect the correlation of the source area beds with the beds outcropping in White Bay and Notre Dame Bay which lie on the same side of the fault.

The Cause of the Gravity Sliding

Evidence of broad epeirogenic movements is suggested by the change in sediment type of the beds in the shelf sequence. The earliest beds were laid down in shallow water whereas the later ones are deep water types. The implied sinking may have led to the beds in the source area being relatively elevated and thus gravity sliding onto the shelf sequence.

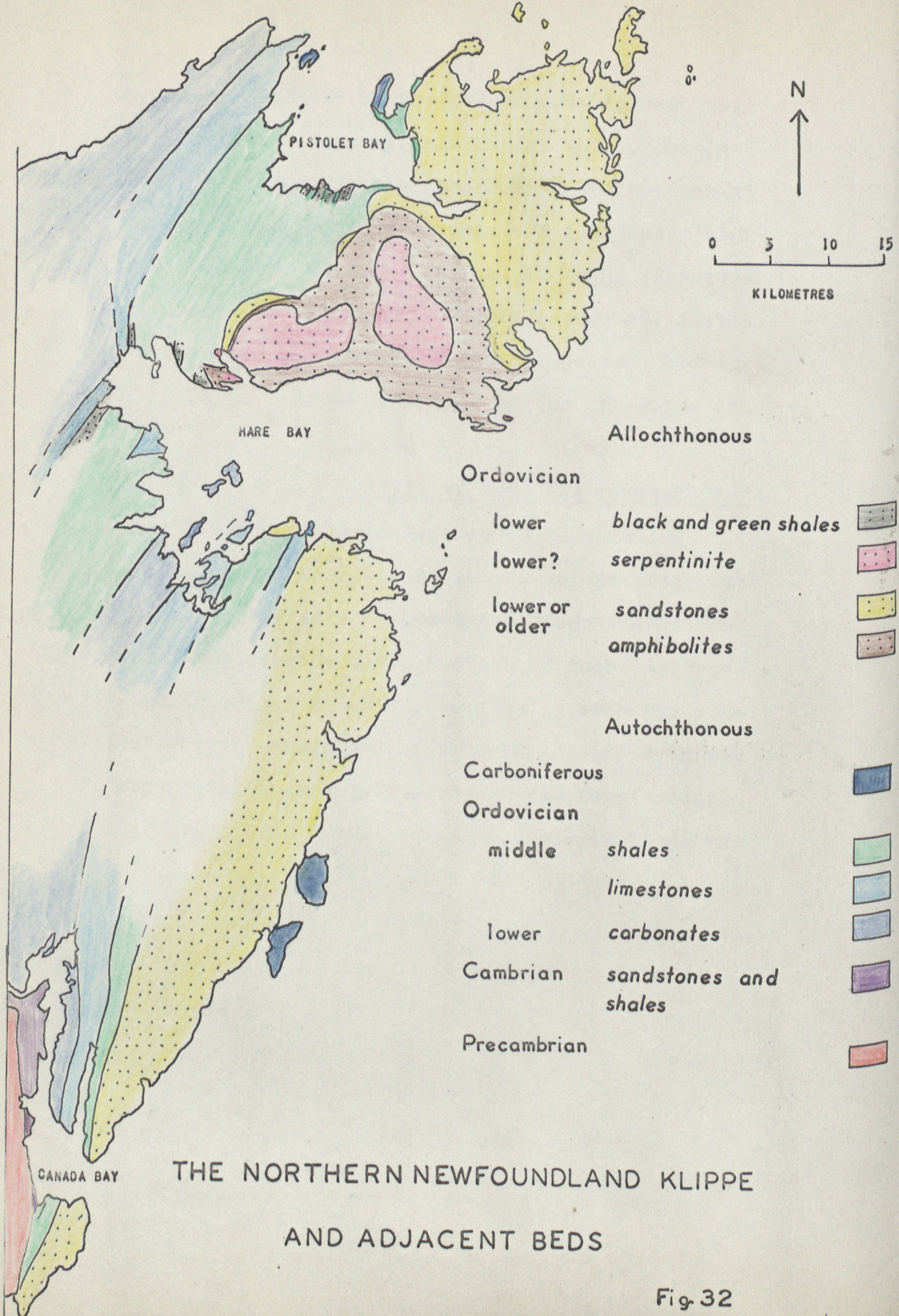


Fig. 32

COMPARISON OF PISTOLET BAY WITH OTHER AREAS

Canada Bay and Hare Bay

The beds on the south side of Hare Bay were studied by Cooper (1937) and the geology of Canada Bay was described by Betz (1939). The beds in both areas are very similar to those north of Hare Bay (Fig. 32).

The Lower Cambrian sandstones in Canada Bay are thinner and ^dredder than their equivalents in the Pistolet Bay area. Middle and Upper Cambrian shale and dolomite outcrop in Canada Bay but not to the north. The St. George and Table Head Formations are much alike in both areas but the Middle Ordovician Englee Formation contains many more limestone beds than its northern equivalent the Goose Tickle Formation. Limestone breccia beds occur both to the north and south of Hare Bay but were not noted in Canada Bay. Betz mapped the contact between the Englee Formation (Goose Tickle) and the Canada Head (Maiden Point) as conformable but this was probably based on the parallelism of the beds; the contact is not visible.

Schist and gneiss outcrop on the Fishot Isles and on the Grey Islands to the east.

Several thrusts are present on the south side of Hare Bay and in Canada Bay but the displacements on them cannot be determined. As in Pistolet Bay, the folds and dominant normal faults trend NNE. The folds in both areas are inclined WNW but air photographs suggest that those in the south plunge NNE whereas those in the north plunge SSW.

A three week reconnaissance south of Hare Bay showed that the rocks there are very similar to those to the north, so that any origin postulated for the rocks in one area must be applicable to the other.

The West Coast of Newfoundland

The area of the klippe proposed by Rodgers and Neale (1963) and the adjacent rocks on the west coast of Newfoundland is larger than the Pistolet Bay area and contains more complete sequences of both the shelf and eugeosynclinal facies. However the beds of the west coast pose the same field and spatial problems as the beds in Pistolet Bay - a eugeosynclinal sequence bounded by a contemporary shelf sequence.

The Lower Cambrian is quartzite, shale and limestone in Hawke Bay but further south the beds are more argillaceous. Nowhere is the thickness

of quartz sandstones as thick as that on the White Islands. Middle and Upper Cambrian shales and carbonates outcrop at Eddies Cove, near Port au Port and in Canada Bay.

The Lower Ordovician is represented by the St. George Formation of which only the upper part is found in Pistolet Bay area but in St. Georges Bay there is a complete section from the top of the Cambrian to the top of the Lower Ordovician. The St. George and Table Head Formations appear to be conformable in the Pistolet Bay area but they are separated by an erosional disconformity further south.

The Middle Ordovician Table Head Formation is much thicker at Table Point than to the north or south of it. Shales occur at the top of the Table Head Formation both in Pistolet Bay and further south and contain limestone breccias in Pistolet Bay and at Port au Port.

No eugeosynclinal beds of certain Cambrian age have been found in Pistolet Bay but on the west coast Kindle and Whittington (1958) have shown that some of the limestone breccias are Upper Cambrian. These beds are thought to be allochthonous by Rodgers and Neale (1963). Oxley (1953) suggested that the Middle and Upper Cambrian are represented in the breccia beds at Green Point.

Two different lithologies of Lower Ordovician age are found in the west coast allochthon; shales and limestone breccias of the Green Point Formation (Schuchert and Dunbar, 1934, p. 38) and black and green shales, like those of the Northwest Arm Formation, that outcrop near Corner Brook (R. Stevens, personal communication). The breccia beds in the Cow Head region are Upper Cambrian to Middle Ordovician (Kindle and Whittington, 1958) and are thought to be allochthonous (Rodgers and Neale, 1963).

Ultrabasic and volcanic rocks between Bonne Bay and St. George Bay are similar to those in the Pistolet Bay area. Massive grey-green sandstones, intruded in places by gabbros occur in both allochthonous areas but they are not associated with volcanic rocks in most parts of the west coast allochthon. The grey-green sandstones and the black and green shales are commonly found together.

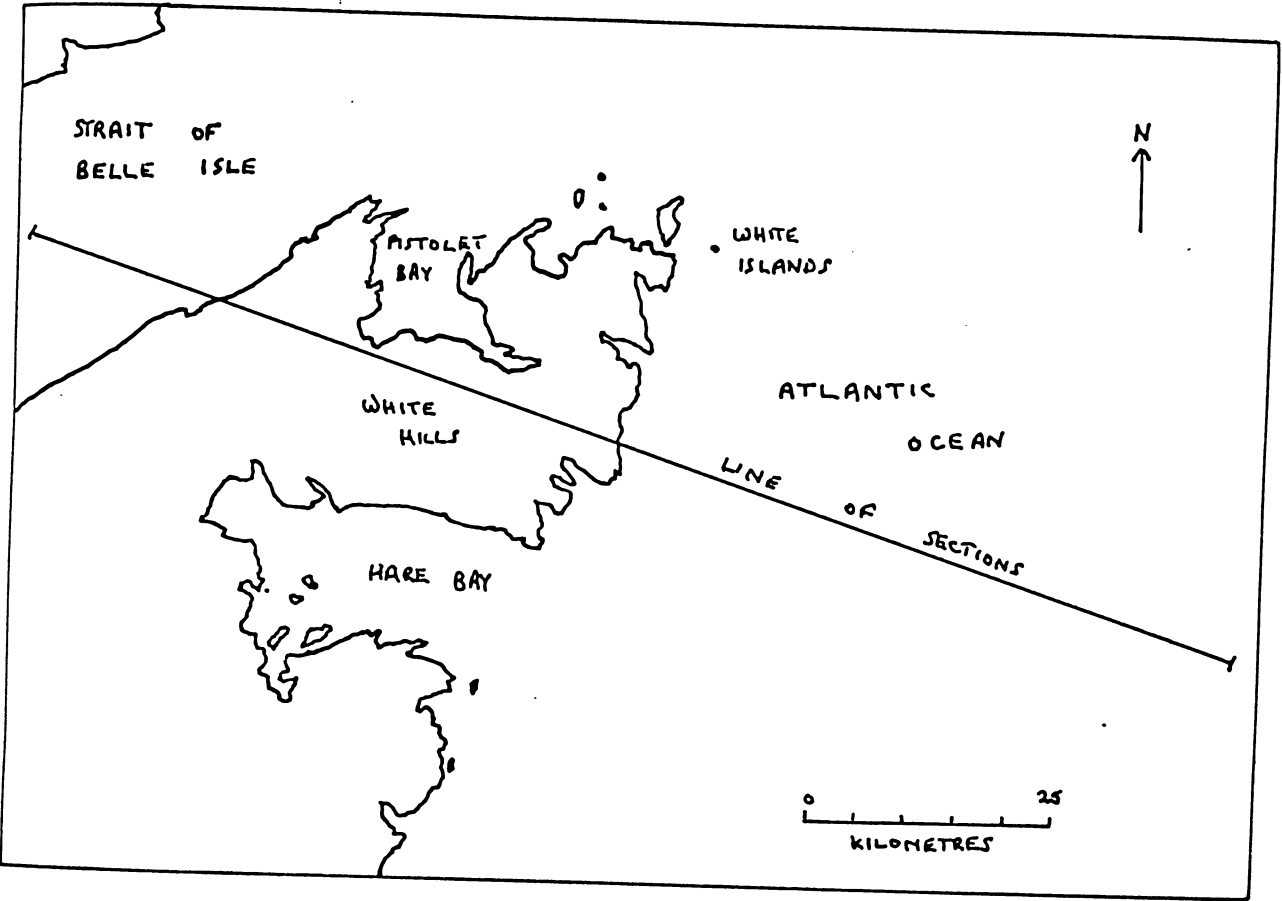
No beds comparable to the Long Point and Clam Banks Formations occur in Pistolet Bay.

Both the klippen are cut by thrusts and by normal faults. The folding is disharmonic and the competent sandstone beds are broken in the sequences where shales are abundant. The pattern of the faults is not consistent. NNE trending faults are dominant in some areas and the northwest ones in others. The folds and outcrop pattern trend NNE both on

the west coast and in the Pistolet Bay area.

The autochthonous terrains are similar in both areas but the allochthonous beds on the west coast contain a sequence absent in the Pistolet Bay area which consists of shales, limestone breccias with thin limestone beds. The lithology suggests that these beds were deposited close to the shelf rocks because similar beds are found at the top of the Table Head Formation. They are miogeosynclinal but allochthonous whereas in Pistolet Bay the miogeosynclinal beds, the Goose Tickle Formation, are autochthonous.

Another important difference between the west coast and the Pistolet Bay areas is the thickness of the ultrabasic masses. Gravity data suggest that one of the west coast intrusions, the Trout River intrusion, has a thickness of 5000 m (Weaver, personal communication).

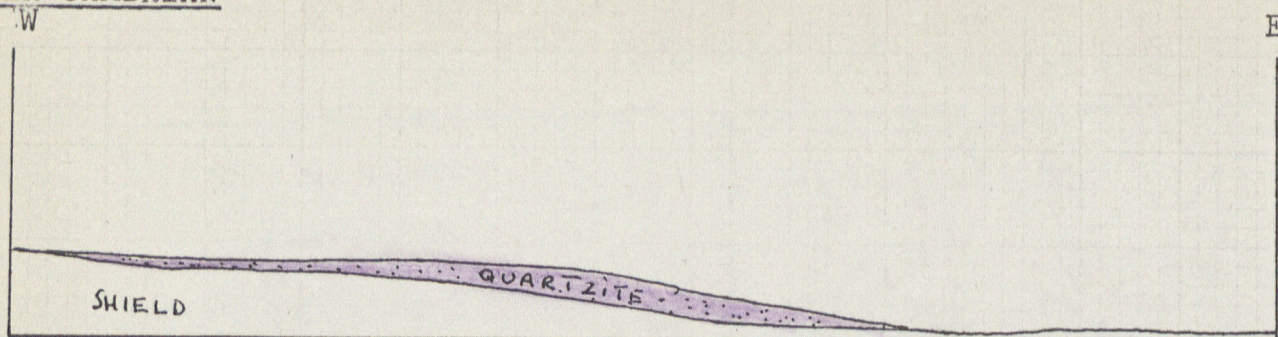


Map showing line of sections

Scale on sections = 
 Vertical exaggeration 25 : 1 approximately

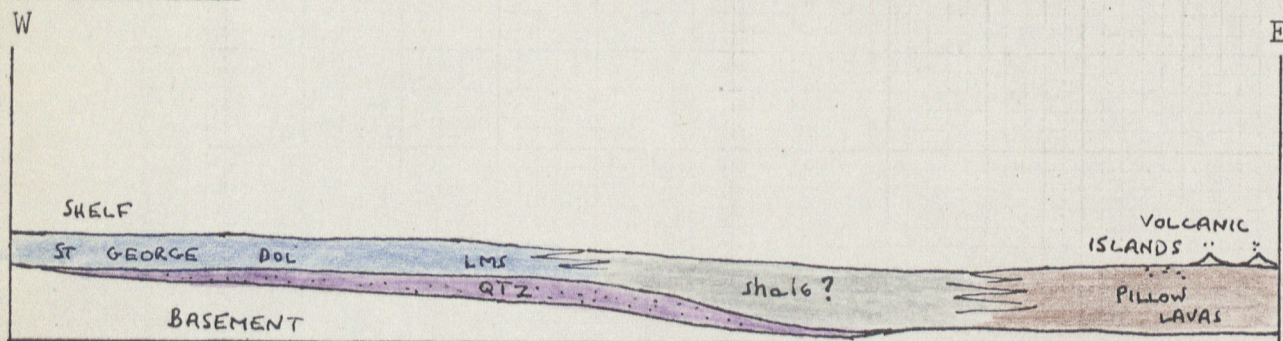
Fig 34 GEOLOGICAL HISTORY

LOWER CAMBRIAN



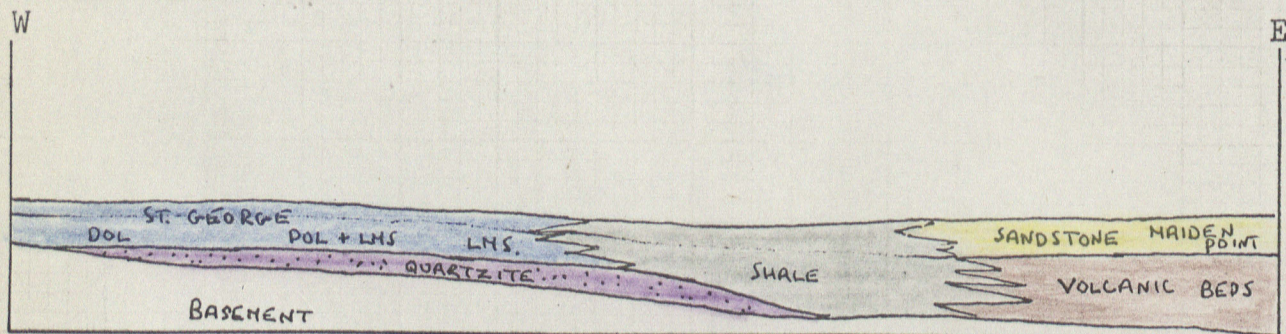
- I. Sea transgresses onto shield and deposits basal sandstone. Sandstone is red near shore and white away from it.

MIDDLE CAMBRIAN



- 2 Deposition of dolomites in the west and of volcanic material in the east.

UPPER CAMBRIAN



- 3 Further deposition of dolomites in the west. Volcanic beds are followed by coarse sandstones in the east. These probably graded into shales to the west.

GEOLOGICAL HISTORY

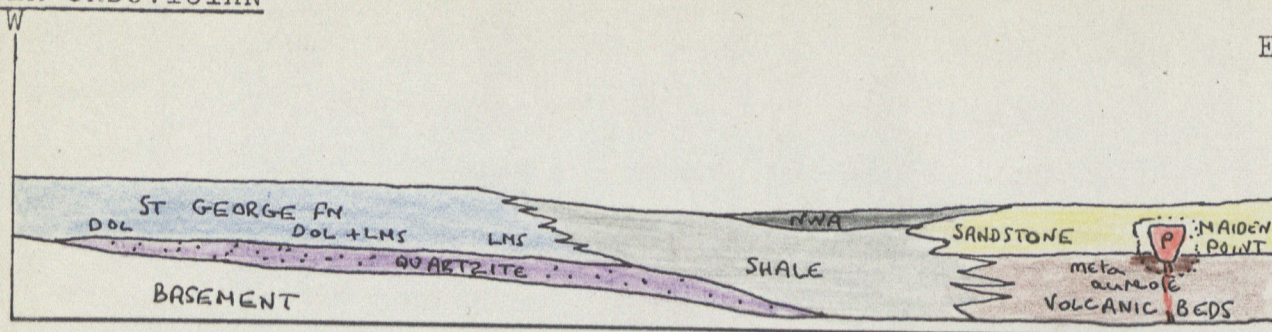
The sequence of events and paleogeography described below are based mainly on data from Pistolet Bay, from northern Newfoundland and to a lesser extent from the rest of Newfoundland. The following geological history should be considered as a very hypothetical framework.

Cambrian

The sea transgressed onto the shield in Lower Cambrian times depositing basal quartzites and arkoses on both sides on the Long Range and in the White Islands (Fig. 34 - 1). This was followed by the deposition of limestone and dolostone which continued into the Middle and Upper Cambrian. The basal quartzite and succeeding beds are not found further east than the White Islands or in Notre Dame Bay thus it is likely that the northeast trending basin which controlled sedimentation during the Ordovician had already formed.

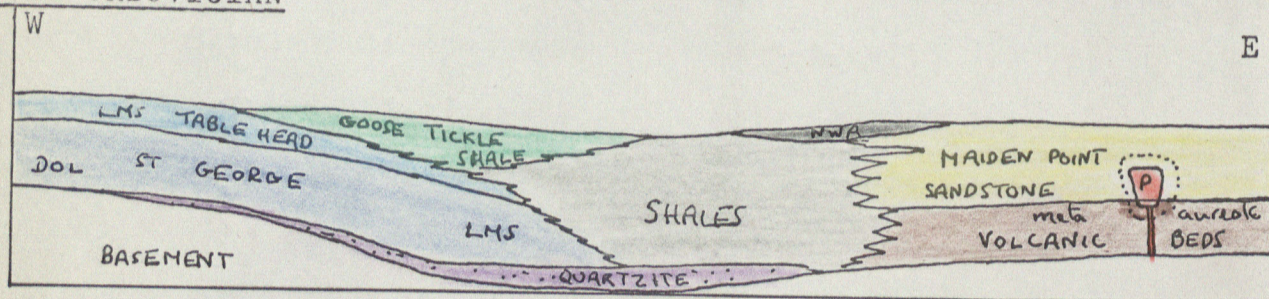
To the east a belt of volcanoes (possibly an island arc) gave rise to agglomerates, tuffs and pillow lavas (the Goose Cove Formation and the lower part of the Maiden Point Formation, Fig. 34 - 2). Above the volcanic beds sandstones derived from the erosion of a plutonic and metamorphic terrain

LOWER ORDOVICIAN



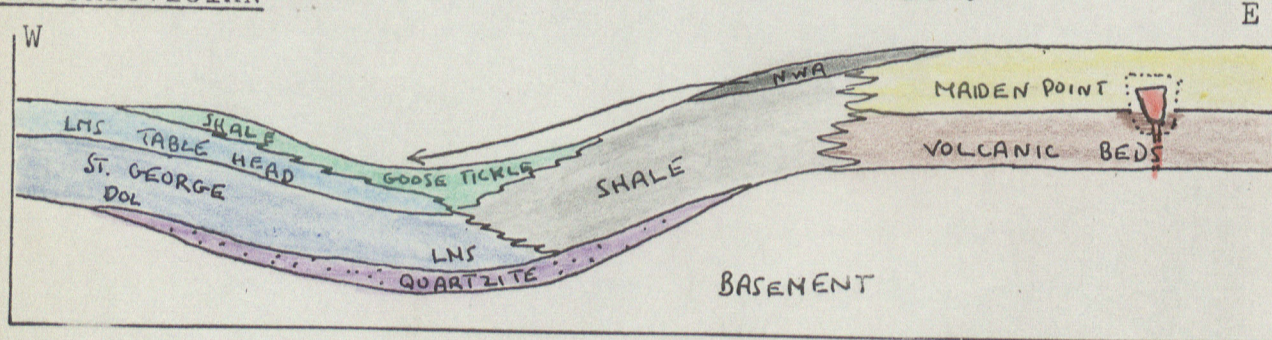
- 4 Deposition of limestones and dolomites which form the upper part of the St. George Fm in the west. Toward the east the Black and green shales of the Northwest Arm Fm. were laid down. An ultrabasic body was intruded into the beds in the east, (P).

MIDDLE ORDOVICIAN



- 5 Deposition of Table Head limestone and Goose Tickle shale. Basement rises in east causing erosion of Northwest Arm Fm. and sinks in west allowing shales to be deposited on former shelf area.

UPPER ORDOVICIAN



- 6 The basement continues to sink in the west causing the Northwest Arm Fm. to slide onto the Goose Tickle Fm.

Fig. 34 GEOLOGICAL HISTORY

lying to the east were deposited on a delta. The delta sediments were disturbed by slumping, and were carried by turbidity currents to form a succession of greywackes on the sea floor (Maiden Point Formation). Volcanic activity continued during the deposition of these beds (Fig. 34 - 3).

Lower Ordovician

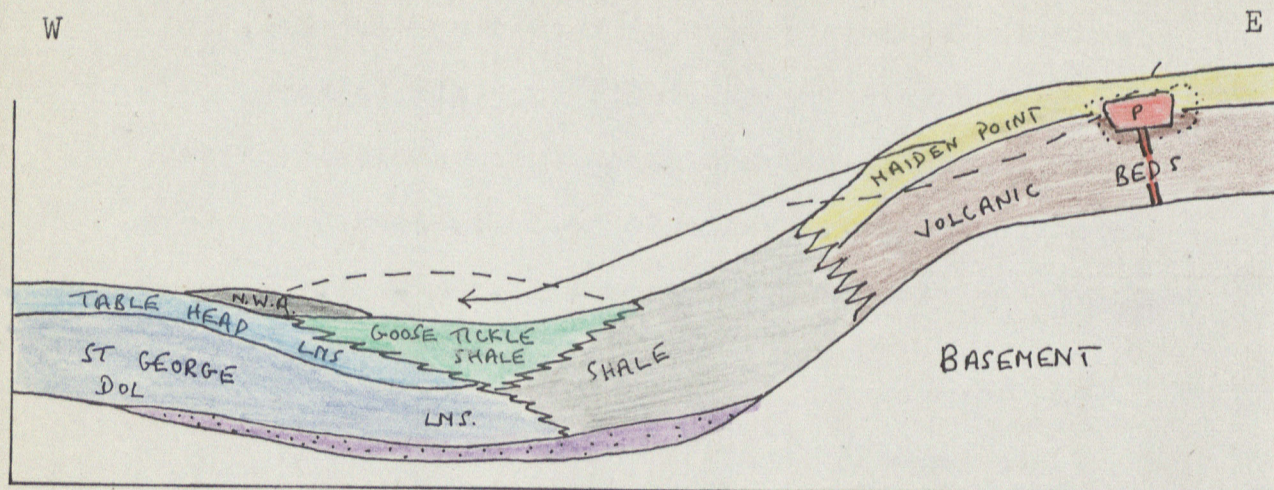
The deposition of limestones and dolomites initiated during the Cambrian continued into the Lower Ordovician and formed the thick shelf deposits found on the west coast of Newfoundland. The edge of the shelf was unstable and material slumped off and was deposited by turbidity currents to the east of the shelf edge.

While the shelf limestones and dolomites were being laid down in the west, to the east, away from the shelf, deposition of black and green shales with some sandstone and limestone occurred (Fig. 34 - 4). Peridotite intruded the volcanic beds on the eastern side of the basin and metamorphosed them to amphibolites.

Middle Ordovician

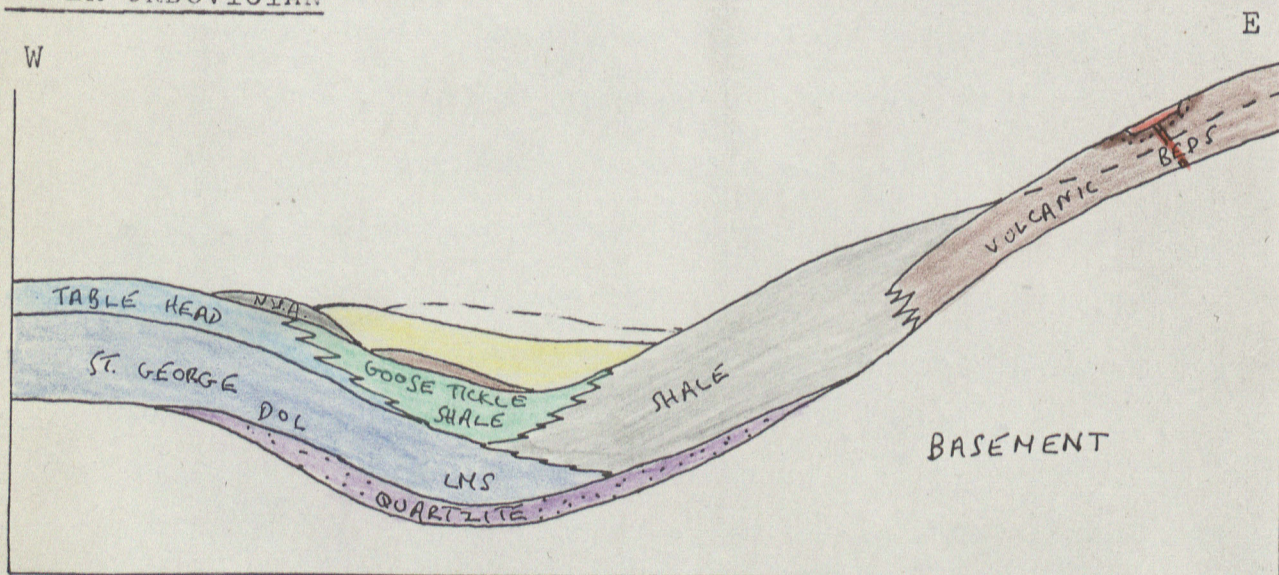
The basin became deeper in the western part so the areas of previously shallow water began to receive some of the clastic material coming from the east. Thus pure limestone and dolomite (St.

UPPER ORDOVICIAN



- 7 Continued sinking of the basement in the west and rise in the east results in the Maiden Point Formation sliding onto the Goose Tickle Formation.

UPPER ORDOVICIAN



- 8 Further movement of the basement causes further gravity sliding, the Goose Cove Formation and peridotite slides onto the Goose Tickle and Maiden Point formations.

Fig. 34 GEOLOGICAL HISTORY

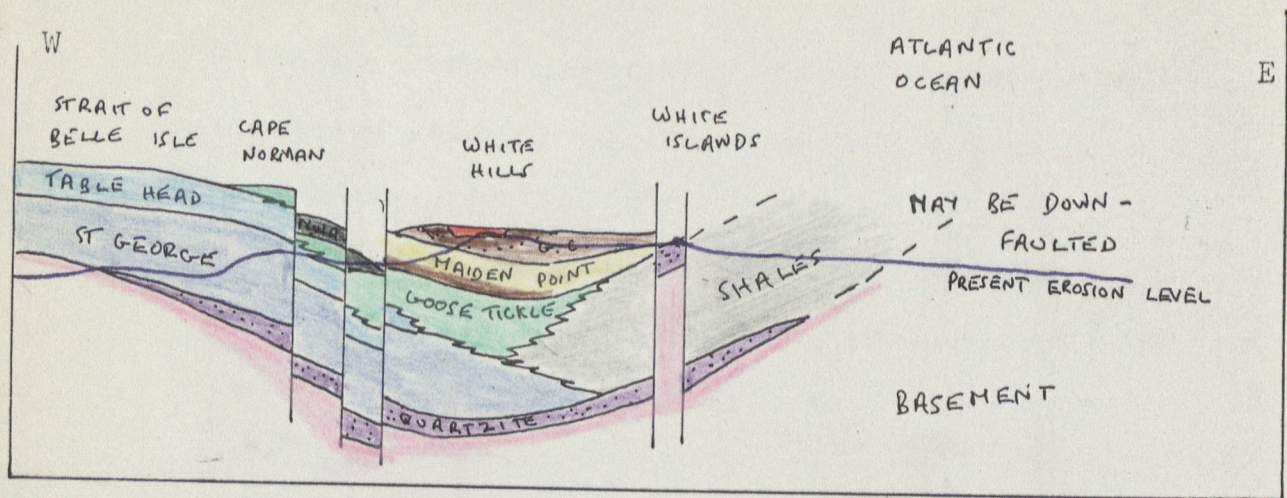
George Formation) were succeeded by slightly argillaceous limestone (Table Head Formation). Towards the top of the latter formation, shale lenses occur in the limestone, and the formation is followed by a thick sequence of shale and greywacke (Goose Tickle Formation). The change from argillaceous limestone to shale is sudden in Pistolet Bay but further south shales with interbedded limestones are common. The argillaceous material was first deposited only on the eastern edge of the shelf but later it spread further and further westwards. The calcareous material on the edge of the shelf became unstable and collapsed to flow eastward to form limestone breccias. The instability may well have been caused by movements, possibly faulting, associated with the deepening of the western part of the basin (Fig. 34 - 5).

The eastern part of the trough was uplifted, causing some erosion of the Northwest Arm Formation so that fragments were included in the upper part of the Goose Tickle shale than being deposited in the west.

Upper Ordovician

Beds of the Northwest Arm Formation slid down the slope created by the uplift in the east to come to rest on the Goose Tickle shale in the

POST ORDOVICIAN



- 9 Normal faults cut the area. Younger formations may have been deposited on top but if so, have since been completely eroded away.

Fig. 34

GEOLOGICAL HISTORY

west (Fig. 34 - 6).

After emplacement of the Northwest Arm Formation further deepening of the trough in the west caused the Maiden Point beds to slide onto the Goose Tickle Formation (Fig. 34 - 7). Still further crustal movement resulted in beds of the Goose Cove Formation and the peridotite sliding down onto the Maiden Point sheet (Fig. 34 - 8). The movement of these large masses was accompanied by folding in the shelf beds.

The region was later subjected to stresses so oriented as to cause NNE and NW trending normal faulting (Fig. 34 - 9) and the intrusion of dikes into the Long Range which was then much below the depositional surface of the Goose Tickle Formation.

The Long Range rose to its present level. Lateral movement along the Cabot fault may have subsequently displaced the source area of the allochthon in relation to its present position. Younger formations may have been deposited (Silurian, Devonian and Carboniferous are found on the west coast) but have been later eroded away. Subsequent erosion has produced the present outcrop pattern.

FUTURE RESEARCH

Many of the uncertainties in the structural history and the correlation of the Maiden Point and Goose Cove Formations are due to a lack of direct evidence for the age of these beds. Much time has already been spent looking for fossils but further search might be productive. Age determination by radioactive methods may produce significant results, especially if unweathered biotite rich rock can be found. This would give the age of metamorphism associated with the peridotite intrusion, and the minimum age for the gravity sliding.

Another possible fruitful line of research in the Pistolet Bay area, is the structural analysis of the Northwest Arm Formation. The beds do not underlie a large area and exposures are limited to the shore where they are well exposed at low tide. The Maiden Point and Goose Cove Formations might also yield interesting structural data but exposures are much less accessible than those of the Northwest Arm Formation.

Detailed mapping of the beds between Hare Bay and Canada Bay would, in conjunction with this study provide a complete picture of the northern Newfoundland klippen. However the beds south of Hare Bay are less well exposed and as far as is

known do not include beds of the Northwest Arm
sheet or the Goose Cove sheet.

SUMMARY

The beds in the Pistolet Bay area have been divided into two sequences, shelf and eugeosynclinal, on the basis of their facies and on their stratigraphic and structural relationship to each other. The stratigraphy of these sequences is summarized in Table 3 (p. 9) and the main elements of the structure of the region can be seen on Fig. 20 (p. 74).

The eugeosynclinal sequence is thought to be allochthonous because major low angle faults are visible beneath two of the formations and because of the strong facies contrast between this sequence and the shelf sequence. The allochthonous beds arrived in three separate thrust sheets which are thought to have moved by gravity sliding. This mechanism is preferred because it does not involve the great stresses to which the rocks would be subjected if the beds had been pushed from behind, and because the basement slopes upward to the east to provide the necessary gradient. The nature of the deformation of the Northwest Arm Formation also suggests gravity sliding. The allochthonous beds arrived in the area sometime after the Middle Ordovician.

The NW-SE trend of the slickensides and the SE dip of the axial planes of folds suggest that

the allochthonous sheets moved northwest relative to the underlying strata and thus that the source area for them lies to the SE. The minimum displacement of the sheets is 24 km but facies differences suggest a greater movement. The lithologies of the allochthon are best correlated with the Fleur de Lys and Baie Verte groups in the NE coast of Newfoundland and the source area is thought to lie along strike to the NNE of the outcrop of these groups. If this is so then the allochthon has moved 60 km.

The Pistolet Bay area compares with the west coast of Newfoundland in having two rock sequences one of which was deposited to the east but was subsequently moved into the area by gravity sliding.

APPENDIX

The Breccias and Conglomerates in the Goose Tickle Formation

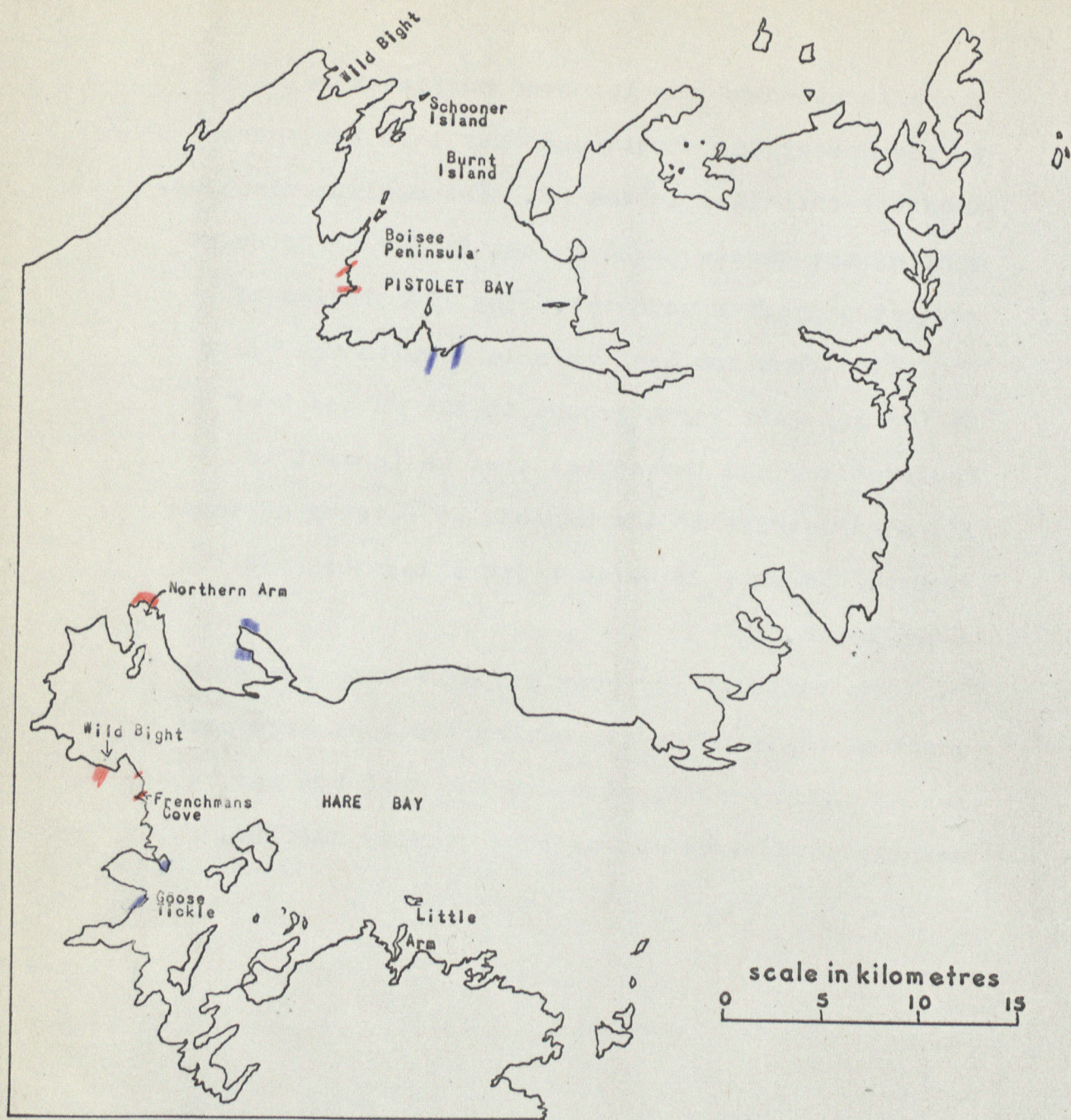
The Limestone Breccias

Breccias with angular limestone clasts in a matrix of calcareous shale outcrop in the southwest of Pistolet Bay and in the western part of Hare Bay (Fig. 35).

The thickest limestone breccia bed occurs about 10 m above the disconformable junction of the Table Head Formation and the Goose Tickle Formation. Other thinner breccias lie close to the faulted junction of the Table Head and Goose Tickle Formations and their exact stratigraphic position is unknown although they are thought to lie near the base of the Goose Tickle Formation.

The breccias are underlain by greywackes and shales, which in many cases are depressed by the clasts of the breccias but in no place were the beds seen to be broken. On the other hand, several fragments of greywacke and shale identical with the underlying beds occur in the breccia, indicating local erosion of these beds.

The limestone clasts are identical in lithology to the limestone of the Table Head Formation and are



Distribution of Breccias and Conglomerates

Breccias ■
 Conglomerates ■

APPENDIX

The Breccias and Conglomerates in the Goose Tickle Formation

The Limestone Breccias

Breccias with angular limestone clasts in a matrix of calcareous shale outcrop in the southwest of Pistolet Bay and in the western part of Hare Bay (Fig. 35).

The thickest limestone breccia bed occurs about 10 m above the disconformable junction of the Table Head Formation and the Goose Tickle Formation. Other thinner breccias lie close to the faulted junction of the Table Head and Goose Tickle Formations and their exact stratigraphic position is unknown although they are thought to lie near the base of the Goose Tickle Formation.

The breccias are underlain by greywackes and shales, which in many cases are depressed by the clasts of the breccias but in no place were the beds seen to be broken. On the other hand, several fragments of greywacke and shale identical with the underlying beds occur in the breccia, indicating local erosion of these beds.

The limestone clasts are identical in lithology to the limestone of the Table Head Formation and are

mostly irregular shaped masses, though rarely they are tabular. Other clasts include shale and sandstone.

The shale clasts are tabular and much larger than the limestone ones, the largest being 4 m by 2 m. They were soft when deposited, for the limestone clasts have been pressed into the edges of the some of them. The largest shale clast is bedded and contains a siltstone layer. The shale clasts resemble the shale above and below the breccia in that they are darker than the matrix and are not calcareous.

A few sandstone clasts are lithologically similar to the coarser layers in the Goose Tickle Formation.

The breccias show no sign of grading except in the uppermost 10 cm, where the larger clasts are absent and the proportion of smaller clasts (less than 1 cm) increases at the expense of the matrix. The tops of the beds consist of fine clastic limestone which grades upward into calcareous shale and then to non-calcareous shale. The best example of grading was found on a loose block near the breccias (Plate 33).

1600 measurements of the direction of clast elongation were made on the thickest breccia bed in Pistolet Bay and these showed two maxima, one

trending NE - SW and a second trending NW - SE. It is common for rudites to show two maxima but it does not indicate the direction of movement of the depositing current.

Breccia beds in Hare Bay, outside the thesis area, are discussed because they help in understanding the relationship between the exposures.

A 50 m breccia bed is found in Northern Arm, (repetition by faulting may contribute to the apparent thickness). The clasts are much the same size as those in the Pistolet Bay breccias (i.e. about 3 cm average) but they are more widely dispersed in the matrix. A patch of breccia about 10 m thick occurs in Wild Bight in Hare Bay but the beds are distorted and cut by many minor faults. Two small breccias are found near Frenchmans Point both of which are a few metres above the Table Head Goose Tickle boundary.

Wherever the stratigraphic position of the beds is determinable it lies just above the base of the Goose Tickle Formation. The outcrop pattern of the breccia bed shows its lenticular nature; it is absent in the north and in the south and thickest in the centre, (see Table p. 127).

Several other beds of breccia are found in Pistolet Bay, and one of these passes laterally into a limestone bed of the same thickness (20 cm).

While difficult to explain, it seems possible the limestone bed broke into pieces due to thixotropic action, perhaps initiated by the shock of an earthquake and a clay matrix was forcefully injected. Bailey^{et al.} (1928) noted evidence for the forceful injection of finer material into cracks in the clasts of the Levis breccias.

The average size of the clasts in each of the breccia exposures was calculated to investigate possible changes in the transporting ability of the depositing currents.

<u>Locality</u>	<u>Thickness of bed</u>	<u>Average size</u>
North		
Schooner and Burnt Islands	no breccia found	-----
Pistolet Bay	8 m	12.3 cm
Northern Arm, Hare Bay	150 m	12.5 cm
Wild Bight Hare Bay	50 m	12.1 cm
Frenchmans Point	2 m	not measured
Little Arm, south Hare Bay	no breccia found	-----
South		

Table 5. Thickness of Breccia Beds and average of 10 largest Clasts

The variation in clast size is too small to be

significant but this is to be expected since the area covered is not large and the sense of current movement not known.

Breccia beds occur at several places on the west coast of Newfoundland (Schuchert and Dunbar, 1934, p. 73), and also in Quebec and New England. The breccias are very similar although many of them have a more calcareous matrix. All the clasts in any one bed are of the same age, the earliest being Upper Cambrian and the latest Middle Ordovician, (Kindle and Whittington, 1958, and Bailey, 1928).

From an examination of the known outcrops in eastern Canada and Mordener Kill in New York and a survey of the literature the following features are thought to be typical of the northern Appalachian examples of this kind of breccia.

- 1) The breccias are intraformational and the underlying beds are unbroken even by large boulders.
- 2) There are no cavities between the boulders such as are often found in beach deposits.
- 3) The boulders rarely touch each other.
- 4) Grading (except at the top) has not been recorded.
- 5) The boulders are not obviously aligned but may be flat lying.
- 6) The majority of clasts in any one breccia are contemporaneous with the surrounding strata.

7) Within the Appalachians they all occur close to the boundary between miogeosynclinal and eugeosynclinal deposits.

8) Individual beds vary in thickness and die out laterally.

9) A clear distinction exists between the clasts and the matrix.

Schuchert and Dunbar (1934, p. 84) thought that the breccias were formed in front of a westward moving thrust sheet, (see diagram in Dunbar and Rodgers, 1961, p. 177), but this does not explain the repetition of the breccias or the contemporaneity of clasts and matrix. Later workers have considered that the breccias of the chaotic type were caused by submarine landslips of carbonate material which turned into turbidity currents down slope (Dunbar and Rodgers, 1961; Kindle and Whittington, 1958; Baird, 1960).

Nelson (1955) attributed the formation of breccias he examined on the west coast of Newfoundland to earthquakes which fragmented partially consolidated lime mud and gave rise to the interlocking texture found in some breccias. This does not explain the mixture of lithologies found in some breccias. One block of limestone found imbedded in a shale lens in Wild Bight has this interlocking texture and might well have originated in such a manner

and subsequently rolled to its present position.

Any proposed origin must explain:

The penecontemporaneous nature of the clasts and surrounding strata at any one horizon.

The repeated occurrences of the breccias.

The contemporaneity of the clasts and matrix.

The cause of the limestone collapsing from its original depositional site might be the oversteepening of beds by tectonic movements or the slow building up of sediment until it was unstable. Tectonic movements were certainly occurring at that time because despite the great thickness of sediments that accumulated the basin was becoming deeper.

Normal faults are present throughout the Appalachians but no direct connection between them and the breccias can be established. Displacement certainly occurred on many of these faults after deposition of the breccias, but some may also have occurred before and during sedimentation. Spasmodic movements on such faults might well explain the collapse of the limestones. If the instability was due to faulting it is necessary that the total deposition for the upper Cambrian to Middle Ordovician interval was greater than the erosion in the uplifted areas. This must be so or the clasts of the individual breccias would not be mostly of the same age as the surrounding strata. It is possible that

the faults never reached the surface but merely caused an increase of the slope and thus slumping of the limestone beds into deeper water. Several small slumps of limestone beds were found south of the thesis area in Hare Bay.

The precontemporary nature of the clasts and the surrounding strata and the repetition of the breccias from Upper Cambrian to Middle Ordovician suggest that the source area repeatedly became unstable and recently deposited sediment collapsed into deeper water and turned into turbidity currents. The supposed sequence of events is as follows:

- 1) Deposition of limestone.
- 2) Collapse of recently accumulated material.
- 3) Dislodged material causes turbidity current to start.
- 4) Accumulation of more limestone followed by collapse . . . etc . . .

Once the clasts and lime mud had started moving they would continue to the foot of slope where a decrease in the velocity of the turbidity current would cause them to be deposited. While travelling, the turbulent motion would pick up some of the underlying material which in deposition would form part of the matrix. Fragments of partially consolidated material would also be engulfed to form shale and sandstone clasts. It is to be expected

that the breccia beds closest to the source would have a lime matrix whereas those that have travelled further over mud will have a more argillaceous matrix. Thus the Pistolet Bay breccias are thought to have travelled farther than those at Cow Head because the former has an argillaceous matrix while the latter has a lime matrix, also the clasts are smaller in the Pistolet Bay breccia. Any proposed mechanism of deposition must, if it is to be acceptable account for the

- a) lack of erosion of underlying beds
- b) suspension of clasts in matrix
- c) clear distinction between clasts and matrix

Glacial origin can be discarded because of the lack of striae on clasts and substrate, erosion and any indication of cold climate.

The clasts might have fallen into their present position from a cliff, but this is unlikely because there is no sign of such a cliff, and if they had fallen they would not be suspended in the matrix but would be in contact with one another. Further the underlying beds would be more disturbed.

Clasts deposited from waning currents usually show some form of bedding, the clasts touch each other and are rounded and sorted.

The lack of erosion of the underlying beds and the suspension of the clast in the matrix can only be

explained by deposition from turbidity currents, or slide breccias with turbid mixing at the top to account for the grading there.

To summarise, it is thought that the breccias are the deposits of turbidity currents or slide breccias which were caused by the repeated collapse of limestone masses which accumulated in a region of tectonic instability.

The Conglomerates

Conglomerates with black and green shale and limestone clasts set in grey shale matrix occur near the top of the Goose Tickle Formation (Plate 34). Many beds of conglomerate outcrop in Howe Harbour and just west of Lock's Cove but only a few are seen in Pistolet Bay. The type section of the Goose Tickle Formation contains rare thin beds of conglomerate near the top.

The beds rest conformably on the underlying shale and are usually less than 30 cm thick, sometimes less than one cm, but show no sign of internal bedding. The clasts are tabular fragments of limestone about 3 cm thick and rounded lumps of black and green shale very similar to that of the Northwest Arm Formation except they lack cleavage. The limestone clasts may have come from the same source, but clasts of Northwest Arm sandstone are absent, perhaps because they disintegrated during transport.

Plots of the orientation of longest axes of pebbles show a north-south maximum. As with the breccias the greatest thickness of beds is in the northern part of Hare Bay, but unlike the breccias there is considerable variation in the average size of the ten largest clasts at each exposure. The largest clasts are found in the thin conglomerate beds in the south.

<u>Locality</u>	<u>Approximate bed Thickness</u>	<u>Average size</u>
Pistolet Bay	1 m	11.5 cm
Northern Hare Bay	1.5 m	11.3 cm
Goose Tickle	0.5 m	20.5 cm

Table 5. Thickness of conglomerate beds and average of 10 largest clasts

The features of the conglomerates are best explained by deposition from turbidity currents. The material was apparently derived from the Northwest Arm Formation before that formation developed cleavage. In view of the mechanism by which the Northwest Arm Formation is thought to have arrived in its present position it is probable that the conglomerate was derived from the front of the advancing klippe.

REFERENCES

- Bailey, E.B., Collet, L.W., and Field, R.M., 1928,
Paleozoic submarine landslips near Quebec City:
Journ. Geol., v.36, p. 557.
- Baird, D.M., 1953,
Reconnaissance geology of Part of the New World
Island - Twillingate Area: Newfoundland Geol. Surv.
Rept. 1, 20 p.
- Baird, D.M., 1954,
Geological map of Newfoundland: Newfoundland Geol.
Surv.
- Baird, D.M., 1957,
Carboniferous rocks of the Conche - Northern Grey
Island area: Newfoundland Geol. Surv. Rept. 12, 25 p.
- Baird, D.M., 1960,
Observations on the nature and origin of the Cow
Head breccias of Newfoundland: Geol. Surv. Canada.
Paper 60-3.
- Baird, D.M., 1966,
Carboniferous rocks of the Conche - Groais Island area,
Newfoundland: Canadian Jour. of Earth Sciences, v.3,
p. 247.
- Betz, F., 1939,
Geology and mineral deposits of the Canada Bay area,
Northern Newfoundland: Newfoundland Geol. Surv. Bull.
16, 53 p.
- Bouma, A.H., 1962,
Sedimentology of some flysch deposits: Amsterdam,
Elsevier Publishing Co., 168 p.

- Brongsma-Sanders, M., 1948,
The importance of upwelling to vertebrate paleontology
and oil geology: K. Nederlandsche Akad. Wetensche.
Amsterdam Verh., Afd. Natuurk., Sec. 2 v. 45 no. 4, p.1.
- Bucher, W.H., 1957,
Taconic klippe (N.Y.) - a stratigraphic-structural
problem: Geol. Soc. America Bull. v. 68, p.657.
- Challis, G.A., 1965,
Contact metamorphism at the Red Hills ultrabasic
intrusion New Zealand: Jour. Petrology v.6, p.3.
- Clifford, P.M., and Baird, D.M., 1962,
Great Northern Peninsula of Newfoundland - Grenville
inlier: Canadian Mining Metall. Bull. 599, p.150.
- Cooper, J.R., 1937,
Geology and mineral deposits of Hare Bay: Newfoundland
Geol. Surv. Bull. 9, 36 p.
- Crook, K.A., 1964,
Cleavage in weakly deformed mudstones: Am. Jour. Sci.
v. 262, p.523.
- Cummins, W.A., 1962,
The greywacke problem: Liverpool and Manchester
Geol. Jour. v. 3, p.51.
- Daly, R.A., 1903,
Variolitic pillow lava from Newfoundland: Amer. Geol.
v. 32, p.65.

- DeRigi, M.R. and Ortesini, A., 1964,
Gravity tectonics in foothills structure belt of
southeast Turkey: Amer. Assoc. Petr. Geol. Bull.
v. 48, No. 12, p. 1911.
- DeSitter, L.U., 1964,
Structural geology 2nd Edit. New York, McGraw-Hill
Book Co., 551 p.
- Ericson, D.B., et al., 1951,
Deep sea sands and submarine canyons: Geol. Soc. America
Bull., v. 62, p. 961.
- Gillis, J.W., 1966,
Great Northern Peninsula: Geol. Surv. Canada, Paper 66-1.
- Green, D.H., 1964,
Peridotite intrusion in the Lizard area Cornwall:
Jour. Petrology. v. 5, p. 134.
- Hamblin, W.K., 1965,
The origin of reverse drag on the downthrown side of
normal faults: Geol. Soc. America Bull. v. 76, p. 1145.
- Hawley, D., 1957,
Ordovician shales and submarine slide breccias of the
northern Champlain Valley in Vermont: Geol. Soc. America
Bull. v. 68, p. 55.
- Hubbert, M.K. and Ruby, W.W., 1959,
Role of fluid pressure in mechanics of overthrust
faulting: Geol. Soc. America Bull. v. 70, p. 115.
- Illing, L.V., 1965,
Penecontemporary dolomite in the Persian Gulf:
Soc. Econ. Paleontologists and Mineralogists,
Special Pub. 13, p. 89.

- Johnson, H., 1941,
Paleozoic lowlands of western Newfoundland:
New York Acad. Sci. Trans. ser. 2, v.3, p.141.
- Kay, G.M., 1945,
Paleogeographic and palinspastic maps: Amer. Assoc.
Petrol. Geol. Bull. v. 29, p.426.
- Kay, G.M., 1951,
North American Geosynclines: Geol. Soc. America
Mem. 48.
- Kindle, C.H., 1945,
Geology of Pistolet Bay area: Summary report.
- Kindle, C.H. and Whittington, H.B., 1958,
Stratigraphy of the Cow Head region, western Newfoundland: Geol. Soc. America Bull. v. 69, p.315.
- Kuenen, Ph.H., 1964,
Deep sea sands and ancient turbidites; in Turbidites,
edit. A.H. Bouma, Elsevier, Amsterdam p.3.
- Kuenen, Ph.H., 1952,
Graded and non graded deposits: Jour. Sed. Pet.
v. 22, p.83.
- Kuenen, Ph.H., and Migliorini, C.I., 1950,
Turbidity currents as a cause of graded bedding:
Jour. Geol. v. 59, p.91.
- Levin, E.M., McMurdie, H.F., and Hall, F.P., 1956,
Phase diagrams for ceramists: American Ceramic
Society, Ohio. 286 pp.

LochmanBalk, C., 1956

Stratigraphy, paleontology and paleogeography of the Elliptocephala asaphoides strata in Cambridge and Hoosick quadrangles, New York: Geol. Soc. America Bull. v.67, p.1331.

Logan, W.E., 1863,

Geological survey of Canada, report of its progress from its commencement to 1863: Montreal, 1863.

• MacGregor, I.D., 1963,

Geology and geochemistry of Mount Albert ultrabasic intrusion, Quebec: Abstract Canadian Mining and Metallurgy Bull. 1963, pt.7, p.154.

• MacKenzie, D.B., 1960,

High temperature alpine type peridotite from Venezuela: Geol. Soc. America Bull. v. 71, p.303.

• Maxwell, J.C., 1959,

Turbidite, tectonic and gravity transport, northern Appenine Mountains, Italy: Amer. Assoc. Petrol. Geol. Bull. v. 43, p.2701.

Murray, A., and Howley, J.P., 1864,

Newfoundland Geol. Surv. Report for 1864, p.21.

• North, F.K., 1964,

Gravitational tectonics: Bull. Canadian Petrol. Geol. v. 12, p.185.

• Oxley, P., 1953,

Stratigraphy and structure of Western Brook, St. Paul's and Parson's Pond area, St. Barbe District, western Newfoundland: Newfoundland Geol. Surv. Rept. 5, 53p.

- Parkinson, D., 1957,
Lower carboniferous reefs on Northern England:
Bull. Amer. Assoc. Pet. Geol., v. 41, p. 511.
- Pettijohn, F.J., 1957,
Sedimentary Rocks, 2nd edit. New York, Harper
and Brothers, 718 p.
- Potter, P.E., and Pettijohn, F.J., 1963,
Paleocurrents and Basin analysis: Springer Verlag
Gootingen, 290 p.
- Rodgers, J., 1966,
Long Point and Clam Bank Formations, western Newfoundland:
Geol. Assoc. Canada, v. 16, p. 83.
- Rodgers, J. and Neale, E.R.W., 1963,
Possible "Taconic" klippen in western Newfoundland:
Amer. Jour. Sci. v. 261, p. 713.
- Ruedemann, R., 1909,
Types of inliers observed in New York: New York State
Mus. Bull. v. 169, p. 164.
- Schuchert, C. and Dunbar, C.O., 1934,
Stratigraphy of western Newfoundland: Geol. Soc.
America, mem. 1.
- Shepherd, N., 1962,
Investigation of White Hills area, Hare Bay, Newfound-
land: Rept. to Patino Mining Co.
- Shinn, E.A., 1965,
Recent supratidal dolomite from Andros Island,
Bahamas: Soc. Econ. Paleontologists and Mineralogists
Special Pub. 13, p. 112.

- . Smith, C.H., 1958,
Bay of Islands igneous complex, Newfoundland:
Geol. Surv. Canada, Mem. 290, 132p.
- Turner, F.J., and Verhoogan, J., 1960,
Igneous and metamorphic petrology, 2nd. edit. New
York MacGraw-Hill Book Co., 694 p.
- Ulrich, E.O., 1902,
Paleozoic seas and barriers in Eastern North America:
New York State Mus. Bull. v. 52, p.633.
- Walton, E.K., 1956,
Limitations of graded bedding and alternative
criteria of upward sequence in the rocks of the
Southern Uplands: Trans. Geol. Soc. Edinburgh,
v. 16 pt. 3, p.262.
- . Whittington, H.B., and Kindle, C.H., 1963,
Middle Ordovician Table Head Formation, western
Newfoundland: Geol. Soc. Amer. Bull., v. 74, p.745.
- ✓ Whittington, H.B., and Kindle, C.H., 1966,
Middle Cambrian strata at the Strait of Belle Isle,,
Newfoundland: Abstract. Geol. Soc. America, N.E.
sect. 1st. annual meeting.
- . Wilson, J.T., 1962,
Some further evidence in support of the Cabot Fault,
a great paleozoic transcurrent fault zone in the
Atlantic Provinces and New England: Trans. Roy. Soc.
Canada, v. LVI ser. 3, sect. 3, p. 31.

Williams, H., 1964,

The Appalachians in northeast Newfoundland - a two sided symmetrical system: Amer. Jour. Sci. v. 262, p.1137.

Wolve, W.J., 1964,

Blue River ultramafic intrusion, Cassiar District, B.C.: Canadian Geol. Surv. paper 64 - 48.

Zen, E-an., 1961,

Stratigraphy and structure at the north end of the Taconic Range in west-central Vermont: Geol. Soc. America Bull., v. 72, p.295.

Plate 1. Land surface underlain by flat-
lying carbonate South of Cape Norman.

Plate 2. Evenly dipping quartzites of the
Bradore Formation on the White Islands.

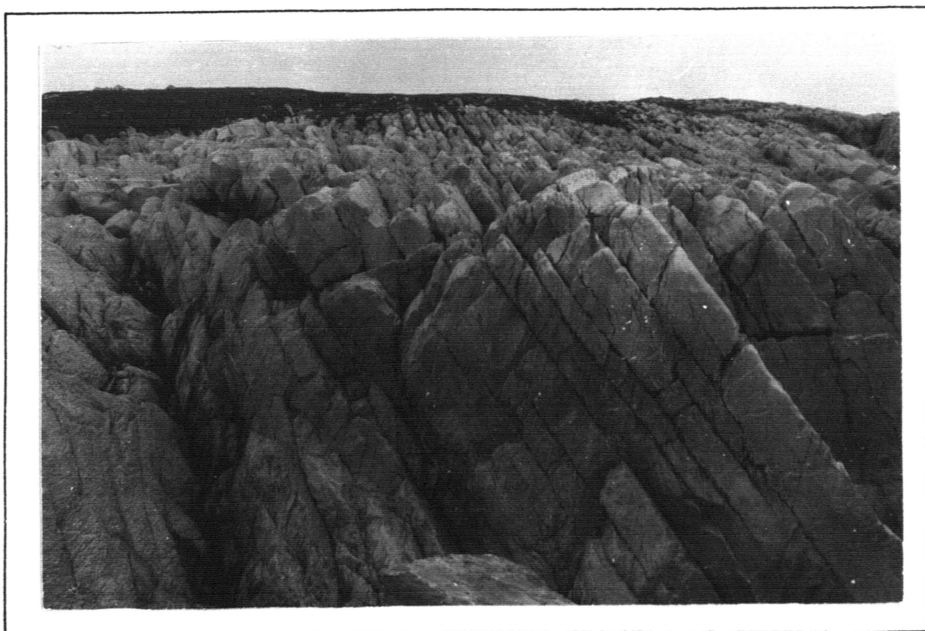


Plate 3. The St. George Formation, 3 miles south of Cape Norman. The hummocks on the surface in the foreground are algal structures.

Plate 4. Algal structures in the St. George Formation north of Boat Harbour.

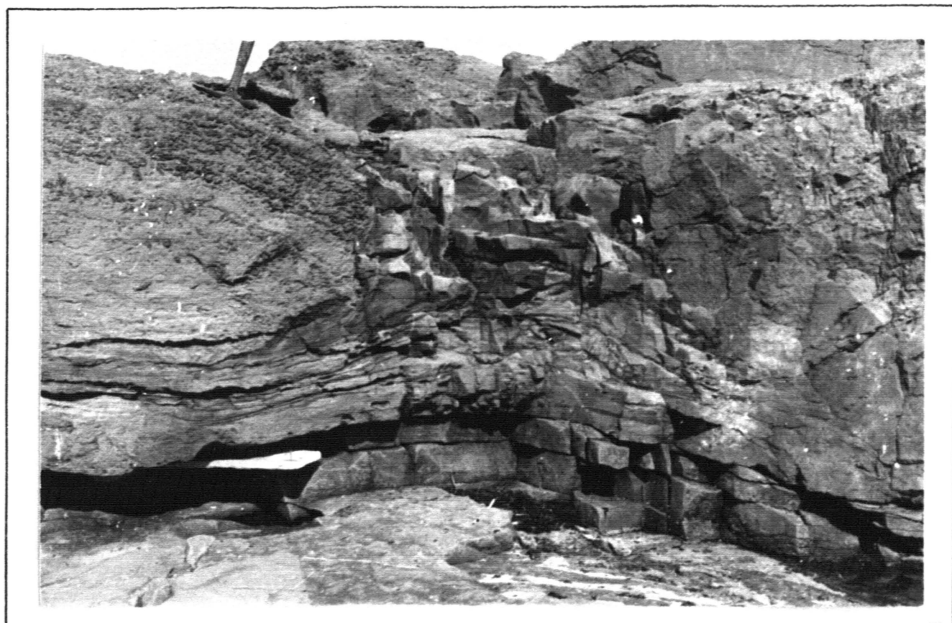


Plate 5. Contact of the Table Head Formation
(limestone) and the Goose Tickle Formation
(shale) on Schooner Island.

Plate 6. Vertical beds of shale and greywacke
of the Goose Tickle Formation in Shallow Bay.



Plate 7. Black and green shale of the Northwest Arm Formation in Pistolet Bay.

Plate 8. The Northwest Arm Formation - boudins of sandstone surrounded by shale.



Plate 9. Pillow lavas north of Raleigh
in the lower member of the Maiden Point
Formation.

Plate 10. Tuff in the Maiden Point
Formation just north of Griquet where
erosion has formed unusual pinnacles.

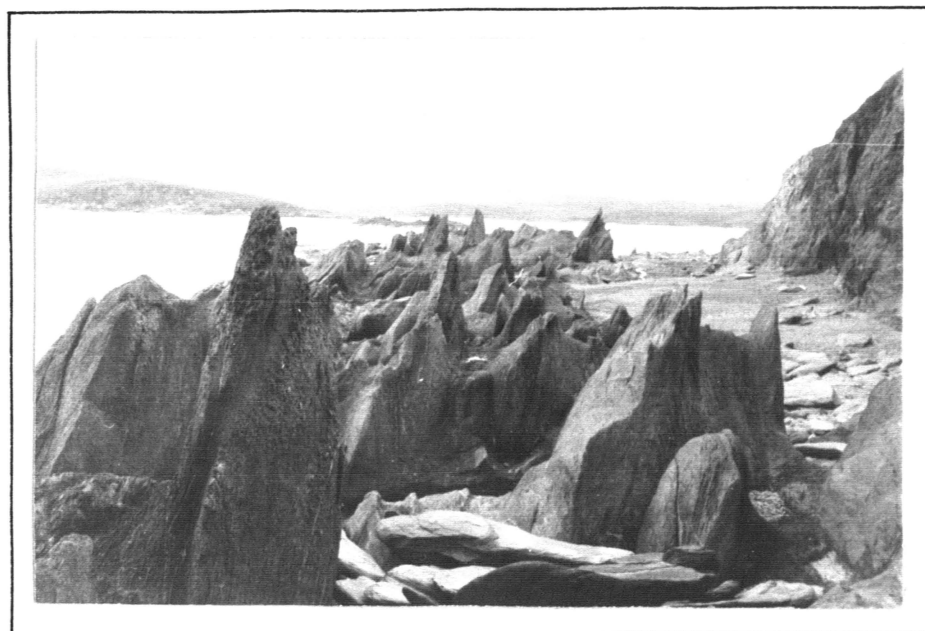
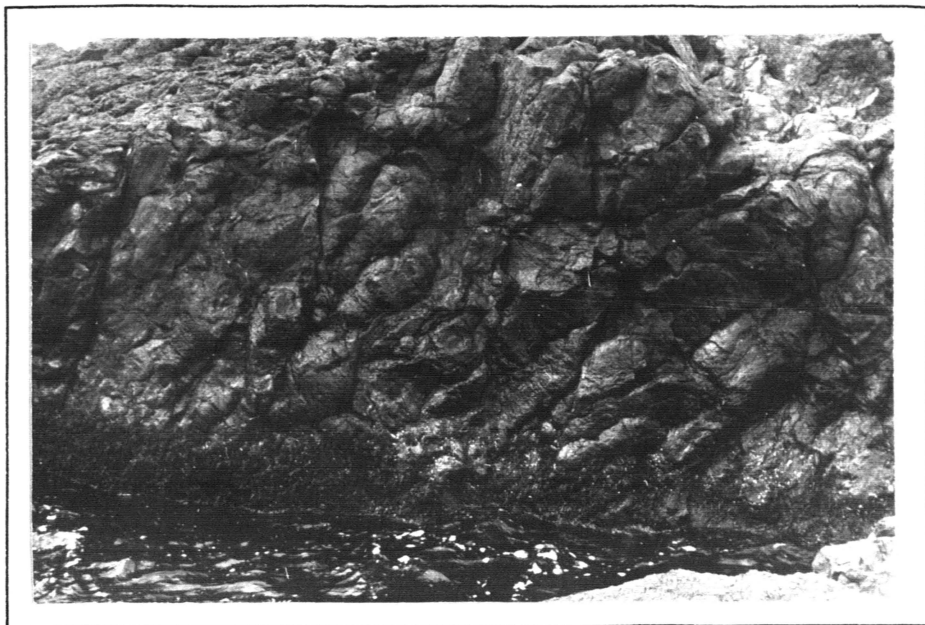


Plate 11. Agglomerate in the Maiden Point
Formation north of Raleigh; calcite fills
the spaces between the clasts.

Plate 12. Agglomerate in Milan Arm in the Maiden
Point Formation with a matrix of smaller volcanic
fragments

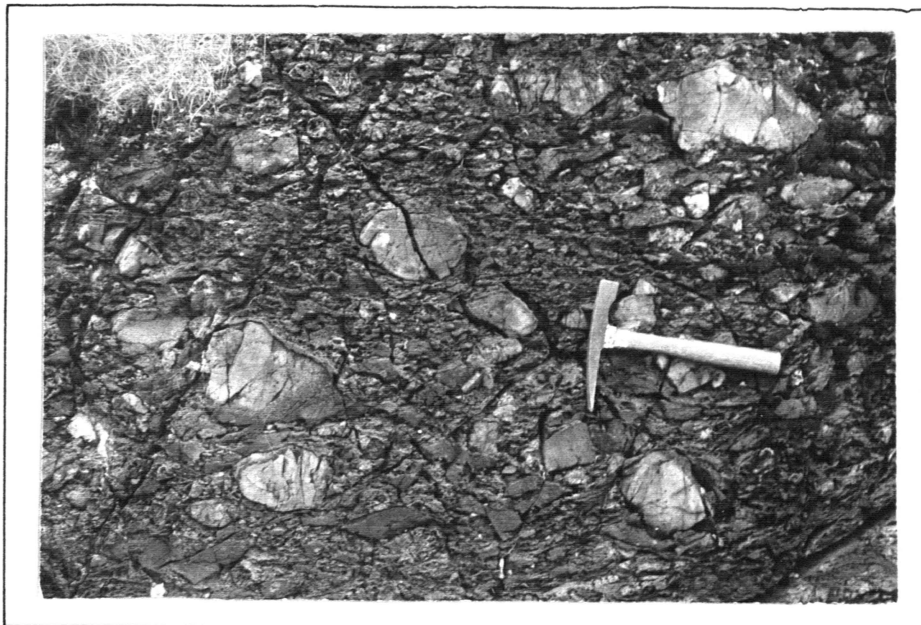


Plate 13. Slates of the Maiden Point
Formation exposed in a road cut on the road
to Griquet.

Plate 14. The thrust at Raleigh with
volcanic beds overhanging soft shales.

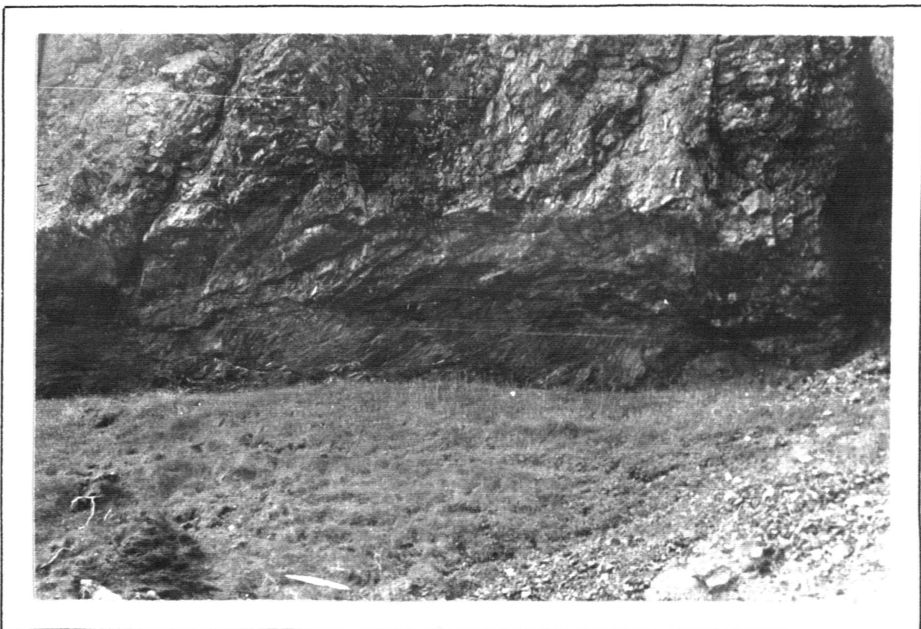
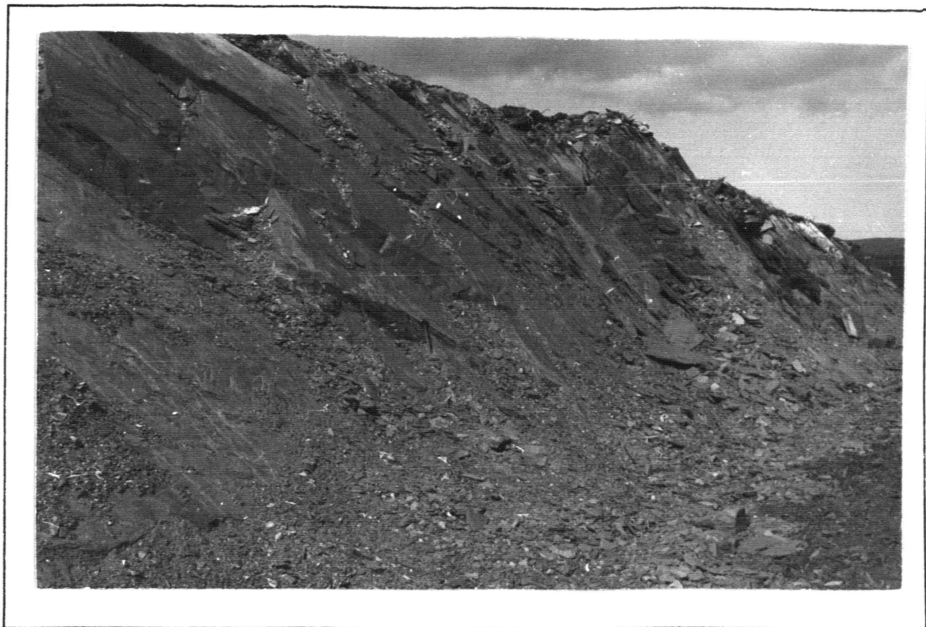


Plate 15. The thrust at Raleigh with shale overlain by volcanic beds.

Diagram of the above photograph.

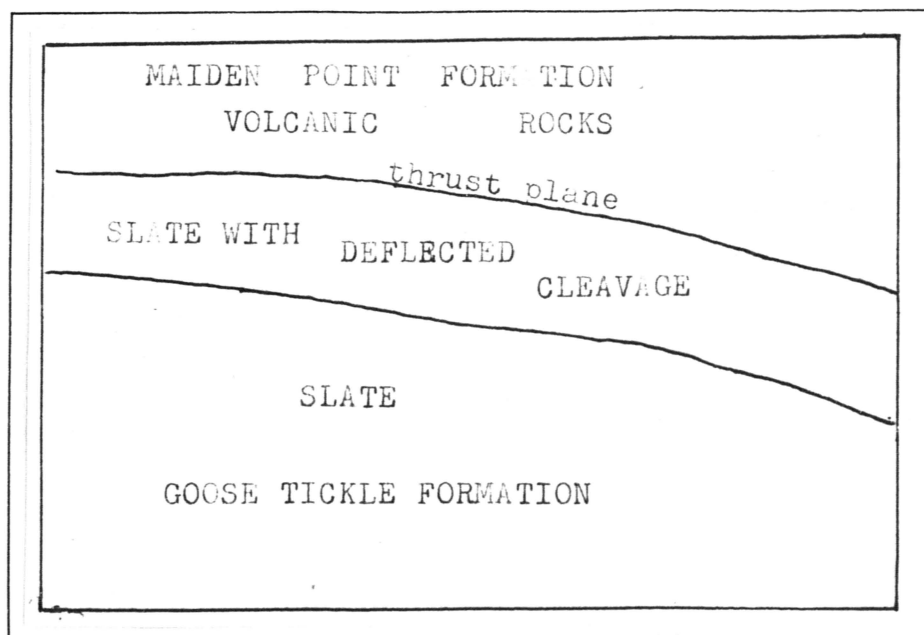
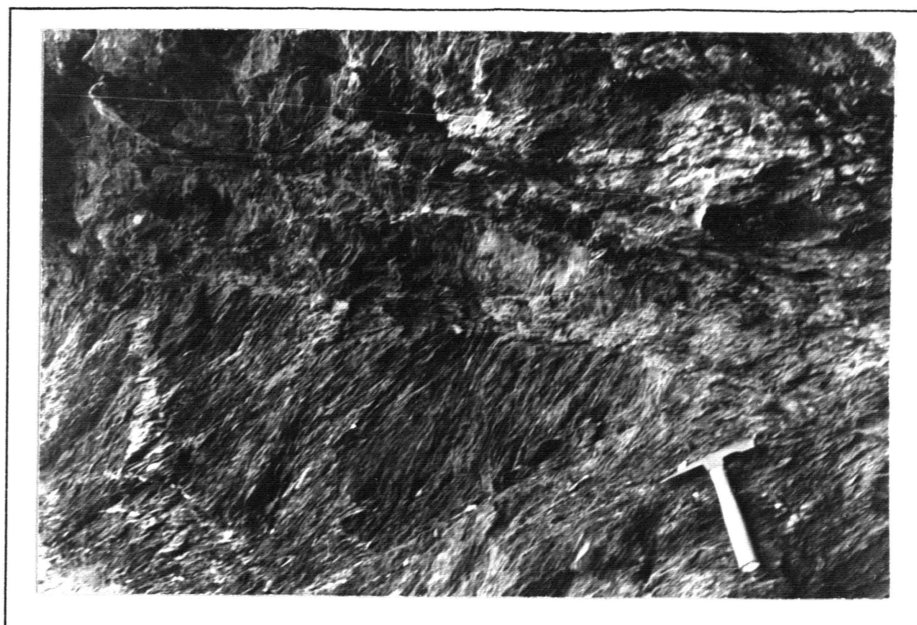


Plate 16. Folds in a shale lens in the Table
Head Formation in Wild Bight. Axial planes
dip eastward.

Plate 17. Folded beds of the Goose Tickle Formation
just below the thrust on Burnt Island. The headland
in the background is formed of the St. George
Formation

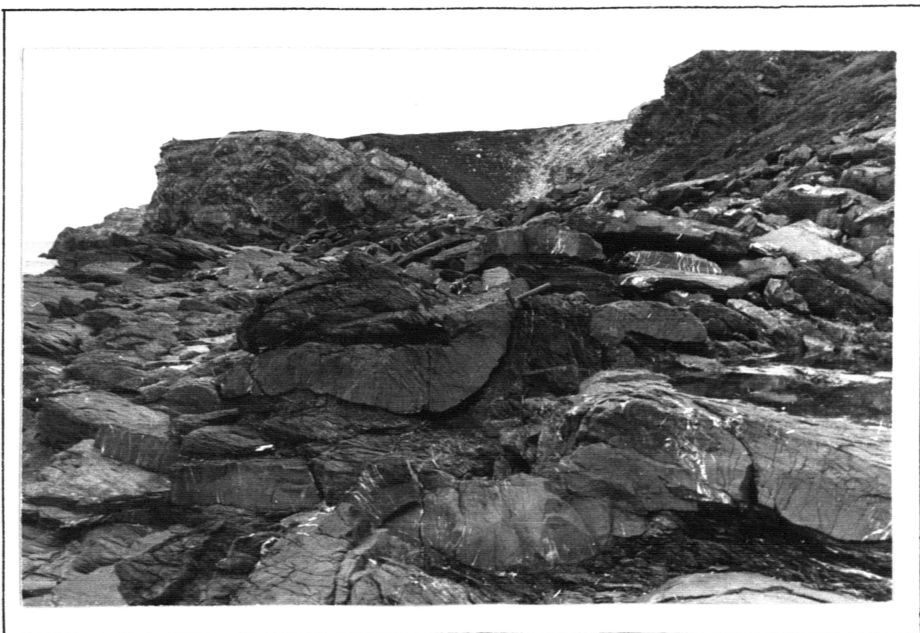
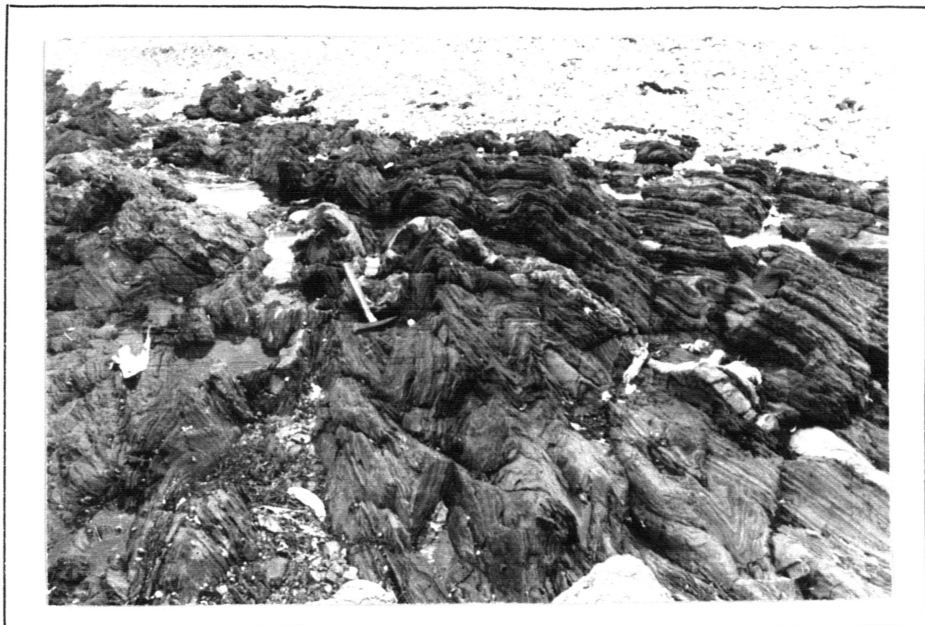


Plate 18. Sandstone and limestone boudins
surrounded by shale in the Northwest Arm
Formation, Pistolet Bay.

Plate 19. Contorted beds in the Northwest
Arm Formation, Pistolet Bay.

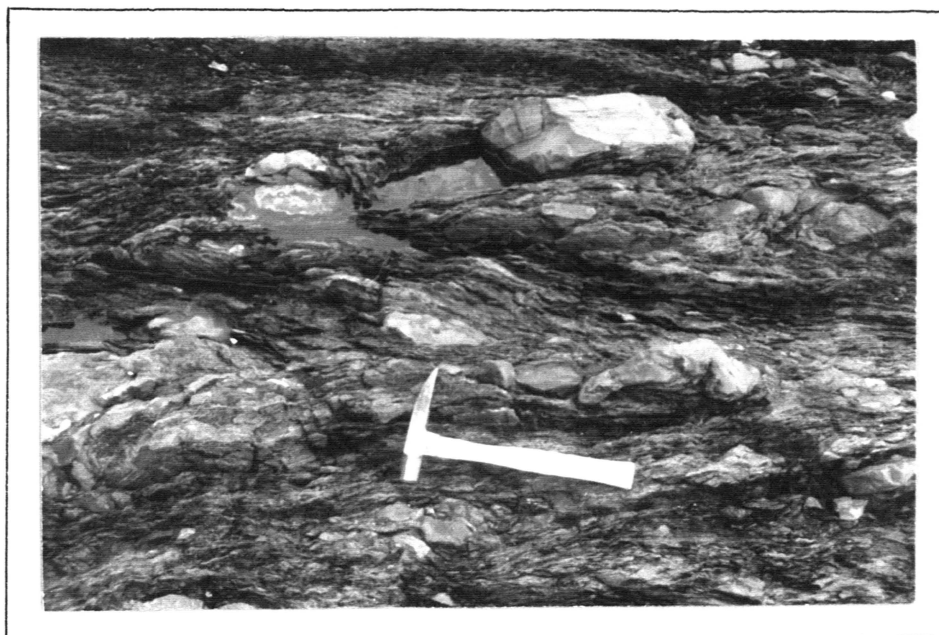


Plate 20. Recumbent fold in the Maiden Point
Formation in St. Anthony Bight, looking east.

Plate 21. Zigzag folding in the Maiden Point
Formation in St. Anthony Bight.

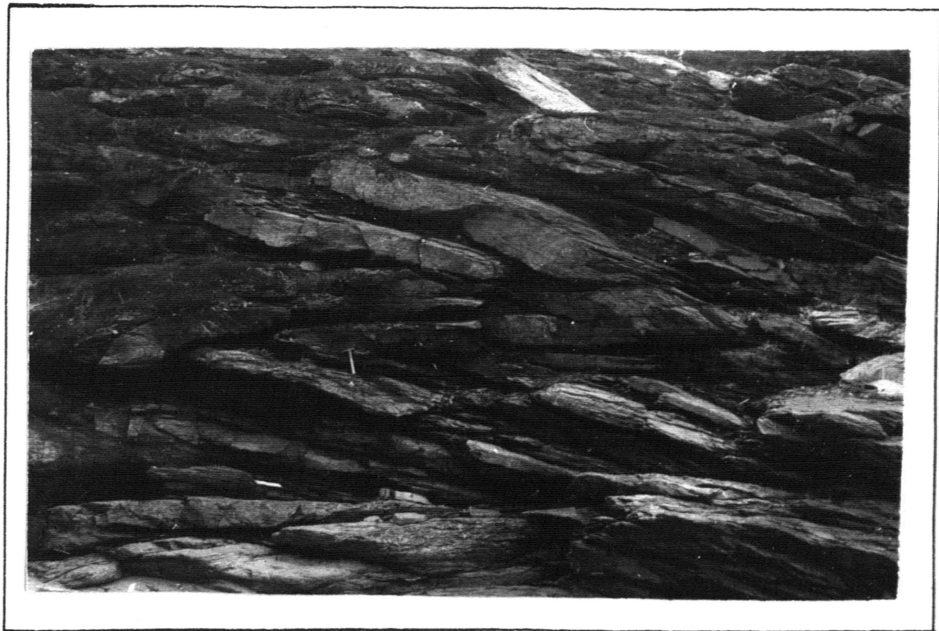
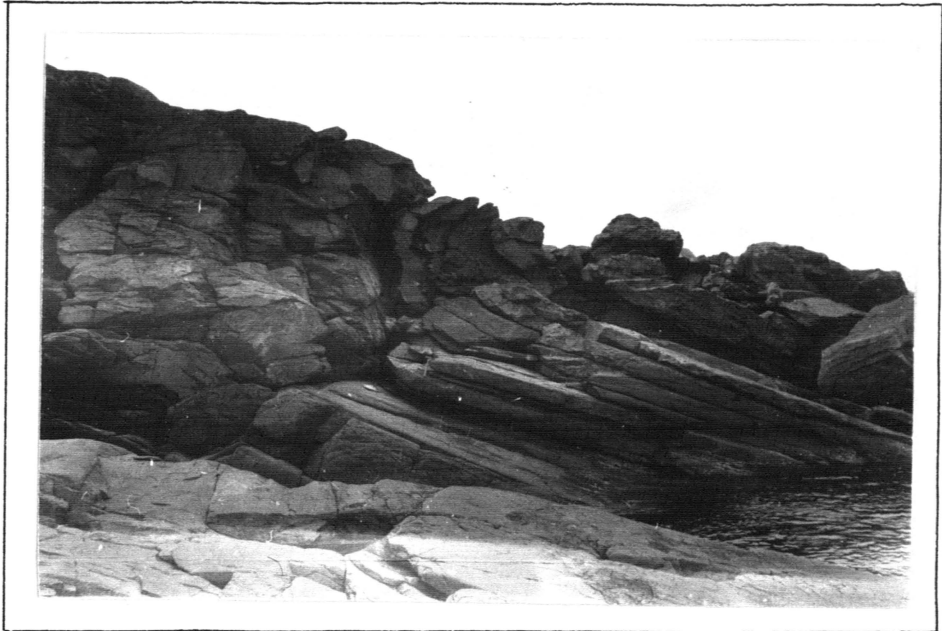


Plate 22. Recumbent fold in the Maiden Point
Formation in St. Anthony Bight, looking east.

Plate 23. Asymmetric folds in the Maiden Point
Formation near Quirpon. Axial planes dip eastward.



Plate 24. Desiccation cracks in the St. George
Formation at Wild Bight.

Plate 25. Partially dolomitized limestone
near Cape Norman.

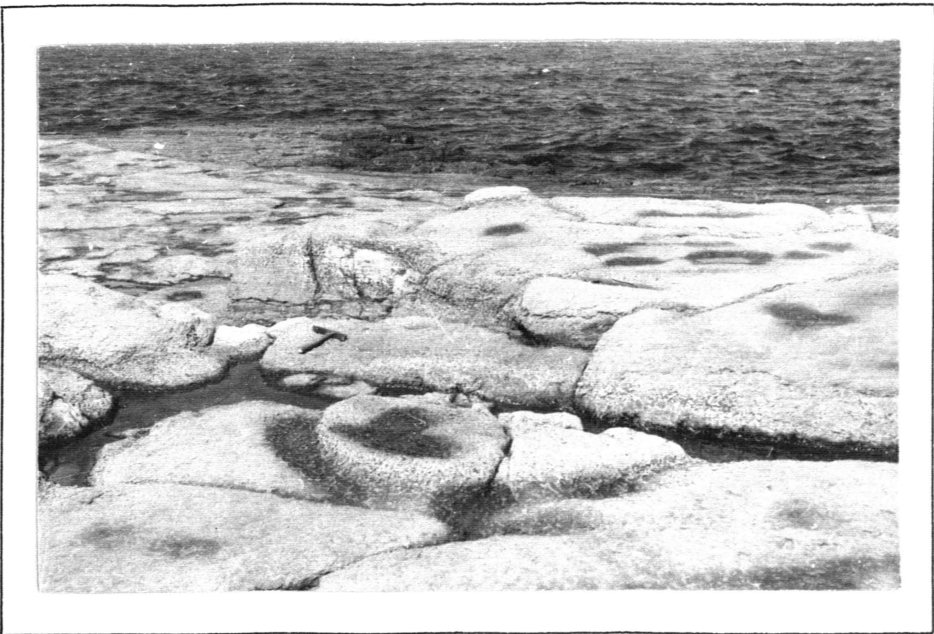
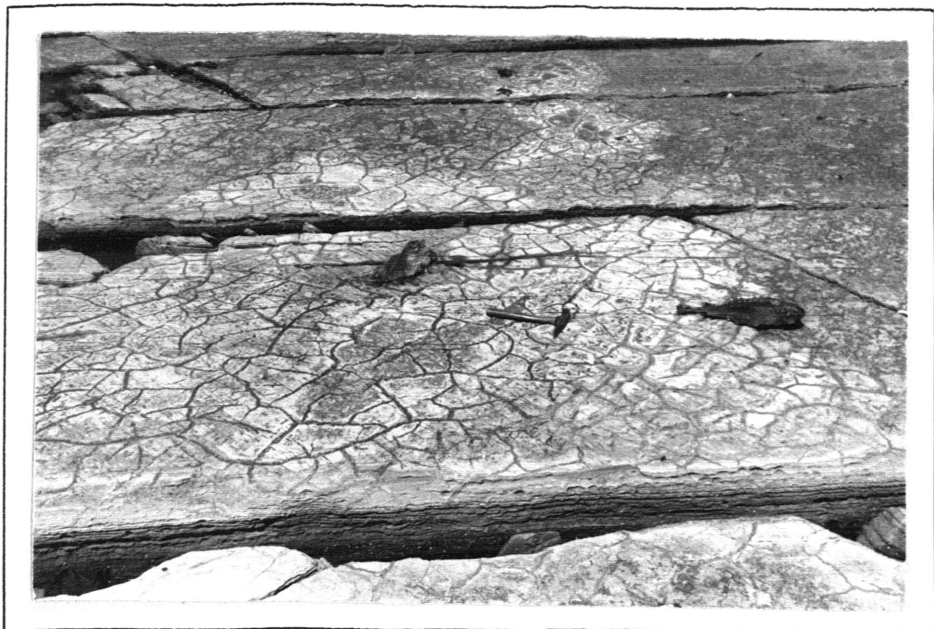


Plate 26. Partial dolomitization in the St. George Formation. The light coloured "tubes" are dolomite and the dark rock between is limestone.

Plate 27. Vuggy dolomite from the upper part of the St. George Formation, east of Boat Harbour.



Plate 30. Convolute bedding in the Goose Tickle
Formation in Shallow Bay.

Plate 31. The base of the limestone breccia in the
Goose Tickle Formation on Boisee Peninsula.

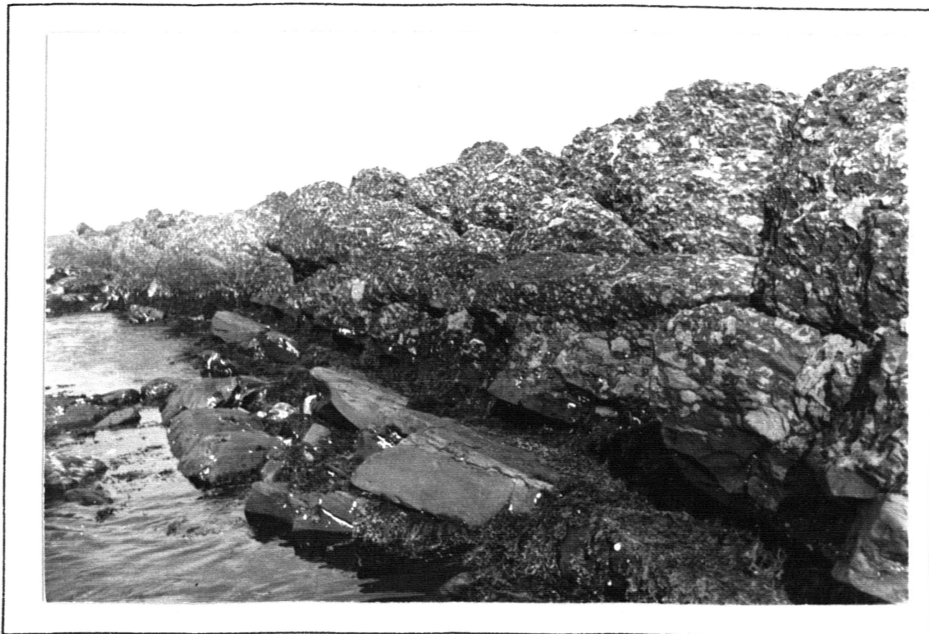
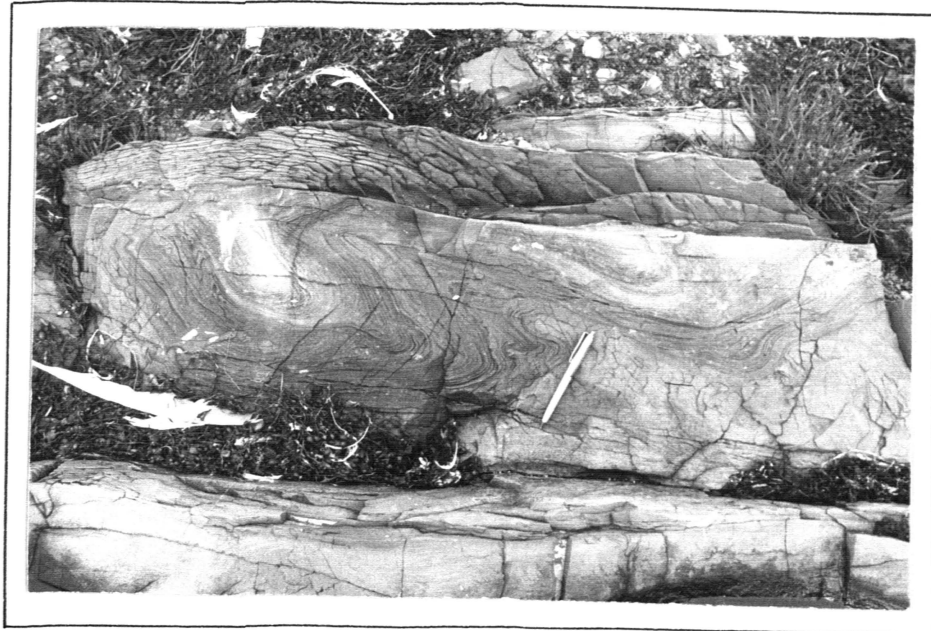


Plate 32. Limestone breccia in Pistolet Bay.

Plate 33. Graded bedding at the top of the
limestone breccia on Boisee Peninsula.



Plate 34. Conglomerate at the top of the
Goose Tickle Formation in Hare Bay.

Plate 35. Graded bedding in the Maiden Point
Formation in Milan Arm. Tops are to the right.



Plate 36. Graded bedding in the Maiden Point Formation. Notice the shale flakes.

Plate 37. A channel in the Maiden Point Formation filled with coarse cross bedded sandstone. The bed is upside down.

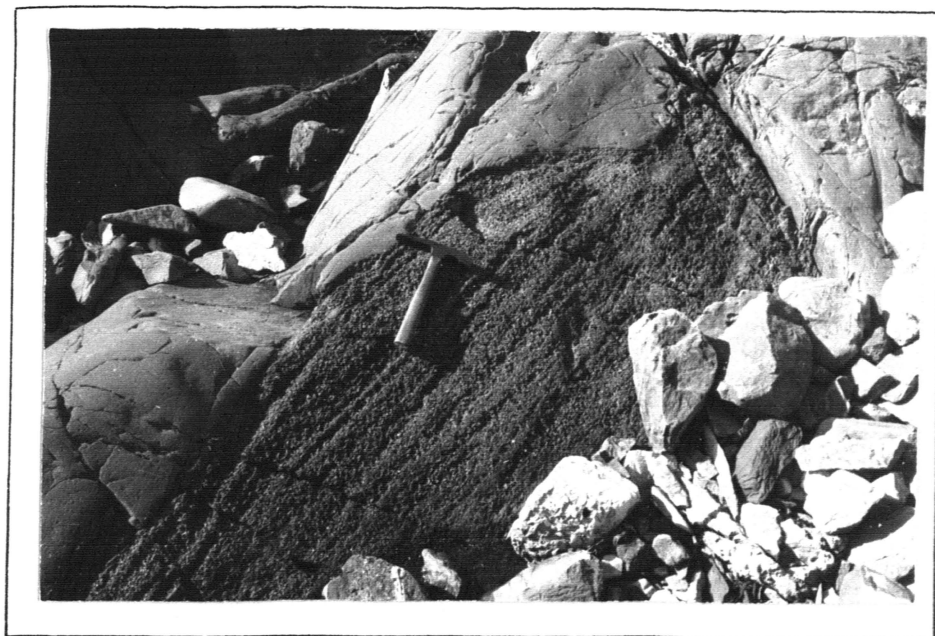


Plate 28. Ball and pillow structure and pseudo nodules
in the Goose Tickle Formation, Burnt Island.

Plate 29. Flute casts in the Goose Tickle Formation
on the west side of Burnt Island.

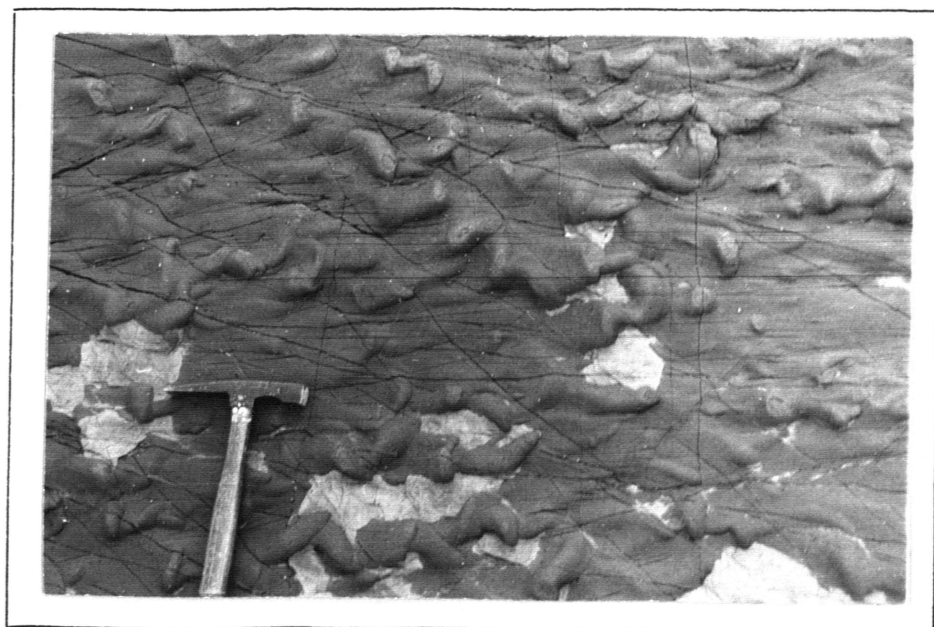
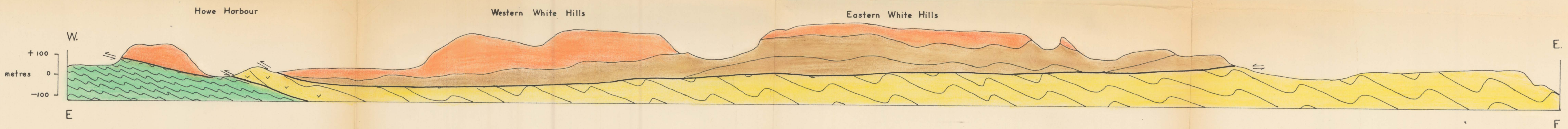
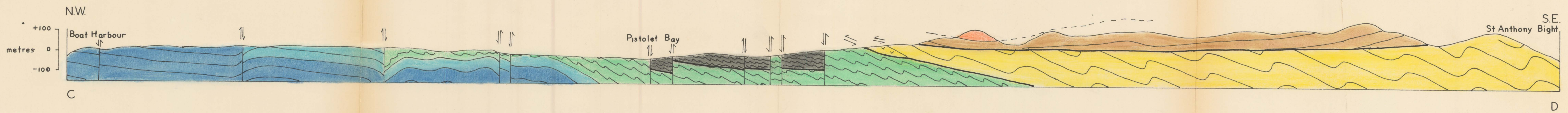
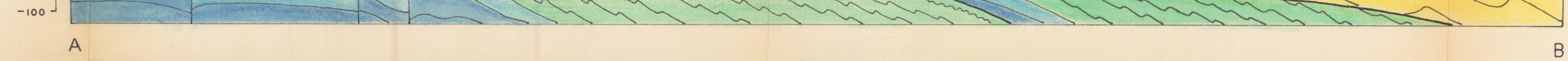
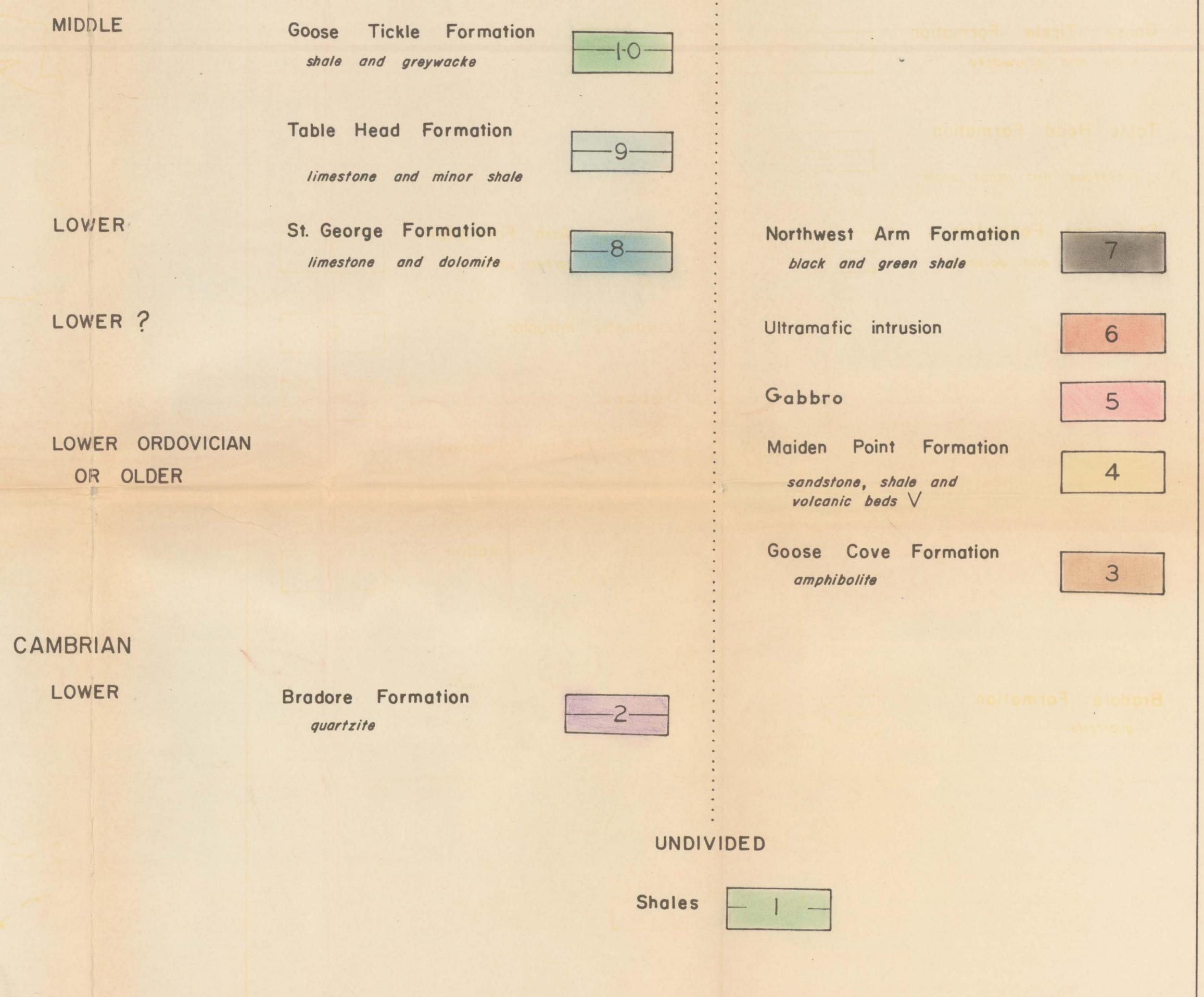
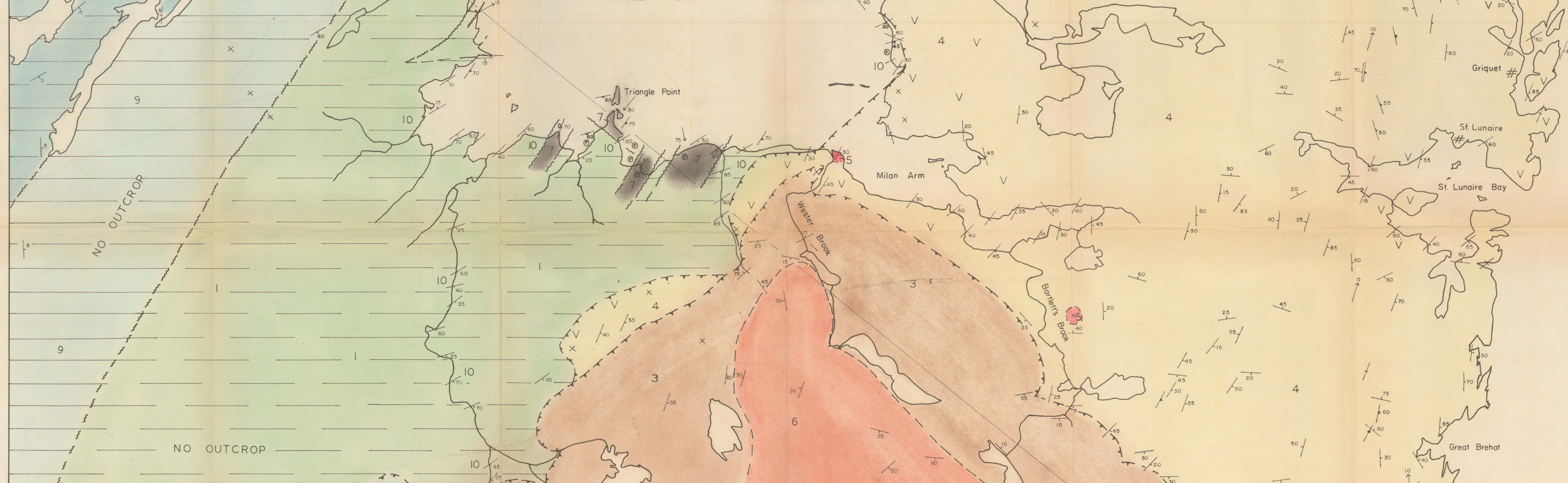


Plate 38. Coarse grained, current bedded sandstone
in a channel in the Maiden Point Formation in St.
Anthony Bight.

Plate 39. Slump structure in the Maiden Point
Formation in St. Anthony Bight.







Geological boundary, defined, approximate