1

National Library
of Canada

Bibliothèque nationale
du Canada

CANADIAN THESES
ON MICROFICHE

THÈSES CANADIENNES
SUR MICROFICHE

44434

NAME OF AUTHOR/NOM DE L'AUTEUR David Robert Troyer

TITLE OF THESIS/TITRE DE LA THÈSE Petrography, ~~Stratigraphy~~ and Paleoenvironments of the
Chazyan Rockcliffe Formation of the Ottawa-Hull Area

UNIVERSITY/UNIVERSITÉ Carleton

DEGREE FOR WHICH THESIS WAS PRESENTED/
GRADE POUR LEQUEL CETTE THÈSE FUT PRÉSENTÉE M.Sc.

YEAR THIS DEGREE CONFERRED/ANNÉE D'OBTENTION DE CE DEGRÉ 1979

NAME OF SUPERVISOR/NOM DU DIRECTEUR DE THÈSE Dr. R.W. Yole

Permission is hereby granted to the NATIONAL LIBRARY OF
CANADA to microfilm this thesis and to lend or sell copies
of the film.

*L'autorisation est, par la présente, accordée à la BIBLIOTHÈ-
QUE NATIONALE DU CANADA de microfilmer cette thèse et
de prêter ou de vendre des exemplaires du film.*

The author reserves other publication rights, and neither the
thesis nor extensive extracts from it may be printed or other-
wise reproduced without the author's written permission.

*L'auteur se réserve les autres droits de publication; ni la
thèse ni de longs extraits de celle-ci ne doivent être imprimés
ou autrement reproduits sans l'autorisation écrite de l'auteur.*

DATED/DATE

R. Troyer

SIGNED/SIGNÉ

Oct 2, 1979

PERMANENT ADDRESS/RÉSIDENCE FIXE

2918 Hill Ave.

Regina, Sask. S4S 0V8

National Library of Canada
Collections Development Branch

Canadian Theses on
Microfiche Service

Bibliothèque nationale du Canada
Direction du développement des collections

Service des thèses canadiennes
sur microfiche

NOTICE

The quality of this microfiche is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us a poor photocopy.

Previously copyrighted materials (journal articles, published tests, etc.) are not filmed.

Reproduction in full or in part of this film is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30. Please read the authorization forms which accompany this thesis.

**THIS DISSERTATION
HAS BEEN MICROFILMED
EXACTLY AS RECEIVED**

AVIS

La qualité de cette microfiche dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de mauvaise qualité.

Les documents qui font déjà l'objet d'un droit d'auteur (articles de revue, examens publiés, etc.) ne sont pas microfilmés.

La reproduction, même partielle, de ce microfilm est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30. Veuillez prendre connaissance des formules d'autorisation qui accompagnent cette thèse.

**LA THÈSE A ÉTÉ
MICROFILMÉE TELLE QUE
NOUS L'AVONS REÇUE**

PETROGRAPHY AND PALEOENVIRONMENTS
OF THE CHAZYAN ROCKCLIFFE FORMATION OF
THE OTTAWA-HULL AREA

by

© D. Robert Troyer, B.Sc.

A thesis submitted to the Faculty of
Graduate Studies and Research in partial fulfilment
of the requirements for the degree of
Master of Science

Department of Geology

Carleton University

Ottawa, Ontario

September 20, 1979

The undersigned recommend to the Faculty of Graduate
Studies and Research acceptance of the thesis

"Petrography and Paleoenvironments of
the Chazyan Rockcliffe Formation
of the Ottawa-Hull Area"

submitted by D. Robert Troyer, B. Sc.,
in partial fulfilment of the requirements for
the degree of Master of Science.

.....
Thesis Supervisor

.....
Chairman, Department of Geology

Carleton University

September 20, 1979

ABSTRACT

The Rockcliffe Formation is a Middle Ordovician (Chazyan) deposit dominated by lenticular-bedded sandstone, siltstone and shale, underlain by the Oxford Formation and overlain by limestones of the Ottawa Group. The area of study is situated on the north-central side of the Ottawa Embayment, a large, well-defined, roughly sub-quadrangle, structural basin occupying part of the St. Lawrence Platform.

The Rockcliffe Formation can be divided into five microfacies and five submicrofacies, based on outcrop and core samples. These are: the shale microfacies, a lagoonal or intertidal mud with minor concentrations of fossil debris; the dolostone microfacies, a fine dolomitic mud deposited in lagoonal areas; the offshore bar or subaqueous dunal subfeldsarenite microfacies of fine quartz and feldspar grains with minor interbeds of shale; the coarse quartzarenite microfacies, consisting of the clean and phosphatic submicrofacies, deposited in interdunal trough areas; and the mixed microfacies, divided into three submicrofacies, composed of subfeldsarenite, shale and quartzarenite microfacies deposited in channel/trough areas by strong tidal or storm currents.

These Chazyan sediments of the Ottawa-Hull area represent coexisting deposits of a very shallow tidally influenced sea, supplied with clastic material from a low, wind-swept land mass to the north. A long, narrow estuarine-like arm of the sea, extending to the northwest, played a marked role in the deposition of phosphate as well as influencing the deposition of the other sediment types in the embayment. Evidence of periodic storm action is also recorded.

The stratigraphy of the Rockcliffe Formation can be summarized as: basal 40 metres subfeldsarenite with scattered occurrences of quartzarenite and mixed microfacies, middle 7.5 metres shale, upper 2 metres dolostone. The lenticular habit of the stratigraphic units make a regional as well as local correlation between wells and between wells and outcrops very difficult.

ACKNOWLEDGEMENTS

I sincerely thank Dr. R.W. Yole who gave unsparingly of his time, energy and patience during the researching and writing of this thesis. In addition, I am grateful for Dr. Yole's and Dr. J.A. Donaldson's critical readings of the manuscript. Acknowledged for his assistance, is R.B. Hutt, Chief Geologist, Ministry of Natural Resources office, London, Ontario.

I would also like to thank my wife, Elizabeth, for her patience and support, and Miss N. Walsh, for her subdued but persistent persuasion to complete this study. I am also indebted to my parents, Mr. and Mrs. J.E. Troyer, for without their generous assistance this thesis would not have been completed.

My gratitude is also extended to Mrs. Shirley Day for typing this manuscript.

TABLE OF CONTENTS

	Page No.
ABSTRACT	iii
ACKNOWLEDGEMENTS	v
TABLE OF CONTENTS	vi
LIST OF FIGURES	viii
LIST OF TABLES	ix
LIST OF PLATES	x
CHAPTER I: INTRODUCTION	1
1.1 General Statement	1
1.2 Purpose of Study	4
CHAPTER II: REGIONAL GEOLOGY OF THE OTTAWA EMBAYMENT	6
2.1 Regional Setting	6
2.2 Stratigraphy	9
2.3 Structure of the Basin	11
CHAPTER III: PREVIOUS WORK ON THE ROCKCLIFFE FORMATION	15
CHAPTER IV: METHODS OF STUDY	20
4.1 Field Study	20
4.2 Core Study	23
4.3 Laboratory Study	25
CHAPTER V: PETROGRAPHY AND SEDIMENTARY STRUCTURES	29
5.1 General Statement	29
5.2 Microfacies Descriptions	30
5.2.1 Shale Microfacies	30
5.2.2 Dolostone	34
5.2.3 Subfeldsarenite or Subfeldswacke Microfacies	40
5.2.4 Coarse-grained Quartzarenite Microfacies	53
5.2.5 Mixed Microfacies	68
5.3 Comparisons with the Rosenstein (1973) and Hoskin (1974) Facies	73
CHAPTER VI: STRATIGRAPHIC SEQUENCE IN THE ROCKCLIFFE FORMATION	78
6.1 Core Description and Correlation	79
6.2 Correlation of the Outcrop Sections and the Cores	82
6.3 Comparison of the Ottawa-Hull Strati- graphy with Cornwall area	89

Contents	Page No.
CHAPTER VII: PALEOENVIRONMENTS OF THE ROCKCLIFFE FORMATION	93
7.1 Previously Conceived Paleoenvironments	94
7.2 Depositional Environment for the Dolostone	97
7.3 Depositional Environment for the Shale Microfacies	99
7.4 Depositional Environment for the Subfeldsarenite Microfacies	99
7.5 Depositional Environment for the Coarse Quartzarenite Microfacies	102
7.6 Depositional Environment for the Mixed Microfacies	104
7.7 Summary of the Overall Environment of Deposition for the Rockcliffe Formation	105
7.8 Depositional Environment Compared to those of the Cornwall Area	106
CHAPTER VIII: CONCLUSIONS	108
BIBLIOGRAPHY	111
APPENDIX A: FIELD DATA FORM	116
APPENDIX B: DETAILED OUTCROP SECTIONS	119
APPENDIX C: FIELD OUTCROP SECTIONS	125
APPENDIX D: DETAILED WELL SECTIONS	194
APPENDIX E: TABULATED TEXTURAL AND COMPOSITIONAL PROPERTIES OF SELECTED SAMPLES STUDIED IN DETAIL	198

LIST OF FIGURES

Figure No.		Page No.
1	Location of the study area within the Ottawa Embayment	2
2	Principal geological elements of Southeastern Canada	7
3	Cross-section of Paleozoic formations of the St. Lawrence Platform from Michigan Basin to Anticosti Basin	8
4	Actual and inferred distribution of the Paleozoic sediments of the Ottawa Embayment	12
5	Structural map of the Ottawa-St. Lawrence Lowland in Canada, showing faults affecting the Paleozoic formations	13
6A	Rockcliffe Formation bore-hole and outcrop locations, and inferred distribution beneath Quaternary cover	21
6B	Field sample locations plotted as outcrop station numbers	22
7	Chart of visual estimation for roundness and sphericity	26
8	The classification prism used for rocks of the Rockcliffe Formation	28
9	Types of internal structures in the phosphatic shell fragments	63
10	Paleocurrent directions within the Rockcliffe Formation, from ripple marks and cross-beds . .	76
11	Diagrammatic interpretation of the three columnar sections of bore-holes	80
12	Fifteen selected outcrop partial sections of the Rockcliffe Formation (cf. Fig. 11)	83
13	Rosenstein's (1973) and Hoskin's (1974) nine columnar sections (interpreted using the present author's microfacies definitions)	91
14	Chazyan paleogeography and lithofacies of Rockcliffe Formation	96

LIST OF TABLES

Table No.		Page No.
1	Paleozoic formations of the Ottawa Region . . .	3
2	Summary of the Paleocurrent and strike and dip data observed in the various microfacies. .	75
3	Summary of the petrographic and sedimentary structure features observed in the Rockcliffe Formation	77

LIST OF PLATES

Plate No.		Page No.
1.	Dolostone overlying flat-bedded, fissile shale (Stn. No. 23)	31
2	Shale microfacies containing pelecypod (mytiloid?) shells (Stn. No. 20)	33
3	Shale microfacies infilling scour on top surface of the subfeldsarenite microfacies (Stn. No. 32) . . .	33
4	Shale lens within lenticular bedded/fractured subfeld- sarenite microfacies (Stn. No. 29)	35
5	Rusty concretions within shale microfacies (Stn. No. 36)	35
6	Thin shale "wisps" extending from the trough over the crests of internally cross-bedded asymmetrical ripples in the subfeldsarenite microfacies (flaser bedding?) (Stn. No. 49)	36
7	"Mud-cracks" within shale microfacies (Stn. No. 71) .	36
8	Small ellipsoidal structures in dolostone microfacies (Stn. No. 26)	38
9	Large, oval ellipsoids in dolostone microfacies (Stn. No. 31)	38
10	Photomicrograph of silty, fine grained dolomitic mud of the ellipsoids (Stn. No. 30)	39
11	Photomicrograph of irregular-shaped, interstitial pyrite in dolostone microfacies (Stn. No. 31)	41
12	Non-fissile, <u>rippled</u> , cross-laminated and flat-bedded subfeldsarenite microfacies (herringbone structure?) (Stn. No. 32)	42
13	Photomicrograph of subfeldsarenite microfacies, plane light (Stn. No. 29)	43
14	Same section as Plate 13, polarized light	43
15	Photomicrograph of heavy grain laminae in subfeldsare- nite microfacies, plane light (Stn. No. 18)	46

Plate No.		Page No.
16	Photomicrograph of calcite in bioturbated portions (burrows) of subfeldsarenite microfacies, plane light (Stn. No. 23)	48
17	Flat-bedding in subfeldsarenite microfacies (Stn. No. 23)	50
18	Decrease in bed thickness toward top in subfeldsarenite microfacies (Stn. No. 29)	50
19	Rippled, fissile subfeldsarenite microfacies with parting along bedding planes of thin shale (Stn. No. 67)	51
20	Channel scour, in subfeldsarenite microfacies, infilled by mixed microfacies (Stn. No. 71).	51
21	Asymmetric ripples on bedding surface in subfeldsarenite microfacies (Stn. No. 56)	52
22	Linguoid ripples on bedding surface in subfeldsarenite microfacies (Stn. No. 34)	52
23	Rib and furrow structures in subfeldsarenite microfacies (Stn. No. 12)	54
24	Burrows (arrows) on subfeldsarenite microfacies bedding plane (Stn. No. 17)	54
25	Load casts on base of bed in subfeldsarenite microfacies (Stn. No. 49)	55
26	Subfeldsarenite concretions elongate parallel to bedding in subfeldsarenite microfacies (Stn. No. 71).	55
27	Ball and pillow subfeldsarenite microfacies over and underlain by phosphatic quartzarenite microfacies (note blue colour) (Stn. No. 31)	56
28	Cross-bedded quartzarenite microfacies overlying the scoured top of ball and pillow subfeldsarenite in Plate 27	56
29	Flat-bedded subfeldsarenite microfacies overlain by "soft-sediment deformed" subfeldsarenite microfacies (Stn. No. 40)	57
30	Photograph of calcite cemented coarse quartzarenite microfacies with a fine-grained quartz/feldspar matrix and minor phosphatic shell fragments (Stn. No. 49)	59

Plate No.		Page No.
31	Photomicrograph of "clean" quartzarenite submicrofacies, plane light (Stn. No. 49)	60
32	Photomicrograph of phosphatic quartzarenite submicrofacies, plane light (note phosphatic quartz/feldspar clast in lower left) (Stn. No. 31). . . .	60
33	Photomicrograph of calcite-cemented quartzarenite microfacies with the fine-grained quartz/feldspar matrix absent (note phosphatic clast and phosphatic quartz/feldspar clast) (Stn. No. 32)	61
34	Photomicrograph of quartz overgrowth on coarse quartz grains in quartzarenite microfacies (Stn. No. 49)	61
35	Photomicrograph of phosphatic oolite aggregate in phosphatic quartzarenite submicrofacies, plane light (Stn. No. 31)	65
36	Photomicrograph close-up of a phosphatic oolite aggregate, plane light (Stn. No. 40)	65
37	Photomicrograph of clay matrix (on the right) in coarse quartzarenite microfacies, polarized light (Stn. No. 59)	66
38	Cross-bedding in coarse quartzarenite microfacies (Stn. No. 59)	69
39	Photograph of mixed microfacies in outcrop (Stn. No. 71)	70
40	Photomicrograph of intraformational shale clasts within subfeldsarenite host rock, plane light (Stn. No. 71)	70
41	Outcrop of typical subfeldsarenite microfacies overlying shale microfacies at Station No. 37	84
42	Rockcliffe/Ottawa contact (along ruler) at Station No. 24	84
43)	)	
44)	) Rockcliffe/Ottawa contact (along grass line) and upper 20 metres of the Rockcliffe Formation (Stn. No. 31)	85
45)	)	

Plate No.

Page No.

46	Hogsback (Station No. 35) showing upper ten metres of Rockcliffe and Rockcliffe/Ottawa contact	86
47	Typical subfeldsarenite microfacies outcrop section (Stn. No. 33) (cf. Fig. 12)	88
48	Type section of mainly interbedded subfeldsarenite and shale microfacies, below Rockcliffe Lookout, used by A. E. Wilson (1946) and E. S. Rosenstein (1973) (Stn. No. 36) (cf. Fig. 12)	88

CHAPTER I

INTRODUCTION

1.1 GENERAL STATEMENT

The Rockcliffe Formation, of the Ottawa Embayment, is a Middle Ordovician (Chazyan) deposit of sandstone, siltstone and shale, underlain by the Oxford Formation and overlain by the limestones of the Ottawa Group.

The majority of the Rockcliffe outcrops within the study area are within one kilometre of the Ottawa River, from just west of Aylmer, Quebec, east to the town of Orleans, Ontario. This area, almost totally within the city limits of Ottawa, Ontario, is on the north-central side of a large, well-defined, roughly subquadrangle, structural basin which occupies some 20,000 square kilometres of the St. Lawrence Platform. The main portion of this structure, the Ottawa Embayment (Fig. 1) is underlain by marine sediments, ranging from Late Cambrian sandstones, exposed around the perimeter, to Middle Ordovician (Frentonian) carbonate rocks exposed in the centre. These sediments lie unconformably upon Precambrian rocks of the Canadian Shield. In the northern section of the basin near Ottawa, a downfaulted block exposes Late Ordovician (Richmondian) sedimentary rocks. (Table 1)

The Embayment was mapped and described stratigraphically, by A. E. Wilson, whose map and written report appear in

FIG.1 Location of the study area within the Ottawa Embayment.
(after A.E. Wilson, 1946)

TABLE I

Paleozoic Formations of the Ottawa Region.*
(Bolton and Liberty, 1972).

ORDOVICIAN	UPPER	Richmond	QUEENSTON	
		Lorraine	RUSSELL	
			CARLSBAD	
		Utica	BILLINGS	
			EASTVIEW	
	MIDDLE	Trenton	OTTAWA	COBOURG
				SHERMAN FALL
				HULL
				ROCKLAND
				LERAY
				LOWVILLE
				PAMELIA
		Chazy	St. Martin	
			ROCKCLIFFE	
	LOWER	Beekmantown	OXFORD	
			MARCH	
	UPPER ?	NEPEAN		
	PRECAMBRIAN	PRECAMBRIAN		

*All of the formations are not present in the study area.

the Geological Survey of Canada Memoir 241 (1946).

This thesis comprises a petrographic, stratigraphic and paleoenvironmental analysis of the outcrops mapped by Wilson (1946) as belonging to the Chazyan Rockcliffe Formation in the Ottawa-Hull area, based on megascopic investigations of outcrop and core sections and microscopic studies of thin sections cut from hand specimens and core samples.

1.2 PURPOSE OF STUDY

The reasons for undertaking this research of the Rockcliffe Formation are as follows:

- 1) The only published work carried out on the Rockcliffe Formation has been the stratigraphic mapping and the lithofacies descriptions of A. E. Wilson in 1946, E. S. Rosenstein in 1973 and R. J. R. Hoskin in 1974. Wilson's work was restricted to the mapping and very brief field descriptions of all the sedimentary formations of the Ottawa Embayment. The work of both Rosenstein and Hoskin is restricted to examination and description of Rockcliffe Formation cores, from around the Cornwall area. From the petrology and sedimentary structures of the Rockcliffe Formation, and mapping and description of the outcrops of the area, the author hoped to be able to reconstruct a paleoenvironmental model for the deposition of the Rockcliffe Formation in the northern part of the Ottawa Embayment.
- 2) No detailed stratigraphic column or stratigraphic cross-section, for the Rockcliffe Formation in the Ottawa-Hull area, was available prior to this work. It was, therefore the author's intent to compile by the use of outcrop and core descriptions, a stratigraphic column and cross-section within the study area.

- 3) Finally, the author hoped to compare and possibly correlate the stratigraphic section, rock types and paleoenvironment of the northern sector of the basin to those of Rosenstein and Hoskin, in the southern part.

CHAPTER II

REGIONAL GEOLOGY OF THE OTTAWA EMBAYMENT

The following description is based largely on the work of A. E. Wilson (1946).

2.1 REGIONAL SETTING

The St. Lawrence Platform, a narrow northeast extension of the stable interior of North America, is bordered on the southeast by the Appalachian Orogen and on the northwest by the Canadian Shield. The Platform (Fig. 2) can be divided into 3 parts. From east to west these parts are:

- 1) Southwestern Ontario lying between the Michigan Basin and the Allegheny Trough.
- 2) The Ottawa-Quebec Lowland (Quebec Basin, including Ottawa Embayment).
- 3) Anticosti-Mingan Island and the coastal plain of western Newfoundland and southeast coast of Labrador (Anticosti Basin).

Figures 2 and 3 show that the Ottawa Embayment is the least extensive, in area, and contains the thinnest Paleozoic section, compared to the other basinal areas.

The Ottawa Embayment (Ottawa-St. Lawrence Lowland) is a large, well-defined, roughly subquadrate, structural basin occupying an area of some 20,000 square kilometres (Fig. 1). The Embayment lies between the Laurentian Mountains of the Canadian Shield, on the north, and the Adirondack Mountains, on

FIGURE 2. Principal geological elements of Southeastern Canada. (after R. J. W. Bouglos, 1970)

FIGURE 3. Cross-section of Paleozoic formations of the St. Lawrence Platform from Michigan Basin to Anticosti Basin (after B. V. Sanford, in R. Douglas, ed., 1970)

the south. Its western margin, the Frontenac Axis, is an irregular, southeast-trending belt of Precambrian rocks extending from the Shield to the Adirondacks. The eastern border is the Beauharnois Anticline, a less prominent axis, named by Logan (1863) and extending again from the Shield to the Adirondacks. This lesser axis is mantled by basal Paleozoic sandstone with the exception of the Rigaud and Lake of Two Mountains areas, where Precambrian rocks emerge.

The surface of the Ottawa-St. Lawrence Lowland rises gently to the west in a series of low steps, from a minimum elevation of 20 m. above sea level near the mouth of the Ottawa River, to an elevation of 150 m. at the Frontenac Axis. Immediately north of the river mouth, along the Beauharnois Anticline, are Precambrian inliers, having an elevation of 180 m. The saddle between the inliers and the Precambrian Shield has an elevation of 50 m. South along the Anticline, toward the Adirondacks, a gentle rise gradually brings the surface elevation to 75 m., then abruptly rises to 180 m. onto a sandstone highland.

Only near the northern margin, where faulting has disturbed the originally flat-lying sediments, is any considerable thickness of Paleozoic bedrock exposed. Elsewhere, within the lowland, the bedrock is covered by unconsolidated Quaternary deposits; displaying only scattered exposures in quarries, road cuts, and low ridges.

2.2 STRATIGRAPHY

In the Ottawa Embayment, quartzose sandstones succeeded by dolomites, limestones, shales and shaly sandstones lie unconformably upon the irregular eroded Precambrian surface. The age of the basal sandstone is late Cambrian or early Ordovician and succeeding sedimentary rocks extend upward into the Late Ordovician (Bolton and Liberty, 1972). The Ordovician formations include rocks of Beekmantown, Chazy, Black River and Trenton, Utica, Lorraine and Richmond age (Table 1). The rocks consist of lenticular and variable lithic units that locally reflect variable environmental conditions that are interpreted as deposits of a series of shelves and basins along the margins of a low,

stable land mass. In the Embayment, the lower Paleozoic sequence is believed to have been deposited in a partially enclosed sea (Bolton and Liberty 1972).

The maximum thickness of the lower Paleozoic sediments in the Ottawa Embayment is about 670 metres, though variations occur from east to west. Of this thickness, the Lower Ordovician and Upper Cambrian is represented by 105 metres, the Middle Ordovician by 275 metres and the Upper Ordovician by 290 metres of sediments.

Although, throughout the basin, the strata are flat-lying or gently undulating with no generally persistent direction of strike or dip, Rosenstein (1973) calculated an average dip of 0.7 degrees to the southeast in the Cornwall area. In the northern part of the basin, the rocks are tilted at various angles in the fault blocks or near the principal fault zones.

The sandstone of the Nepean Formation, at the base of the stratigraphic column, is succeeded by the transitional March Formation (sandstone and dolomite) and the Oxford Formation (dolomite), all of which were deposited, possibly contemporaneously, in a shallow sea transgressing from the east. An extensive erosional interval, within the basin, followed the withdrawal of this sea.

With renewed transgression from the east, and after considerable deposition east of the Beauharnois Anticline, the 50 metres of shale, siltstone and coarse sandstone lenses of the Rockcliffe Formation and the 10 metres of calcarenite of the St. Martin Formation (the latter in the eastern part of the Embayment only) were deposited. The sea once more withdrew for a short period but the surface of the sediments was never much above sea level.

The third transgression interpreted by Wilson (1937), this time from the southwest over the Frontenac Axis, deposited the Ottawa Group of limestones before another regression and short erosional period.

According to Wilson (1937), the sea underwent transgressive/regressive sequences four more times in the Upper

Ordovician depositing, with transgression from the east, the Eastview Formation (limestone), with transgression from the south, the Billings Formation (shale), with transgression from the east, the shale and dolomite of the Carlsbad Formation, and with transgression from the north and south, the Russell and Queenston Formation shales. These four sequences, however, show no evidence of long erosional intervals between the deposition of their respective sediments.

No further deposition is recorded within the Embayment until the unconsolidated Quaternary deposits were laid down. Figure 4 shows the present distribution or inferred distribution of the sediments in the Ottawa Embayment, excluding the Quaternary deposits.

2.3 STRUCTURE OF THE BASIN

The Paleozoic deposits of the Ottawa Embayment have been modified, mainly in the northern half of the basin, by three major sets of faults (Fig. 5). The directions of the three sets are WNW, E-W and NE. The dips of all the faults, except the E-W system which tends to dip south, are essentially vertical, as are the displacements. The faulting roughly forms the northern boundary of the present Paleozoic formations separating them from the Precambrian rocks.

The main structural feature within the basin is a large, down-dropped block which is bounded by fault zones on the north, west and south. This block is elongate in the northeast direction and is tilted so that the maximum throw is on the west and south. The northern fault boundary is the Hawkesbury to Hull section of faulting, the west boundary is the Gloucester fault with its 550 metre throw, and the southern boundary is a long fault, in the centre of the block. The gradual upward inclination eastward is interrupted by a slight break or further down-warping. From here eastward, the upward inclination is resumed. The younger Ordovician formations have been preserved within this block (Wilson et al. 1941).

FIGURE 4" Actual and inferred distribution of the Paleozoic sediments in the Ottawa Embayment.
(modified from Wilson, 1946)

The exact ages of the faults in the basin cannot be established but evidence indicates that faults have been active for a very long period of time, with lines of weakness in the Ottawa valley dating back to the Precambrian. Some faults (the WNW system) have been active in post-Middle Ordovician time. The physiographic expression of the faults and current seismic activity of the region can be taken as evidence of recent activity. Post-Pleistocene faults have been noted in the upper Ottawa graben (Bolton and Liberty, 1972).

CHAPTER III

PREVIOUS WORK ON THE ROCKCLIFFE FORMATION

During the last half of the nineteenth century and early part of the twentieth century, a number of geologists studied the basin. Included among these geologists were Sir William Logan, Alexander Murray and Elkanah Billings in the mid-1800's, H. G. Vennor, J. J. Giroux, R. W. Ells, H. M. Ami and P. E. Raymond in the late 1800's and early 1900's, M. Kay, M. E. Wilson and A. E. Wilson in the early and mid-1900's, and Liberty and Sanford in the early 1970's. While reconnaissance mapping and brief descriptions of the lithologies were presented, most of the stratigraphic reports deal mainly with the paleontological character of the formations. This means that the Rockcliffe Formation, with its few fossils, was virtually ignored. Until E. S. Rosenstein (1973) and R. J. R. Hoskin (1974) studied the Chazy rocks, in the southern sector of the basin near Cornwall, little had been written on the Rockcliffe since A. E. Wilson's work in the 1940's.

The Chazy sediments in the basin are represented by the St. Martin and the Rockcliffe Formations. In the central, eastern and northern parts of the Embayment, the St. Martin lies conformably over the Rockcliffe and unconformably under the Lowville Formation (Ottawa Group) (Table 1). The wedge

shaped St. Martin Formation thins westward from 47 metres thick in the central-eastern part of the basin until it disappears just east of Ottawa (Wilson, 1946). In the Cornwall area, the thickness "would appear to be in order of 70 feet (21 metres)" (Rosenstein, 1973, p.43). Wilson described the St. Martin as being "dominantly limestone, but at its western margin and at its base it is composed of shaly or dolomitic limestone intermingled with thin beds of dark shale and occasional sandstone layers" (Wilson, 1946, p.19). Rosenstein's (1973) core study is in agreement with these findings.

The Rockcliffe Formation appears as a narrow strip from 1.5 to 4.5 kilometres wide, in an irregular belt almost completely encircling a centre north of Cornwall and east of Russell (Fig. 4). The Rockcliffe unconformably overlies the Oxford Formation and is, in turn, overlain unconformably by the Ottawa Group. The Lowville Formation (Ottawa Group) limestone is directly above the Rockcliffe, in the western part of the basin only, where the St. Martin is absent. Whether the overlying beds of the Ottawa Gp. belong to the lowermost Pamela Formation or to the Lowville Formation (which overlies the Pamela) is uncertain due to what Hofmann (1963) calls the Pamela problem. Young (1943) considers the Pamela post-Chazyan in age. However, Hofmann states that the contact between the Chazyan beds and the Pamela is gradational and difficult to define, with both exhibiting dolostone and dolomitic shale beds in their upper and lower parts respectively. He feels the Chazy-Black River boundary in the Ottawa Valley lies within the Pamela, not at its base. He also states that a New York locality of Chazy exhibits a strong lithologic similarity to the Montreal 'Pamela', thus adding difficulty to the problem. Rosenstein (1973) doubts the existence of rocks equivalent to the Pamela in the Ottawa area, after finding little difference between the Lowville rocks of the Cornwall area and Wilson's (1946) Pamela of the Ottawa area. It would appear then that the Pamela (as described in other localities) may be absent in the Ottawa area. The present author placed the Rockcliffe/Ottawa boundary at the first significant showing of dark gray, fossiliferous limestone, disregarding the problem of whether the limestone was from the Pamela or Lowville formations.

east and there is considerable irregularity within the area, but bore holes indicate an average thickness of about 47 to 50 metres (Wilson, 1946). Wilson's description of the Rockcliffe states that it "is composed of friable shales with lenses of sandstone. The shale for the most part is light olive-green with a few pockets of dark iridescent shale. The sandstone is fine-grained and grey in the eastern and central part of the basin, changing to a deep red where it occurs on the Ottawa River above MacLaren Landing. The basal lenses of the Rockcliffe, ... contain small fragments of quartz and dolomite, and some grey-green shale, the last evidently of intraformational origin. These lenses vary from small proportions to thin, widespread sheets and to masses twenty feet or more thick and several miles in extent" (Wilson, 1946, p.18). Hofmann (1963) noted that the limestone units in the Chazy of the Montreal area are also lenticular and postulated that "strong currents... carried them (shell fragments) off in a predominantly southeasterly direction... and piled them into banks and shoals, generally in a cross-bedded fashion, forming calcarenite coquina" (Hofmann, 1963, p.292). Similar currents in the Ottawa area could have been equally capable of producing the lenses of quartz sand and quartz sand/shell fragment mixture.

Rosenstein (1973) studied the Rockcliffe Formation in greater detail. From three wells, in the Upper Rockcliffe, Rosenstein described five major sedimentary facies. The descriptions of these five facies are:

- 1) Very fine-grained subarkosic facies - These rocks are composed mainly of small, angular to sub-rounded, well-sorted grains of quartz and albitic feldspar. The median grain size is 0.1 mm. Minor clay, as matrix or along bedding planes, is present. The other constituents are 15 - 20% phosphatic skeletal fragments and 20 - 25% sparry calcite cement with scattered dolomite rhombs.
- 2) Shale facies - Grey-green coloured, highly fissile,

somewhat pyritic shale locally traversed by less than 6 mm. beds of biosparite.

- 3) Biosparitic facies - "Poorly preserved fossil fragments in a cloudy, sparry, calcite matrix" (p.24) with rare quartz silt and minor thin shale partings.
- 4) Brachiopod-rich silty shale facies - "This facies consists mainly of large, single brachiopod valves, aligned subparallel to the bedding, in a matrix of shale with included quartz silt grains. Thin, relatively pure pelmicrite beds and laminae of coarse quartz grains occur within this facies". (p.27)
- 5) Mixed facies - "This facies is a mixture of all four facies already described, with allochems and detrital fragments present in all possible proportions. The lithology consists of abundant, coarse quartz grains (0.5 to 1.0 mm.), shell debris, shale lithoclasts, some phosphatic debris, and quartz silt grains, with a little silt-sized feldspar in a matrix of clay, calcite and dolomite". (p.27) Hoskin (1974) subdivided this facies into four subfacies according to their composition and structural features.

Wilson (1946) suggested that the Rockcliffe and St. Martin Formations were deposited by an "invading sea from the east" which "might have sufficient carbonates for deposition in its eastern part while depositing clastic material on its western shoreline" (Wilson, 1946, p.16). Hofmann (1963) agreed with Wilson, stating that "westward from Montreal, the sandstone and shales (Rockcliffe Formation) increase in thickness relative to the remainder of the Chazy (St. Martin limestone) until at Ottawa, most of it is shale and sandstone, the Rockcliffe Formation" (Hofmann, 1963, p.277). Rosenstein reported that the deposition of the Rockcliffe was "dominated by terrigenous influx" which was brought into the shallow-marine environment by fluvial means, and "was reworked into broad, lenticular sandbanks by wind-driven marine currents" (Rosenstein, 1973, p.94). The shale facies

are thought to have been deposited in the quieter waters between the banks, while the mixed facies represents, "a deposit left in the wake of storm action" (Rosenstein, 1973, p.35).

A brief comparison of the Chazyan rocks in the Cornwall and Ottawa regions was completed by Rosenstein. He stated that the Chazyan rocks exposed around Ottawa are of the uppermost Rockcliffe Formation, are almost entirely of terrigenous clastics, and are similar to the rocks at Cornwall. However, Rosenstein suggested that "the Ottawa Rockcliffe was nearer the Chazy coastline than the Cornwall Rockcliffe" and "the terrigenous influx was from the north" (Rosenstein, 1973, p.42).

The most recent paper written on the Rockcliffe Formation is by Hoskin in 1974. His petrologic descriptions, facies divisions and paleoenvironmental analysis are very similar to Rosenstein's and, therefore, little reference has been made to his paper in the present study.

CHAPTER IV.

METHODS OF STUDY

4.1 FIELD STUDY

The majority of the outcrop within the study area is along both sides and within one kilometre of the Ottawa River, extending from just west of Aylmer, Quebec, east to the town of Orleans, Ontario (Fig. 6A). The only exception to this is the faulted block at Hogsback (Station Nos. 34 and 35).

Most sections (Fig. 6B), in the western half of the area (west of Station No. 28), are along the river banks, with the thickest exposure at Westboro Beach (Station No. 24) measuring 9 metres. Other outcrops, west of Station No. 28 and away from the river, are mostly either "table-top" (flat and barely breaking through the overburden) or drainage ditch exposures, having an average height of slightly greater than $1\frac{1}{2}$ m. The eastern exposures, from Rockcliffe Park (Station No. 39) to Orleans, are all cliff-type outcrops with the highest, at Rockcliffe Airport Quarry (Station No. 31), measuring approximately 18 metres. The remaining eastern exposures average $6\frac{1}{2}$ metres in height. The horizontal extent of the outcrops is very good, with only minor breaks due to overlying Quaternary sediments burying the outcrops for short distances. This overburden blankets enough lithology, however, to prevent a close outcrop to outcrop correlation.

FIGURE 6A. Rockcliffe Formation bore-hole and outcrop locations, and inferred distribution beneath Quaternary cover.

FIGURE 6B. Field sample locations plotted as outcrop station numbers.

The outcrop distribution was plotted on a two inch to the mile, black and white map of the Ottawa region supplied by the National Capital Commission. Pertinent exposure information for each outcrop was recorded, along with a rough section illustration, on prepared data forms (Appendix A). Any directional data or strike and dip measurements were taken with a Brunton compass. Fist-sized (average) samples were taken of each petrographically and structurally (sedimentologically speaking) different unit. These samples were examined with a 10X hand lens, tested with 10% HCl, labelled according to outcrop station and stored in a cloth sample bag. Photographs of the outcrops, rock types and sedimentary structures, were taken on a Minolta SRT 101 camera equipped with a 1.7 (55mm.) lens and Ektachrome-X (EX-135-20, ASA 64) film.

In the laboratory, the hand samples were stored for further study and detailed outcrop sections were drawn (Appendices B and C), for future reference and stratigraphic comparison, on centimetre graph paper using the information recorded on the data forms. Strike and dip, and paleocurrent directions were plotted on the base map.

4.2 CORE STUDY

The core study was completed on three wells, two drilled within the research area and one drilled in Russell County, to the southeast. Two additional drill holes within the research area were deep enough to penetrate the rocks of the Rockcliffe Formation, but these cores could not be located. (Fig. 6A)

The three cores studied are stored as follows:

- 1) The Russell G.S.C. No. 2 well, drilled in Russell County, Russell Township, Lot 24, Concession 11 in 1964, went down 835 metres and penetrated all 43 metres of the Rockcliffe. The core is stored at the Ministry of Natural Resources Office, London, Ontario and is a 3.2 cm. diameter core, slabbed longitudinally.

- 2) The Dominion Observatory well, drilled within the city of Ottawa at Observatory Hill on Carling Avenue, was sunk 303 metres with all 47 metres of Rockcliffe penetrated. The core is stored at the Geological Survey of Canada warehouse on Laperriere St. in Ottawa. It is an unslabbed, 3.2 cm. diameter core. The author received permission to remove this core and transport it to Carleton University laboratory for further investigation.
- 3) The Kilborn Avenue School well, drilled within the city of Ottawa, in 1962, at latitude 45° 23' 12" and longitude 75° 40' 24", was sunk 281 metres with only 36 metres of the Rockcliffe penetrated. This longitudinally slabbed, 3.2 cm. diameter core is also stored at the Laperriere St. warehouse.

All three sets of cores were examined visually and with the aid of a 10X hand lens. The observatory cores were examined further with the aid of a Wild Heerbrugg binocular microscope, equipped with 10X eyepieces and magnifications of 6X, 12X, 25X and 50X. Each rock type, within the Rockcliffe portion of the cores, was tested with 10% HCl to determine if carbonate was present.

The Rockcliffe sections were then logged for any major lithic and structural differences. These written logs were later converted to illustrations on centimeter graph paper (Appendix D), for easier visual comparison and the hope that a stratigraphic column and cross-section could be compiled from them.

As earlier stated, the observatory cores were the only ones made available for complete investigations required. Therefore, the eleven thin sections from cores came from this well. The exact footages, where the thin sections were longitudinally cut, are 251, 259, 264, 269, 271, 273, 293, 319, 313, 323 and 357. It was hoped that these thin sections might clearly define a change in the shale across the Rockcliffe/Lowville (Ottawa Group) contact.

The compilation of the stratigraphic column and cross-section, resulting from this core study, will be discussed more fully in Chapter Six.

4.3 LABORATORY STUDY

A large portion of the total research was conducted in the laboratory. This phase of the study included the detailed examination of the hand specimens, petrographic descriptions of thin sections cut from the collected field specimens, photographs of petrographic and structurally significant features in both hand specimen and thin section, and the compilation of all the results.

The field specimens were further studied, with a binocular microscope, for any possible detail missed during the field examination. These samples were then visually separated into lithologic groups. This was done with the hope of keeping the production of thin sections, from each obviously different rock type, to a reasonable number for examination. Next, the hand samples were studied for any sedimentary structures or sparse component grains, which could be viewed or identified more fully in thin section. After selection, forty-two hand samples were sectioned in the Geology Thin Section Lab, Carleton University.

Once the thin sections were made, they were viewed with an Ernst Leitz Wetzlar petrographic microscope equipped with a 10X binocular eyepiece (one lens was fitted with a micrometer scale) and objective lenses of 3.5X, 10X, 25X and 50X. The detailed descriptions of the thin sections included the following characteristics:

- 1) composition
- 2) percentage, roundness and sphericity (Fig. 7) and grain size of each component
- 3) sorting
- 4) orientation of component grains and of all the components as a whole
- 5) spatial distribution of the different components
- 6) percentage, composition and distribution of any cement and/or matrix

FIGURE 7. Chart of visual estimation for roundness and sphericity.
(modified from Krumbein & Sloss 1963)

- 7) alteration; if so, what type and where
- 8) grain/grain relationships (i.e. touching, sutured, "floating", etc.)
- 9) internal structure of component grains

After examination of each thin section, a name was given to the rock according to the scheme shown in Figure 8.

As each thin section was examined, distinctive characteristics were noted. Later definitive petrographic and structural features were photographed using the Minolta SRT 101 camera. The camera was fitted with a Minolta microscope extension pipe equipped with an 8X eyepiece. This unit, in turn, was mounted onto an Ernst Leitz Wetzlar microscope. The photographs were taken on Ektachrome EHB 135-20 (Tungsten 3700K, ASA 125) film, using either the 3.5X or 10X magnification lens of the microscope. The light source for the photographs was an Ernst Leitz GMBH Wetzlar power pack, type 301-166.101, lamp CS1250W, using a blue filter.

FIGURE 8. The classification prism used for rocks of the Rockcliffe Formation. (Modified from Pettijohn et al., 1973, fig. 5-3)

CHAPTER V

PETROGRAPHY AND SEDIMENTARY STRUCTURES

5.1 GENERAL STATEMENT

Five major microfacies and five submicrofacies have been defined from an examination of the collected hand specimens, the prepared thin sections, and the available well core. Compositional and textural variations within the microfacies result in some gradation between the five main groups. However, a complete gradation between microfacies is not observed and, therefore, no difficulties were encountered in petrographically segregating the rocks, by microscopic inspection, into their appropriate groups. The five major microfacies are:

- 1) shale
- 2) dolostone
- 3) subfeldsarenite or subfeldswacke
- 4) coarse-grained quartzarenite
- 5) mixed

The coarse-grained quartzarenite microfacies contains two submicrofacies: referred to as a) the clean quartzarenite and b) the phosphatic quartzarenite. The mixed microfacies contains three submicrofacies: a) a subfeldsarenite with intraformational shale clasts, b) a phosphatic quartzarenite with intraformational shale clasts and c) a subfeldsarenite with phosphatic clasts.

The sedimentary structures in the Rockcliffe Formation are abundant and diverse, with all five microfacies exhibiting one or more types. The sedimentary structures recorded within the study area include primary depositional structures and structures due to penecontemporaneous or diagenetic chemical reactions.

The sediments of the five microfacies were deposited in a manner which prevents precise correlation of one outcrop sequence with any other, even when sections are closely spaced. This is a result of the lenticular nature of the rock units and although the lenticular bedding is rarely completely seen in an outcrop, it can be inferred from the preceding observation - that stratigraphic correlation from one section to the other, on a small scale, is virtually impossible. This finding is supported by Wilson (1946) and Rosenstein (1973), with Wilson stating that "the lenses vary from small proportions to thin, widespread sheets to masses 20 feet or more thick and several miles in extent" (Wilson, 1946, p.18). While this gross bedding character holds true for the whole formation over the entire map area, small-scale sedimentary structures differ from outcrop to outcrop and microfacies to microfacies.

Detailed descriptions of the five microfacies and five submicrofacies, their sedimentary structures, and a comparison with those found by Rosenstein (1973) and Hoskin (1974) are given below. Strike and dip measurements, paleocurrent directions, and a summary of the microfacies and associated structures are given in Table 2, Figures 6A and 10, Table 3 and Appendix E.

5.2 MICROFACIES DESCRIPTIONS

5.2.1 SHALE MICROFACIES

This microfacies is primarily a grey-green to dark green (10GY5/2 to 5GY2/1: Geol. Soc. Am. Rock Colour Chart, 1975), highly fissile shale (Plate 1). The colour becomes darker toward the top of the Rockcliffe, with localized occurrences of red-tinged shale scattered throughout the formation (eg. Station 31, 10 metres from the top). The high fissility of the shale imparts

Plate 1. Dolostone microfacies overlying
flat-bedded, fissile shale microfacies
(Station No. 23).

(Note: Scale in this and other outcrop plates is a foot ruler
divided into inches)

a characteristic 3 to 6 mm. thick "poker chip" fracture in some areas.

The shales are composed for the most part of a fine micaceous mud with the microscopic platelets oriented parallel to the bedding. The rocks appear free of any carbonate or large detrital grains but under the microscope minor dolomite rhombs, and coarse and fine sand-sized, well-rounded quartz and feldspar grains can be identified either scattered throughout the mud matrix or concentrated in thin, white lenses. Disseminated, silt-sized pyrite cubes are present with, in some cases, minor rusty coatings. Pyrite also occurs as thin stringers parallel to the bedding and as coatings surrounding a few of the detrital grains.

In most outcrops, the shales are devoid of any body fossils. Abundant sediment-filled tubes, oriented both perpendicular and parallel to the bedding, and other evidence of bioturbation are present. A few thin, widely scattered beds of shale with a high percentage of dark brown (10YR2/2), mainly broken phosphatic brachiopod shells (Lingula) oriented parallel to the bedding occur (eg. Station 20). One complete Lingula shell, measuring 6 mm. by 13 mm., was discovered at Station 20. In another bed at Station 20, single valve pelecypod shells 5.0 to 7.5 cm. long by 4 cm. wide (Plate 2), are oriented parallel to the bedding.

Shale units occur throughout the Rockcliffe and range from as much as 4.6 m. thick to as thin as 2.5 cm., with the thicker beds predominating toward the top of the formation. Most beds within the shale units are 2 to 6 mm. thick but some reach 5 cm. The thicker beds appear parallel-bedded whereas the thinner ones have wavy or rippled bedding surfaces (Station 25), with the rippled bedding in places grading upward into flat bedding. The tops of some units are scoured, and overlain by coarser-grained microfacies whereas the shale fills in scours on the upper surfaces of the coarser units (Plate 3). This "scour-fill" shale occurs frequently at the base of many fining-downward subfeldsarenite sequences although shale at the top of a fining-upward subfeldsarenite sequence is also common. Shale is also present

Plate 2. Shale microfacies containing pelecypod (mytiloid) shells (Station No. 20).

Plate 3. Shale microfacies infilling scour on top of the subfeldsarenite microfacies (Station No. 32).

as 0.3 to 0.6 m. long by 4.5 to 9.0 cm. wide lenses with convex upper surfaces surrounded by subfeldsarenite (Station 29, Plate 4) and which exhibit, in some exposures, convolute internal structures.

Two and a half to 5 cm. long by 1.3 to 2.5 cm. thick, rusty-coloured (10R4/6) concretions within the shale at a number of localities (eg. Stations 36 and 71) are elongate parallel to the bedding (Plate 5).

In many instances, the 2 to 4 mm., dark green shale beds alternate with light green subfeldsarenite beds of the same thickness. These alternations are parallel-bedded but in some cases, the subfeldsarenite forms 6 mm. diameter, inverted mushroom-shaped balls - load casts - or discontinuous, distorted lenses. Hoskin (1974) explains that the "load casts occur typically on the bases of water-laid sandstones overlying shales. The structure represents a case of gravitational instability in which the very fine-grained sandstones are in a more liquefied state and have 'flowed' prior to lithification in response to gravitational forces... In vertical profile it was observed that the denser sand layer therefore forced its way into the soft, less dense shaly material in the form of downward swellings, which varied from slight bulges to deep rounded masses" (Hoskin, 1974, pp. 25-30).

In other places, ripples (Station 25) and cross-bedding (Station 44) are common with the shale present either as thin wisps in the troughs or, rarely, as wisps extending from the trough over the crests of the ripples and cross-beds (Plate 6).

One sedimentary structure found in the shale units appears to be restricted to the upper part of the Rockcliffe Formation. This structure has an appearance, in plan view, similar to mud cracks (syneresis cracks?) (Stations 71 and 55A, Plate 7), although this identification is not positive as they do not have the characteristic mudcrack polygonal shape.

5.2.2 DOLOSTONE MICROFACIES

The rocks of the dolostone microfacies are massive, fine-grained and greyish-green (5G5/2) in colour with 1 mm., equant, rounded quartz and feldspar grains scattered throughout.

Plate 4. Shale lens within lenticular bedded/fractured subfeldsarenite microfacies (Station No. 29) (Lens is 0.3 m. long).

Plate 5. Rusty concretions within shale microfacies (Station No. 36).

Plate 6. Thin shale "wisps" extending from the trough over the crests of internally cross-bedded, asymmetrical ripples in the subfeldsarenite microfacies (flaser bedding?) (Station No. 49).

Plate 7. "Mud cracks" within shale microfacies (Station No. 71).

The dolostone occurs as 5 to 20 cm. thick, massive beds interbedded with the dark grey shale at the top of the formation, with minor occurrences dispersed throughout the formation; and as small to large (up to 0.3 by 1 m.), well-formed ellipsoidal bodies present only within the top few metres of the Rockcliffe overlying dark grey shales (Stations 30, 31 and 35, Plates 8 and 9).

The ellipsoidal-weathering beds are devoid of internal structure but characteristically break into 2.5 to 7.5 cm., blocky pieces with curved sides. The smaller-sized ellipsoids are stacked in multiple tiers to produce a bed; however, the larger ones form layers only one or two ellipsoids thick. This indicates possible stratification within the dolostone beds. The rock surrounding the ellipsoids is identical in composition to the ellipsoids and is also structureless suggesting originally massive beds later jointed and weathered to produce the ellipsoids. The underlying dark grey shale fills the concave-downward spaces between the bases of the ellipsoids.

The ellipsoids are composed of very fine-grained, brown carbonate mud and clear dolomite rhombs which are 0.025 to 0.125 mm. in size (Plate 10). Other constituents present constitute less than 15 percent of the rock and consist of:

- 1) scattered, 0.025 to 0.05 mm., equant to elongate, angular grains of quartz with straight or undulatory extinction.
- 2) rare feldspar grains of the same size and shape as the quartz, with albite and cross-hatched twinning
- 3) a few, scattered, randomly-oriented, 0.125 mm. long phosphatic shell fragments
- 4) rare, cubic to equant and rounded, 0.025 to 0.05 mm. pyrite grains with no particular spatial concentration
- 5) rare thin pyrite stringers parallel to the bedding

Thin chloritic wisps are parallel to the tops of the ellipsoids and give the rock its green colour as well as a faint indication of layering. The carbonate mud is concentrated in the areas of slight burrowing where sub-parallel orientation of the tubes to one another is common. In the tubes or burrows, is a

Plate 8. Small ellipsoids in dolostone microfacies (Station No. 30).

Plate 9. Large, oval ellipsoids in dolostone microfacies (Station No. 31).

0.15 mm

Plate 10. Photomicrograph of silty, fine-grained dolostone mud of the ellipsoids, polarized light (Station No. 30).

zonation of fine, rhombic dolomite and coarse, crystalline calcite, parallel to the burrow sides.

The 5 to 20 cm. thick dolostone beds consist of micrite with 0.05 mm. dolomite rhombs and coarse crystalline calcite. In tubular or lenticular areas bioturbated dolomite and crystalline calcite are concentrated around the perimeter of the burrows, surrounding the micrite within. These features also contain detrital material and minor pyrite. The detrital grains consist of:

- 1) 0.025 to 0.225 mm., equant to elongate, angular grains of quartz
- 2) 0.025 to 0.05 mm., equant to elongate, angular grains of feldspar with albite twinning
- 3) a few randomly-oriented, 0.125 mm. long phosphatic shell fragments

The pyrite occurs as small, irregular aggregates (Plate 11) or long, thin stringers.

5.2.3 SUBFELDSARENITE OR SUBFELDSWACKE MICROFACIES

Viewed in outcrop or hand sample (Plate 12), this microfacies exhibits light grey/green (10GY7/2) colouring with minor rust-red hematite spots, thin green shale and black heavy mineral laminae which outline the cross-beds and ripples within the rock, varying amounts of bioturbation, phosphatic fossil fragments, and a fine-grained texture of fine sand-sized quartz, feldspar and pyrite. Depending on the bedding thickness and the percentage of shale wisps, this microfacies can be fissile and crumbly or well indurated. When tested with 10 percent HCl, any reaction which occurs is in scattered patches.

In thin section (Plates 13 and 14), the rocks of this microfacies, while varying in composition, are extraordinarily similar when a quick visual scan is taken. The mineral components of the microfacies remain the same for each rock sample, differing only in proportion. Even the mode of occurrence for each

0.15 mm

Plate 11. Photomicrograph of irregular-shaped pyrite in dolostone microfacies, polarized light (Station No. 31).

Plate 12. Non-fissile, rippled, cross-laminated and flat-bedded subfeldsarenite microfacies (herringbone structure?) (Station No. 32).

0.15 mm

Plate 13. Photomicrograph of subfeldsarenite microfacies, plane light (Station No. 29).

Plate 14. Same section as Plate 13, polarized light (note: phosphatic shells are isotropic in this plate).

component varies little from rock to rock. This uniformity of composition persists in each bed and from one bed to another, throughout the formation. The components which make up the subfeldsarenite microfacies are quartz, feldspar, pyrite, apatite, zircon, biotite, muscovite, sphene, chlorite, calcite, dolomite, phosphatic fossil fragments, hematite and clay matrix. It is the variation in the percentage of clay matrix which determines whether a particular sample is a subfeldsarenite or a subfeldswacke; the threshold percentage being taken as 15.

The quartz content ranges from 25 to 55 percent of the rock but on the average is about 40 percent. Grains are from 0.065 to 0.15 mm., equant to elongate, and angular to subrounded averaging 0.1 mm. in size and equant to elongate and angular in shape. A few equant, rounded, 0.15 to 0.25 mm. grains are present. Orientation of the elongate grains is best seen in the shale wisps and burrowed areas although a vague orientation, of long axis parallel to the bedding, is evident throughout the rocks (Plate 13 and 14). Overgrowths on the quartz grains are absent, but both straight and undulatory extinction are shown by the quartz. If the percentage of quartz is low then the grains are usually "floating" in either a calcite cement or a fine clay matrix, with very few grains in contact. However, if the percentage is high then the grains are tightly packed and the contacts are straight to tangential with quartz touching quartz but either concavo-convex or long straight contacts with quartz touching feldspar.

The feldspar content ranges from 10 to 25 percent of the rock, from 0.025 to 0.125 mm., from equant to elongate, and from angular to subrounded but on the average exhibits 0.05 to 0.085 mm., elongate, angular grains composing 20 percent of the rock. The feldspar therefore is smaller, less equant and less rounded with respect to the quartz content, but it is always intermixed with the quartz throughout the microfacies. Twinning is common in the feldspar grains with albite, microcline and minor Carlsbad types present. Minor perthitic texture can also be seen. A few of the feldspar grains which exhibit higher relief, rhombic outline and good cleavage are likely potassium feldspar (orthoclase)

but these are a small percentage of the total feldspars, with the plagioclases being of greater abundance. In contrast to these findings, Hoskin (1974) found that, by staining the samples with sodium cobaltinitrate, a percentage of 35 to 40 for potassium feldspar was revealed. This figure he later qualifies but still estimates a total feldspar content of about 30 percent. The 10 percent difference in feldspar content, between Hoskin and this author, accounts for Hoskin's name of arkose rock-type, comparable to this author's subfeldsarenite.

The fossil fragments present are broken, thin (0.025 mm) and range from 0.125 to 0.25 mm. in length (Plate 13). Their percentage ranges from a minor constituent to 9 percent, averaging about 5 percent of the rock. They are usually dark brown (5YR3/4) in plane light but may also exhibit dark brown/light brown layering either parallel or at an oblique angle to the outside surface. In polarized light, the fragments are isotropic, leading to the conclusion that the material is colophane. Some of the pieces are structureless and rounded, due to abrasion during transport, whereas others are bent and broken around other detrital grains. The majority of the shells are scattered throughout the rocks, with a parallel or sub-parallel orientation with the bedding, but some are concentrated along the shale wisps or, rarely, along the heavy mineral grain laminae.

The accessory minerals scattered throughout and/or concentrated in the heavy mineral laminae (one or two grains, thick and varying in length) (Plate 15) which outline the bedding, ripples and cross-beds are apatite, biotite, chlorite, hematite, muscovite, pyrite, sphene and zircon. These minerals usually make-up 4 to 14 percent of the rock, but primarily 4 to 6 percent, and occur as 0.035 to 0.075 mm., equant, angular to subrounded grains.

The biotite is translucent and reddish-brown (10R4/6) in plane light and shows strong pleochroism. Muscovite, on the other hand, is clear and colourless. Both exhibit tabular shape and cleavage traces parallel to the long

0 15 mm

Plate 15. Photomicrograph of heavy mineral laminae (left to right in upper half of plate) in subfeldsarenite microfacies, plane light (Station No. 18).

axis of the grain. Neither show a strong preferred orientation within the rock.

The sphene can be identified by its equant, sub-rounded, dirty brown (5YR2/2) colour and masked high birefringence characteristics.

The zircon shows high relief, high birefringence, clear transparent colour and a short, angular prismatic shape.

The chlorite occurs as elongate, interstitial masses and is closely associated with the matrix. It also appears as rounded grains, but this is rare.

Pyrite is observed as minor interstitial fillings and as aggregates, of 0.375 to 0.75 mm. size, along the shale wisps where they are elongate parallel to the wisps. The hematite always appears in close association with the pyrite.

Coarse, crystalline calcite is present in amounts varying from 8 to 40 percent but averaging 25 to 30 percent. It is in scattered patches, 0.25 to 0.5 mm. in diameter, acting as interstitial cement between the detrital grains. Only one thin section shows even distribution of the calcite throughout the slide. The occurrence of calcite in more than average abundance is in association with the burrows of the bioturbated rocks (Plate 16) and in the concave areas of the shale wisps. If the percentage of calcite is high then the amount of dolomite present remains low.

Up-to-3 percent dolomite occurs as 0.075 mm. (average) rhombic crystals associated with the clay-rich areas or scattered through the calcite cement. Only one thin section showed dolomite present in the absence of calcite. Many of the dolomite rhombs are zoned with red hematitic stain delineating the zones.

The percentage of clay in this microfacies varies thus giving the two rock types, subfeldsarenite (less than 15 percent) and subfeldswacke (greater than 15 percent) according to the classification scheme of Pettijohn et al (1973). The majority of the samples studied fall very close to the 15 percent dividing line, but usually below. The fine, fibrous-looking clay, which is dirty brown in plane light, occurs in

0.15 mm

Plate 16. Photomicrograph of calcite in bioturbated portions (burrows) in subfeldsarenite microfacies, plane light (Station No. 23).

four habits:

- 1) intermixed with calcite, when calcite is present
- 2) as clay balls in the bioturbated areas
- 3) as minor equant, subrounded interstitial pockets scattered throughout
- 4) as long, thin (0.05 to 0.25 mm.), lenticular wisps which are subparallel to the bedding and which have the clay particles oriented parallel to the long axis of the wisp (Plate 6)

The wisps incorporate very fine grains of quartz, feldspar, muscovite, phosphatic shell fragments and pyrite.

The thin shale wisps and heavy mineral laminae allow the cross lamination (herringbone structure) (Plate 12), ripple bedding (Plate 12), and flat bedding (Plate 17) of the subfeldsarenite to be easily distinguished. When these laminae and wisps are absent, it is very difficult to identify the 4 mm. to 45 cm. bedding, which has a general tendency to decrease in thickness toward the top of a section (Plate 18). Occasionally, thicker massive beds are present. Lenticular fracturing of the sandstone is common throughout the fine-grained Rockcliffe sandstones, with the maximum dimension of the lenses varying from 2.5 to 15 cm. (Plate 4).

Depending on the number of shale laminae present in the subfeldsarenite, the rock can vary from highly fissile to non-fissile (Plates 19 and 12). These shale laminae also tend to increase in thickness from their average 2 mm. to either well defined interbeds 6 mm. thick or 5 to 7.5 cm. beds spaced at 30 cm. intervals. In some places, the shale beds pinch out and form lenses within the subfeldsarenite (flaser bedding). Other relationships between the subfeldsarenite and shale microfacies have been discussed in Section 5.2.1.

Scours at the base of, and within, the sandstone units are common, with the grain size decreasing upward in the scour-fill. Rare infilling of the scours by the shale or mixed microfacies also occurs (Plate 20).

Symmetric ripples, asymmetric ripples (Plate 21), interference ripples, linguoid ripples (Plate 22) and rib furrow structures (7.5 to 15 cm. wide

Plate 18. Decrease in bed thickness toward top in subfeldsarenite microfacies (Station No. 29).

Plate 17. Flat-bedding in subfeldsarenite microfacies (Station No. 23).

Plate 19. Rippled, fissile subfeldsarenite microfacies with parting along bedding planes of thin shale (Station No. 67).

Plate 20. Channel-scour, in subfeldsarenite microfacies, infilled by mixed microfacies (Station No. 71).

Plate 21. Asymmetric ripples on bedding surface in subfeldsarenite microfacies (Station No. 56).

Plate 22. Linguoid ripples on bedding surface in subfeldsarenite microfacies (Station No. 34).

crescent-shaped features on bedding surfaces, with a "stoss and lee" cross-section and 2.5 to 4 cm. consecutive spacing; Plate 23) occur on many of the exposed bedding plane surfaces, with the interference ripples and rib and furrow structures the most common. Sediment-filled burrows can be seen both parallel to and perpendicular to the bedding surfaces, with variation in their abundance evident (Plate 24).

Minor load structures of subfeldsarenite into the underlying shale beds have been recorded (Plate 25). Isolated concretions of subfeldsarenite, 2.5 to 7.5 cm. in diameter, are found in the shale-rich areas, but these are rare (Plate 26).

Small-scale stratigraphic successions of the subfeldsarenite shale and coarse-grained lithologies and their related sedimentary structures are highly varied. In one outcrop section (Station No. 19), 7.5 cm. of cross-bedded subfeldsarenite, 7.5 cm. of rippled subfeldsarenite and 7.5 cm. of massive subfeldsarenite alternate. In another (Station No. 19), fine subfeldsarenite is interbedded with, and gradually grades upward into, coarse quartzarenite. In other places (eg. Station No. 29), textural gradation is the opposite - a quartzarenite/shale mixture at the base fines upward into subfeldsarenite. Other outcrops (eg. Station No. 31) show alternating fissile/massive/fissile/massive sequences over a 1.2 metre interval. One 60 cm. section (Station No. 31) displays coarse quartzarenite overlain by a ball and pillow subfeldsarenite (Plate 27) which is in turn overlain by a cross-bedded coarse quartzarenite with a basal scour sequence (Plate 28). Elsewhere (Station No. 7) subfeldsarenite, with shale absent, grades up to subfeldsarenite with shale wisps overlain by thinly interbedded subfeldsarenite and shale, grading upward into pure shale. A 1.8 metre section, at Station No. 40, has the sequence from base to top: coarse quartzarenite, lenticular subfeldsarenite, flat-bedded subfeldsarenite, soft-sediment deformed subfeldsarenite, small-scale rippled and cross-bedded subfeldsarenite (part of sequence shown in Plate 29).

5.2.4 COARSE-GRAINED QUARTZARENITE MICROFACIES

The quartzarenite microfacies is white (N9) or dark grey/black (N3 to 5YR2/1), depending on the amount of phosphatic material present, with a slight blue tinge where weathered phosphatic

Plate 23. Rib and furrow structures in subfeldsarenite microfacies (Station No. 12).

Plate 24. Burrows (arrows) on subfeldsarenite microfacies bedding plane (Station No. 17).

Plate 25. Load casts on base of bed in subfeldsarenite microfacies (Station No. 49).

Plate 26. Subfeldsarenite concretions elongate parallel to bedding in subfeldsarenite microfacies (Station No. 71).

6
Plate 27. Ball and pillow subfeldsarenite microfacies over- and underlain by phosphatic (note blue colour) quartzarenite submicrofacies (Station No. 31).

Plate 28. Cross-bedded quartzarenite submicrofacies overlying the scoured top of ball and pillow subfeldsarenite in Plate 27.

Plate 29. Flat-bedded subfeldsarenite microfacies overlain by "soft-sediment deformed" subfeldsarenite microfacies (Station No. 40).

debris is abundant (Plate 27) and rarely shows a rusty-red (10R4/6 to 10R3/4) weathering surface. The rocks are coarse-grained with a framework of frosted quartz grains and phosphatic shell fragments and a crystalline calcite cement (Plate 30). Thin green shale wisps are rarely present. The induration of the microfacies varies from poor, when abundant fossil fragments are present, to well indurated, when fossils are virtually absent.

The quartzarenite microfacies has been divided into two submicrofacies, the clean quartzarenite (Plate 31) and the phosphatic quartzarenite (Plate 32), on the basis of phosphatic fossil content. The two submicrofacies can be easily discerned in both hand specimen and thin section. The author speculates that the high amount of fossil content is environmentally significant. Excluding the phosphatic material, the composition of the two submicrofacies is essentially the same. Therefore, the components of the two submicrofacies will be described together.

The quartz grains occur in two main size groups, the 0.025 to 0.125 mm. and the 0.375 to 4.25 mm. The smaller-size grains are equant to elongate, angular and total only 5 to 10 percent of the rock. They occur, exhibiting no apparent preferred orientation, within the shale wisps, phosphatic clasts or suspended in the calcite cement. The larger grains, comprising 40 to 50 percent of the rock are primarily equant and well rounded (Plate 31). They either float in the calcite cement (Plate 33) or have a thin layer of fine-grained quartz/feldspar matrix between the grains (Plate 31). Occasionally, tangential contacts with the other quartz grains are seen, and it is in such places that minor quartz overgrowths occur (Plate 34). There are also radiating fractures, within the grains, along these contact zones. The few elongate, rounded grains show orientation of the long axis parallel to bedding. Grain sizes 1.0 to 1.5 mm. are equant, rounded, monocrystalline and display straight extinction. The larger grains are equant to elongate, rounded, mainly polycrystalline and have undulatory extinction. A few grains are chipped with the chips resting only a very short distance away. The polycrystalline grains display either 3 to 5 equidimensional crystals with sutured contacts or elongate crystals

Plate 30. Photograph of calcite-cemented, coarse quartzarenite microfacies with a fine-grained quartz/feldspar matrix and minor phosphatic shell fragments (Station No. 49).

0.15mm

Plate 31. Photomicrograph of "clean" quartzarenite submicrofacies, plane light (Station No. 49).

0.15mm

Plate 32. Photomicrograph of phosphatic quartzarenite submicrofacies, plane light (note phosphatic quartz/feldspar clast in lower left) (Station No. 31).

Plate 33. Photomicrograph of calcite-cemented quartz-arenite microfacies with the fine-grained quartz/feldspar matrix absent (note phosphatic clast and phosphatic quartz/feldspar clast) (Station No. 32).

Plate 34. Photomicrograph of quartz overgrowth on coarse quartz grains in quartzarenite microfacies (Station No. 49).

characteristic of a metaquartzite.

The coarse, crystalline calcite cement ranges from 20 to 35 percent, averaging 27 percent of the rock. It is distributed evenly throughout, in areas devoid of matrix, and surrounds most grains and clasts except where the grains are in contact (Plate 33). Dolomite and micrite are absent.

The phosphatic fossil fragments studied in the quartzarenite microfacies range from 1 to 15 percent of the total volume, averaging 10 percent in the phosphatic submicrofacies. The fragments are light to dark brown (5YR5/6 to 10YR2/2) under plain light but are isotropic under polarized light suggesting that they are composed of collophane or, in the case of the layered shells, chitino-phosphate. Four categories of phosphatic fragments are present: shell fragments, quartz/feldspar clasts, pure clasts and oolitic aggregates.

The phosphatic shells are 0.125 to 4.25 mm. long (the majority 1.0 mm.), 0.25 to 0.5 mm. thick and broken (Plate 32). The smaller fragments are equant and rounded, most likely the result of long exposure to current action, whereas the larger shells are still angular, the result of only a short period of abrasion. They are oriented with long axes parallel to the bedding except in proximity to large quartz grains where they curve up and around the grains. A few of the shells are fractured where they bend around the large grains. Except for minor tangential contacts, the shells are suspended in the calcite cement. The larger shell fragments exhibit a variety of internal structural patterns: massive shells, shells which appear "cross-laminated", and layered shells with three different configurations of layering (Figure 9). These layers are believed to be alternations of chitin and phosphate. Therefore, taking into account the age of the rocks, evidence found elsewhere in the outcrops (ie. a whole Lingula shell), the internal structure of the shell, the composition and information obtained from the literature (Williams et al. 1965), it is believed the broken shells are those of inarticulate brachiopods, more precisely a type of lingulid. This view differs from Hoskin (1974) who considers the phosphatic material to be fish platelets or of some other

FIGURE 9. Types of internal structures in the phosphatic shell fragments.

vertebrate origin. However, the rocks are too old for this hypothesis to be probable, and the properties observed fit those of inarticulate brachiopods.

The phosphatic quartz/feldspar-rich clasts range in size from 0.75 to 5.0 mm. (averaging 1.25 to 1.5 mm.) and are ovoid to equant and rounded in shape, with an irregular outline (Plate 32 & 33). The clasts are dark brown and contain varying amounts of 0.025 to 0.05 mm., angular quartz, feldspar, biotite, muscovite, sphene and zircon grains. Quartz and feldspar are most abundant. The long axes of the ovoid clasts are parallel to the bedding but the clasts themselves are scattered throughout the rock. Large quartz grains embay the clasts suggesting that the clasts were still soft when incorporated into the sediment or have been subsequently subjected to solution at contacts.

The pure phosphate clasts are dark brown (5YR3/4) 0.5 to 0.625 mm. in size, equant, angular grains scattered throughout the rock (Plate 33). The clasts are uniform textured except for a minor pitted texture in a few.

The oolitic clasts vary in colour from light brown 5YR5/6 to dark brown (5YR3/4) to black (N1) and occur scattered throughout as 0.75 to 1.25 mm. circular to ovoid aggregates composed of 0.125 to 0.175 mm., equant, rounded oolites and minor fine-grained quartz (Plates 35 and 36). The individual oolites are mainly structureless but a few exhibit faint dark nuclei with surrounding concentric rings. Found singly, and not as a part of an aggregate, the structureless oolites are difficult to distinguish from the pure phosphatic clasts. The best indication that they are oolites and not clasts is their near-circular cross-section.

The clay matrix averages 9 percent of the rock, occurs in spherical patches, in lenses (wisps) or as interstitial material (Plate 37) and is light brown (5YR6/4) in colour. Minor pyrite cubes and other fine grains of quartz, feldspar, biotite and muscovite are scattered throughout. The clay particles are oriented parallel or sub-parallel to the overall bedding. The wisps show a faint small-scale lamination that is absent in the matrix patches.

0.15 mm

Plate 35. Photomicrograph of phosphatic oolite aggregate in phosphatic quartzarenite submicrofacies, plane light (Station No. 31).

0.065 mm

Plate 36. Photomicrograph close-up of a phosphatic oolite aggregate, plane light (Station No. 40).

Plate 37.: Photomicrograph of clay matrix (on the right) in coarse quartzarenite microfacies, polarized light (Station No. 59).

Clay wisps or lenses, in some places, drape over the large grains suggesting post-depositional compaction.

The feldspar grains, ranging from negligible to 7 percent and averaging 4 percent, are primarily 0.025 to 0.05 mm., equant and angular. They occur dispersed in the shale wisps and phosphatic clasts with a minor amount scattered throughout the calcite cement. There is no orientation of the grains except when they are associated with quartz grains in oriented layers in the shale wisps. Albite and cross-hatched twins are present, as well as perthitic texture. Cleavage can be seen in a few grains with alteration along the cleavage traces and in grain centres. Only two 0.5 mm., ovoid, rounded grains and one 0.75 mm., equant rounded, perthitic clast were observed.

Zircon, sphene, biotite and muscovite are found in very minor proportions. All of these minerals occur as 0.05 to 0.075 mm. size grains but their shapes vary. Tabular cross-sections of muscovite, sometimes broken between other large grains, show orientation sub-parallel to the bedding. The biotite are more concentrated in the matrix than elsewhere in the rock. The equant, angular grains of zircon and sphene are scattered throughout. Heavy mineral grain laminae are not seen.

Minute amounts of pyrite are in three forms:

- 1) 0.05 mm., cubic to equant and rounded, scattered grains
- 2) 0.5 mm., interstitial, irregular-shaped masses which occur both in the phosphatic quartz/feldspar clasts and in the calcite cement
- 3) within polycrystalline quartz grains as minute stringers between the quartz crystals

Layering, defined by grain size and compositional variations, is visible on hand specimen and thin section scale. Alternating layers consist of:

- 1) 1.0 to 1.5 mm. quartz grains and phosphatic shell fragments in calcite cement
- 2) 3.0 to 4.25 mm. quartz grains in calcite cement; shells and smaller-sized grains are absent

Large-scale sedimentary structures are also found in this microfacies. The quartzarenite forms scour-fill lenses at the base of the subfeldsarenite (Station No. 36) but occasionally lenses 5 cm. to 30 cm. thick occur within the subfeldsarenite or shale beds (Station No. 34). The lenses are flat-topped and internally cross-bedded. Horizontal bedding of the quartzarenite, visible other than in the lenses, is 5 to 15 cm. thick within 0.3 to 0.6 m. units (Station No. 58). However, cross-bedding on a scale of 0.3 m. is the most common type of stratification seen (Plates 28 and 38).

5.2.5 MIXED MICROFACIES

The mixed microfacies comprises a mixture of most of the microfacies previously described (Plate 39). Three dominant submicrofacies of the mixed microfacies are defined and separated according to their compositional and structural characteristics. These submicrofacies are thought by the author to be a result of various energy levels of the environment with all levels initiated by a sudden, short-lived, catastrophic-type event (eg. a storm). In this way, the gradation between the submicrofacies and the other major microfacies can be explained by a slow, continuous decline of the physical forces which often produces a complete sedimentation record, beginning with the catastrophic event and ending with the normal physical conditions. Occasionally, however, the slow return to normal is absent, replaced by an abrupt return to the normal (conditions which then, of course, eliminates the gradational rock record). It is these abrupt returns to normal that allow the division of the mixed microfacies into three submicrofacies without difficulty.

SUBMICROFACIES 1 (SUBLITHARENITE)

Macroscopically this submicrofacies shows green-brown (10Y6/2) weathered and light grey-green (5G5/2) fresh colours, a uniform structure with faint bedding defined by very minor green shale wisps, abundant intraformational shale clasts parallel to or imbricate to the bedding, minor small phosphatic shell fragments elongate parallel to the bedding, and a patchy acid reaction. Overall, it appears similar to the subfeldsarenite microfacies except for the intraformational shale clasts (Plate 40).

Plate 38. Cross-bedding in coarse quartzarenite micro-
facies. (Station No. 59).

Plate 39. Photograph of mixed microfacies in outcrop
(Station No. 71).

0 15 mm

Plate 40. Photomicrograph of intraformational shale
clasts within subfeldsarenite host rock, plane light
(Station No. 71).

The differences between this submicrofacies and the subfeldsarenite microfacies become more apparent in the microscopic properties. In thin section, submicrofacies 1 exhibits the following characteristics not seen in the subfeldsarenite:

- 1) heavy mineral grain laminae and dolomite rhombs are absent
- 2) more abundant (8 to 20 per slide), scattered, 0.4 to 1.5 mm., equant, rounded and monocrystalline quartz grains which, when elongate in shape, show long axis orientation parallel to the bedding
- 3) only 15 to 20 percent crystalline calcite cement is present, mainly in scattered patches
- 4) the presence of intraformational shale clasts with minor minute, elongate quartz, feldspar, muscovite and pyrite grains scattered throughout, but oriented parallel to the long axis of the clast
 - these clasts are lens-shaped, wisp-shaped, barbell-shaped and equant to ovoid-shaped with either blunt or jagged broken ends
 - the bent shape of the clasts and embayment by large quartz grains suggest that the clasts were poorly indurated when incorporated into the sediment

SUBMICROFACIES 2 (SUBLITHARENITE)

Submicrofacies 2 is composed of coarse quartz grains, phosphatic shell fragments and phosphatic clasts, and intraformational shale clasts set in a calcite cement. Although the various components appear well mixed, occasional bands of quartz alternate with bands of shell fragments, where the elongate grains are parallel to the faint bedding. The rock has a characteristic brown-black (5YR2/1) colour when weathered and a black/grey (N4) - brown (5YR3/2) fresh colour. A bluish tinge from the weathered shells is present but not as noticeable as in the quartzarenite microfacies.

This submicrofacies is very similar to the phosphatic quartzarenite submicrofacies except:

- 1) quartz overgrowths and clay matrix are absent

- 2) minute rhombs of dolomite are present in the intraformational shale clasts, concentrated in elongate lenses or equant patches 0.5 to 1.5 mm. across or are scattered throughout as 0.075 to 0.1 mm. rhombic crystals
 - near pyrite, the rhombs show a faint red colouring
- 3) intraformational shale clasts, 0.5 to 1.0 mm. long and 0.125 to 0.5 mm. thick, are oriented parallel or imbricate to the bedding
 - the clasts contain minute quartz, feldspar and dolomite grains scattered throughout
 - some clasts have rounded ends as if minor abrasion occurred before deposition
 - the clasts, poorly indurated when incorporated, display bending and embayment by quartz grains

SUBMICROFACIES 3 (SUBLITHARENITE)

This submicrofacies weathers grey-green (5G5/2)/brown (5YR3/4) but has a fresh, mottled light green (5G7/2)/brown-green (5Y4/4) colour. The rock appears structureless except for a minor mixed texture, from current action and bioturbation. Shale wisps and heavy mineral grain laminae are absent but elongate grains are oriented parallel to the bedding. Phosphatic clasts, 4 to 25 mm. in length, and minor phosphatic shell fragments weather blue/white and exhibit preferred orientation. This submicrofacies appears to be a gradation between the subfeldswacke microfacies and the phosphatic quartzarenite submicrofacies, with the subfeldswacke microfacies dominating. The clay matrix, in a few instances, forms 0.375 to 1.25 mm. lenses draping over the large quartz grains.

In summary, a change in the physical energy of the environment after a catastrophic event, from high to low energy would produce the gradational sequence of Submicrofacies 2 to Submicrofacies 1 to Submicrofacies 3, with a gradual decrease in coarse quartz grains and shale clasts and an increase in fine material. Eventually the sequence would conclude with the subfeldsarenite microfacies. Another possibility is that these three

submicrofacies are not related but that each grades into one of the major microfacies; No. 2 grading into the phosphatic quartzarenite, and Nos. 1 and 3 grading into the subfeldsarenite. However, these gradations are not observable in outcrop.

Sedimentary structures are in all three submicrofacies, but with differing frequencies and associations. The bedding, lenticular in most outcrops, varies from 8 mm. to 10 cm. thick. The finer grained submicrofacies are mainly rippled whereas the coarser ones exhibit coarser cross-bedding. Fine, flat laminations are rare. The units of the mixed microfacies generally occur as channel fills, 5 cm. to 1 m. thick by 5 cm. to 8 m. wide, cut down into the underlying subfeldsarenite microfacies (Plate 20).

5.3 COMPARISONS WITH THE ROSENSTEIN (1973) AND HOSKIN (1974) FACIES

Rosenstein's five facies descriptions are less detailed than the above and, therefore, anything more than a general comparison cannot be attempted. Two of his facies, the biosparitic and the brachiopod-rich silty shale, are absent in the present study area although the brachiopod-rich silty shale could be similar to the beds containing Lingula shells and mytilid at Station 20. His other three facies, the shale, the very fine-grained subarkose and the mixed, are all represented herein with the only major difference being that his subarkose has a grain size of 0.1 mm. whereas the present author's subfeldsarenite averages less than 0.1 mm. Other differences are:

- 1) Rosenstein does not describe a coarse-grained facies equivalent to the quartzarenite around Ottawa. However, he may have grouped it into his mixed facies as he states that this facies contains coarse quartz grains.
- 2) trilobites, bryozoans and crinoids have not been found in the present study, whereas, Rosenstein noted their presence in his mixed facies
- 3) the quartzarenite microfacies exhibits a much coarser grain size than any described by Rosenstein.

Hoskin describes in greater detail his four facies: the biosparitic, the shale, the very fine-grained arkose, and the mixed which he divides into four subfacies. Again, the biosparite is absent in the Ottawa area. The shale facies description is identical

to the present shale microfacies. In the arkose facies, Hoskin describes grains of 0.1 mm. size, fish platelets, phosphatic nodules, bryozoans and sparry calcite grains. Of these characteristic features, the present author found only the 0.1 mm. size grains in the subfeldsarenite. Hoskin also states that quartz comprises 50 to 60 percent of this rock, feldspar 15 percent and phosphatic fossil fragments "appeared in 5 to 10 percent of the rocks of this facies individual concentrations ranging from 5 to 30 percent". The present study shows quartz averaging 40 to 45 percent, feldspar 15 to 20 percent and phosphatic fragments in at least 90 percent of the rocks with individual percentages ranging from negligible to 9. Hoskin's four mixed subfacies are different than submicrofacies 1 to 3 of this thesis. His mixed subfacies 1 is identical to the present author's submicrofacies 3. His other three subfacies are characterized by absences of the coarse quartz grains (subfacies 2), the phosphatic shells (subfacies 3) and then both the shells and coarse quartz (subfacies 4) from his subfacies 1. Hoskin does not mention the presence of intraformational shale clasts so prominently seen in the Rockcliffe Formation around Ottawa. No description of a quartzarenite can be found other than a brief statement about 10 to 12 cm. thick sandstone beds of coarse, clean, spherical, rounded quartz with calcite cement interbedded rarely with the arkosic facies.

It can be seen from these comparisons that, whereas the facies described by the two earlier authors and those microfacies in this thesis are similar, they are by no means identical. The minor and major differences are important when interpreting the paleoenvironment.

TABLE 2

A Summary of the paleocurrent and strike and dip data observed in the various microfacies.

75

MICROFACIES TYPE	STATION NUMBER	DIP/DIP DIRECTION*	PALEOCURRENT DIRECTION #		
			RIB & FURROW	RIPPLE	CROSS-BED
SHALES	25			255°	
	31	5-10°/170°			0°
	44	5°/0°			
SUBFELSARENITE	02		80°		
	12	5°/330°	90°		
	13	5°/0°	90°		
	16		85°		
	18	10°/140°			
	21			90°	90°
	23	2°/200°			
	32	5°/200°			
	34			210°	
	35			255°	
	40				260°
	45	2°/350°			
	50			225°	
	52		110°		
	56			0°, 20°	
	59			260°	
	69			265°	
	70	5°/90°	265°	140-190°	
	71	3°/90°		295°	
COARSE QUARTZARENITE	21				90°
	29	5°/135°			110°
	31				220°
	32				260°
	33				95-100°
	34				130°
	36				60°
	37				50°
	59				265°
	69				265°
	71				265°
	72				265°
MIXED	70				140-190°

* All other beds exhibited horizontal dips.

Visual estimate of general paleocurrent direction at each station.

FIGURE 10. Paleocurrent directions within the Rockcliffe Formation, from ripple marks and cross-beds.

TABLE 3

Summary of the petrographic and sedimentary structure features observed in the Rockcliffe formation.

PHYSICAL CHARACTERISTICS	MICROFACIES			TYPE	
	Dolastone	Shale	Subfeldsarenite	Coarse Quartzarenite	Mixed
COLOUR - light green	X		X		X
- dark green/grey		X			
- white				X	
- dark grey/black				X	
GRAIN SIZE - clay size	A	A	M		
- fine (0.25 - 15 mm)	M		A	M	A
- coarse (3 - 40 mm)				A	A
- intrafm. shale clasts					A
- fines-upward			M		M
- coarsens-upward			M		
FAUNA - insitu shells		M			
- phosphatic shell fragments		M	M	M & A	M
PHOSPHATIC CLASTS				A	M
BEDDING - massive	A		M		
- flat or laminated		A	M		M
- lenticular			A	M	M
- graded			M		
- cross			M	A	A
- convolute			M		
- flaser		M	M		
- scoured		M	M		A
- contorted lens of shale			M		
RIPPLES - symmetric			M		
- asymmetric		M	M		M
- linguoid			M		
- interference			A		M
BURROWS			M		
BIOTURBATION	M	A	M		
ELIPSOIDS	A	M	M		
"MUDCRACKS"		M			
CHANNELS ("conglomerate at base)				A	A
SCOUR-FILL (small scale)		M	M	A	A
LOAD CASTS			A/M		

X - Characteristic

A - Abundant

M - Minor

CHAPTER VI

STRATIGRAPHIC SEQUENCE IN THE ROCKCLIFFE FORMATION

In the original proposal for this study of the Rockcliffe Formation, the stratigraphic analysis was to be attempted using only the outcrop sections. However, when the formation outcrops in the study area had been located and described, the majority were found to be too small, too widely scattered, and the contained micro-facies too lenticular for the compilation of a complete stratigraphic sequence. During the field work, the top or the base of the formation were located in some sections. The top and bottom contacts of the Rockcliffe with the overlying Ottawa and underlying Oxford formations were based on the following criteria:

- a) the Rockcliffe/Ottawa contact was placed where either the green-shale of the Rockcliffe changed to dark gray shale of the Ottawa or at the first significant appearance of dark gray, fossiliferous limestone, if the gray shale was absent.
- b) the Rockcliffe/Oxford contact was placed where the green sandstone/shale of the Rockcliffe gave way to dark gray dolostone of the Oxford.

However, the formation thickness based on these determinations compared to the reported total thickness of the formation in the Ottawa area (Wilson, 1946), was significantly less. This is due to the fact that the position of the measured sections, not containing either a basal or upper contact, was uncertain.

This stratigraphic problem led to the necessity for an additional means of piecing together the stratigraphic sequence. To this end, a study of all available drill holes penetrating the Rockcliffe Formation in or near the study area was undertaken. It was discovered that cores of only three wells were still available. The locations of the three wells are plotted on Figure 6A (also see p.22, 23).

To construct a complete stratigraphic sequence of the Rockcliffe, the three cored wells were studied macroscopically.

From the core descriptions, a columnar section was drawn for each, grouping the lithologies into the previously defined microfacies. Any possible correlation between the cores was also studied. Once this was completed, the larger outcrop sections were compared to the closest well available.

This chapter describes the cores, attempts to correlate the wells, and then compares the cores to the larger outcrop sections in order to fit the latter into the stratigraphic column of the Rockcliffe Formation. Finally, a tentative correlation of the Ottawa area sections of the Rockcliffe Formation with those of the Cornwall area, as described by Rosenstein (1973) and Hoskin (1974), is outlined.

6.1 CORE DESCRIPTION AND CORRELATION

Two of the three cored wells logged, the Observatory Well and the Russell Well, penetrate the entire section of the Rockcliffe Formation with formation thicknesses of 47.5 and 45.5 metres respectively. The third well, the Kilborn Avenue School Well, penetrates only the top 35.5 metres of the Rockcliffe (including a 3 m. missing interval in the centre section of the cored interval). Figure 11 is a diagrammatic interpretation of the lithological logs of the three wells.

All three wells exhibit the shale, subfeldsarenite, quartzarenite and mixed microfacies in random sequence. The absence of the dolostone microfacies is not unexpected, considering the variable thickness and distribution of the dolostone in the outcrop sections. The most significant result of comparison of the columnar sections of the wells is the absence of a marker horizon with which to stratigraphically correlate the three wells. In the absence of internal marker horizons, the three wells could be correlated only by their formation "tops" (tops being in quotations due to the difficulty in distinguishing between the base of the St. Martin in the Russell well, Pamela or Lowville in the remaining two wells and the top of the Rockcliffe, and therefore possibly leading to an error in picking the top of the Rockcliffe Formation in the wells).

An accurate, bed by bed correlation between the wells is difficult, if not impossible, owing to the lenticular nature of the microfacies contained and the distance separating the drill holes

FIGURE 11. Diagrammatic interpretation of the three columnar sections of bore-holes (see Section and Figure 6A for exact well locations).

(3.2 kilometres between the Observatory and Kilborn wells, and over 32 kilometres between the Kilborn and Russell wells). Hoskin (1974) states that "a relatively good lateral correlation can be made both on a local and a more regional scale" for the shale microfacies but the "degree of lateral continuity in the fine-grained arkose and mixed facies can only be expected to exist (poorly) on a local scale and not at all on a regional scale". Hoskin's "local scale" ranged from 80 to 920 metres between wells, a great deal smaller than the distances between the three wells described here, leading to the conclusion that the present scale of correlation is of "regional" size, in Hoskin's terms.

Putting aside the obstacles obtained above, a number of gross similarities between the wells emerge, permitting at least gross correlation (Figure 11, the lines are very tentative in the correlation). The similarities existing between the Rockcliffe sections in the wells are:

- 1) Division B: a high percentage of shale is seen in the top 7.5 metres of two wells and possibly the third, considering the possibility of an error in the formation top pick, or a disconformity at the top
- 2) Division A: the lower 40 or so metres are dominated by thick beds of subfeldsarenite with minor beds (2.5 to 7.5 cm. thick) of shale, coarse quartzarenite or mixed microfacies scattered throughout; matching individual subfeldsarenite units is impossible due to their distribution and lithological similarities
- 3) a) three significant thicknesses of an association of shaly/mixed/coarse quartzarenite units occur in Division A, with additional minor occurrences (2.5 to 7.5 cm. thick) throughout the subfeldsarenite (Figure 11)
- b) the individual microfacies of this association cannot be correlated between wells, correlation is possible only by consideration of the "package" of units
- c) minor occurrences of the shale/mixed/quartzarenite unit occur in Division B
- d) a vertical ordering of the shale/mixed/quartzarenite units within the association is absent

- e) the mixed microfacies appears to be the most abundant of the three in association
- f) the mixed and quartzarenite microfacies are consistently either 0.3 to 0.6 metres or 2.5 to 7.5 cm. thick
- g) the quartzarenite beds are thickest when in the association; when the quartzarenite microfacies occurs in subfeldsarenite, it is found to be only a grain or two thick.

Considering the similarities outlined above (especially the associated shale/mixed/quartzarenite units and the possibility that they were created by the same event (see p.67)) a correlation is attempted (Figure 11 and section 6.2).

6.2 CORRELATION OF THE OUTCROP SECTIONS AND THE CORES:

The majority of the outcrops are too small (15 cm. to 2 metres of vertical section) and lithologically undiagnostic for correlation. A few show lithic variability and characteristic sedimentary structures and some reveal, or are close to, the upper contact with the Ottawa Group (Station Nos. 25, 28, 55A) but do not expose enough of the formation to permit their correlation with the cores. One or two thin beds of the quartzarenite, mixed or shale microfacies in a 15 cm. to 2 m. outcrop of subfeldsarenite cannot be placed with certainty in the stratigraphic column.

Selection of 3.5 metre-minimum outcrop sections for comparison resulted in only fifteen meeting the standard (Figure 12). A number of these (Station Nos. 34, 37 (Plate 41) and 40) contain mainly homogeneous subfeldsarenite and, therefore could occur almost anywhere in the previously described Division A of the stratigraphic column. Station Nos. 23, 24 (Plate 42), 30, 31 (Plates 43, 44 and 45) and 35 (Plate 46) can be easily placed in their respective stratigraphic locations because they exhibit an upper contact with the Ottawa Group while Station No. 29 includes the underlying Oxford Formation. Some which reveal the upper formation contact, also demonstrate good microfacies correlations (a high percentage of shale with dolostone at the top overlying predominantly subfeldsarenite). A close similarity to the top 20 metres of the Rockcliffe Formation in the Observatory and Kilborn Avenue wells is also evident, except

2

Plate 42. Rockcliffe/Ottawa contact
(along ruler) at Station No. 24.

Plate 41. Outcrop of typical subfeldsarenite
microfacies overlying shale microfacies at
Station No. 37.

Plate 43

Plate 44

Plate 45

Rockcliffe/Ottawa contact (Plate 43: along grass line) and upper 20 metres of the Rockcliffe Formation, at Station No. 31 (Intervals shown: 0-5m. in Plate 43, 8-11m. in Plate 44, 13-20m. in Plate 45).

Plate 46. Hogsback (Station No. 35)
showing upper ten metres of Rockcliffe
and Rockcliffe/Ottawa contact (approx.
at the person's feet).

for the presence of the ellipsoidal dolostone beds in the outcrop sections (Station No. 31, page No. 36). The dolostone beds overlie the thickest upper shale unit only.

The remaining six outcrops (Station Nos. 32, 33 (Plate 47), 35 (2), 36 (Plate 48), 38 and 44), showing the characteristic random sequence of microfacies, can be placed with relative accuracy at or near the top of Division A, when lithology and proximity (both horizontal and vertical) to neighbouring outcrops are taken into account. The lithologic combination of interbedded pure shale (ie. no thin subfeldsarenite beds within), quartzarenite and subfeldsarenite beds suggests these outcrops are in Division A but close to the overlying shale unit of Division B. Where the quartzarenite beds are absent, the shale is of sufficient thickness to locate it in the upper part of Division A. The six outcrops show a close resemblance to the section between 12 and 20 metres below the top of the Rockcliffe in the Observatory well.

The results of the outcrop/core comparison indicate that all of the large outcrops except one (Station No. 29) can be placed stratigraphically into the top 20 to 24 metres of the Rockcliffe Formation whereas the smaller outcrops (other than those composed of 100 percent shale) probably fit into the stratigraphic column somewhere between the 24 metre mark and the base of the section.

Together, the core description and correlation, and the outcrop/core comparison allow a formulation of the following characteristics of the Rockcliffe Formation and its stratigraphy in the Ottawa-Hull area:

- 1) The total thickness of the Rockcliffe Formation is approximately 48 metres.
- 2) The Rockcliffe unconformably overlies the Oxford Formation and is in turn unconformably overlain by the Ottawa Group (Plate 42) (Wilson, 1946).
- 3) The composite stratigraphic column has 30 to 40 metres composed of light green subfeldsarenite interbedded with shale/mixed/quartzarenite sequences at the base overlain by 8 to 12 metres of dark green shale which is in turn overlain by 2 metres of light green, ellipsoidal dolostone.

Plate 47. Typical subfeldsarenite microfacies outcrop section (Station No. 33) (cf. Fig. 12).

Plate 48. Type section of mainly interbedded subfeldsarenite and shale microfacies, below Rockcliffe lookout, used by A.E. Wilson (1946) and E.S. Rosen stein (1973) (Station No. 36) (cf. Fig. 12).

quartzarenite sequences.

- 4) The majority of the large outcrops (i.e. those exceeding 3.5 metres of section) can be placed either near the top or near the base of the stratigraphic column.
- 5) The small outcrops, unless they are pure shale, are impossible to locate precisely within the stratigraphic column due to their undiagnostic subfeldsarenite nature.
- 6) If the smaller outcrops contain the mixed microfacies then there is a good chance they occur in the lower $\frac{1}{2}$ to $\frac{2}{3}$ of the subfeldsarenite section, but selecting their exact location is impossible.
- 7) A distinctive interbedding sequence on a small scale is absent amongst the different microfacies, even in the shale/mixed/quartzarenite associations.
- 8) The Rockcliffe Formation composite stratigraphic column suggested from this study compares most closely to the Observatory well log (Figure 11), with the exception of the 1 to 2 metres of dolostone overlying the upper shale, determined from outcrop data alone.

6.3 COMPARISON OF THE OTTAWA-HULL STRATIGRAPHY TO THE CORNWALL STUDIES:

As cited earlier, Hoskin (1974) stated that a good correlation on a local and regional scale existed for the shale and biosparite facies but for the fine-grained arkose and mixed facies there was very little chance for a correlation. The distance between Ottawa and Cornwall areas is about 80 kilometres and therefore, the correlation of the stratigraphy of the two localities is difficult. However, a comparison of the two stratigraphic sequences is necessary to further the knowledge of the areal variations within the Rockcliffe Formation and to assist in the construction of paleoenvironmental models.

Of the wells studied by Rosenstein (1973) and Hoskin (1974) in the Cornwall area, nine penetrate the Rockcliffe, with

four of these wells exhibiting the upper contact between the Rockcliffe and the overlying St. Martin limestone. The lengths of the cores range from 6 to 18 metres and reveal approximately 24 metres of the Rockcliffe Formation. Since the thickness of the formation in the Ottawa-Hull area is 48 metres, this 24 metre figure suggests that the wells of the Cornwall area reveal only the upper part of the Rockcliffe assuming no change in overall thickness (Figure 13).

Comparison of the nine Cornwall wells with the three wells and fifteen large outcrops of the Ottawa area reveals the following points:

- 1) a rigorous comparison is difficult because the facies/microfacies identification of the three authors is not exactly the same
- 2) the logs of the three wells described by both Hoskin and Rosenstein indicate differences of interpretation between the two authors
- 3) the upper shale unit (Division B) overlain by dolostone is absent in the Cornwall wells
- 4) the shale of the Cornwall area is interbedded throughout the (sub)arkose in thin (0.5 to 1.0 metre) beds which always occur two or three at a time and with only minor separation by (sub)arkose between beds, but with large thickness of (sub)arkose between shale sequences
- 5) the shale commonly overlies the coarser mixed facies in the Cornwall wells, an uncommon feature around Ottawa-Hull
- 6) the random vertical succession of facies is present, as in Division A of the Ottawa section
- 7) at Cornwall, biosparite is abundant near the top of the Rockcliffe and also as 1 to 2 metre beds scattered throughout; biosparite totals up to 20 percent of the core in some instances
- 8) The mixed microfacies occurs in thicker units in the Cornwall area (according to this author's interpretation of Hoskin's descriptions)

FIGURE 13. Rosenstein's (1973) and Hoskin's (1974) nine columnar sections (interpreted using the present author's microfacies definitions)

- 9) due to the presence of biosparite and the thicker mixed beds, there appears to be less subfeldsarenite in the Cornwall wells; however, it is still the dominant microfacies
- 10) the coarse quartzarenite is not as common in the Cornwall area as in the Ottawa-Hull area; it characteristically occurs dispersed in the mixed and (sub)arkose facies
- 11) the shale/mixed/quartzarenite association in the Ottawa-Hull area is not as well pronounced in the Cornwall area
- 12) a greater variety of fossil remains were noted in the Cornwall wells (eg. brachiopods, bryozoans and echinoid stems).

While it is obvious that the well logs are similar and reveal the same geological formation, a correlation between the Ottawa-Hull and Cornwall wells must be done on only the broadest terms (ie. rock types present, unit thickness, general sequence of microfacies, abundance of each microfacies, etc.).

The Cornwall wells do, however, exhibit a greater similarity to the Russell well which, of the wells and outcrops used for the present study, is the closest geographically to the Cornwall area (Figure 4).

CHAPTER VII

PALEOENVIRONMENTS OF THE ROCKCLIFFE FORMATION

The term "sedimentary environment" refers to the place of deposition and to the physical, compositional and biological conditions which characterize a particular depositional setting. There are a great variety of depositional environments with each one characterized by a set of physical, compositional and biological parameters which may or may not leave a diagnostic mark on the sediments. It is this record of environmental conditions that provides the basic criteria for delineating ancient sedimentary environments from rock exposures or from a stratigraphic column.

Among the physical characteristics used in this study are such features as bedding and other large-scale structures, nature of contacts between beds, sedimentary textures (i.e. grain size, grain shape, etc.) and related small-scale structures, and such directional properties as ripple marks and cross-beds.

The compositional characteristics are reflected in the mineralogy and the gross composition of the rocks (limestone, dolostone, shale, sandstone, siltstone), or subordinate but distinctive components (eg. phosphatic).

As to biological characteristics, the minor fossils present, the nature of occurrence, and the shell composition of the various forms, are most useful.

In addition to these parameters, the lateral and vertical microfacies relationships and the external shape of the deposit can greatly strengthen any environmental interpretations and at the same time add an important regional aspect to the study.

The paleoenvironmental interpretations of the Rockcliffe Formation microfacies will take into account the three groups of parameters. The interpretations will be accomplished in a series of steps starting with the environments previously envisaged for the area, followed by the proposed depositional environments of each microfacies defined in Chapter V, and ending with an overall model accounting for the contemporaneous deposition of the five microfacies. Then, a regional depositional environment will be outlined on the broadest terms, taking into account studies from neighbouring areas.

7.1 PREVIOUSLY CONCEIVED PALEOENVIRONMENTS:

Of the previous studies of the Chazy formations or, more generally, the Ottawa Embayment/Quebec Basin, only three (Hofmann (1963), Rosenstein (1973) and Hoskin (1974)) discuss the paleoenvironments in any detail.

Wilson, in 1937, described Chazy rocks of the area as deposits of a broad, shallow basin with a shallow but fluctuating water depth. However, in 1956, she stated that the Chazy rocks were deposited by a marine invasion which spilled over the Beauharnois anticline to the east after depositing 700 feet (215 metres) of sediments east of the anticline. As the sandstone and shale "were being deposited along the western margin of the Ottawa Embayment, the solubles became more and more concentrated and were deposited in the eastern part of the basin" (Wilson, 1956, p.8). Then uplift resulted in a short erosional interval during which the land surface was never very much above sea level.

Bolton and Liberty (1972) postulated that the lenticular Rockcliffe microfacies were deposited under "variable environmental conditions that would be found on a series of shelves and basins along the margins of a low, stable land mass. In the Ottawa region the lower Paleozoic sequence is believed to have been deposited in a partially enclosed sea now called the Ottawa Embayment. Recent studies show that the rocks are of the same type that are forming

today in a variety of energy-sedimentation situations that characterize banks and shallow seas..." (Bolton and Liberty, 1972, p.15).

A facies interpretation of the basin is illustrated in Figure 14. It shows a central area of limestone surrounded by a zone of terrigenous sediments which were deposited in a narrow arm of the sea that then occupied the Ottawa-St. Lawrence-Champlain Lowlands. "In some places... one can find a Lingulella coquina, representing a shallow-water fauna... Strong currents, some of them perhaps tides, carried shell fragments off and piled them up in banks and shoals, generally in a cross-bedded fashion, forming a calcarenite coquina... Where these burial grounds were close to shore considerable quartz sand and silt detritus mixed with the shell remains... During the deposition of the upper Chazy the sea became somewhat restricted, and ... calcareous muds accumulated followed by more shaly, silty and dolomitic sediments. Ripple marks developed locally, and in the uppermost parts soft-shelled pelecypods abounded" (Hofmann, 1963, p.293-294). At the close of Chazy time, in the Montreal area, "calcareous oozes covered the floor of large lagoons, and evaporation was taking place in the restricted warm waters, increasing the salinity of the waters. The calcareous ooze was then perhaps dolomitized while still in contact with the highly saline waters. With further receding of the waters ripple-marked silts and muds accumulated, and at times when the sea moved out altogether the muds developed dessication cracks. When water returned the mudflakes were spalled off the floor and swept away, and deposited with silt and sand to form intraformational conglomerate or breccia" (op. cit., p.294).

Hoskin (1974) fails to give an environmental setting for the deposition of the Rockcliffe as a whole, but does describe depositional sub-environments for each facies he defined. He suggests that the shale and biosparite were deposited some distance from shore in a shallow sea (less than 30 feet (9 metres) deep) by minimal to gentle current action. The shale, in places, is a product of deposition of final storm residue. The four mixed subfacies are interdunal, subaqueous storm deposits and the fine-grained arkosic facies a result of "wind action on an ill-sorted sandy source

FIGURE 14. Chazyon paleogeography, and lithofacies map of Rockcliffe Formation.
(modified from H.J. Hofmann, 1963)

sediment that tends to sort the sand by selectively removing the 'intermediate' grain size, 'heaping' it up into well-sorted, nearly unimodal dunes; leaving behind on the 'source area floor' a bimodal mixture of very fine and very coarse size grains. It was found that the sands of the unimodal dunes had a mean size distribution seldom less than 0.20 mm. and rarely greater than 0.45 mm. Therefore, it was the bimodal interdunal sand that was easily transported to the sea by runoff waters, which would maintain the bimodality. On reaching the sea, the majority of the finer grained mode was carried the furthest distance from shore "and piled into sandbars and banks by the gentle currents". It was found that the very fine grained mode comprises most of the arkosic sandstone"... "The appearance of the well-rounded, frosted, coarse quartz grains is seen... to be the result of stronger current action and turbulence induced by storm activities resulting in a greater influx of this coarser fraction from the land source area" (Hoskin, 1974, p.61).

Similarly, Rosenstein (1973), formulates a paleoenvironment for each facies but he also describes a general setting for the simultaneous deposition of all the rock types present. He submits that "the fine sand-size, aeolian-sorted terrigenous influx was brought into the shallow marine environment (average water depth of a few feet) by fluvial means, and was reworked into broad, lenticular sandbanks by wind-driven marine currents. Periodic storm action thoroughly mixed all material from the upper few inches of the sediment over large areas, redepositing this as a 'homogenized' unit" (op. cit., p.94). The shale was deposited adjacent to and between the banks while interbedded subarkose and interbank shale are a result of fluctuations in supply of fluvial material. Also found in this interbank position are the brachiopod-rich silty shales. The presence of material of aeolian origin was explained in a manner similar to that of Hoskin outlined above.

7.2 DEPOSITIONAL ENVIRONMENT FOR THE DOLOSTONE MICROFACIES:

The dolostone microfacies is thought by the present author to have been deposited on the floors of lagoons as a calcareous ooze, due to the evaporation and increased salinity of the waters in these areas. It was, "perhaps

dolomitized while still in contact with highly saline waters" (Hofmann, 1963, p.294). However, the presence of some calcite illustrates either that the dolomitization was not complete or that the dolomite mud was primary and underwent minor dedolomitization, which is possibly indicative of subaerial exposure (Blatt *et al.*, 1972, p.499).

The presence of minor quartz, feldspar, shell fragments and other detrital grains is likely the result of on-shore movement of these materials at high tide and the effect of strong off-shore or onshore winds carrying detritus into the lagoonal areas (Blatt *et al.*, 1972, p.209).

The thin dolostone units **in the upper** Rockcliffe were likely produced from minor fluctuations in the sea level, thus alternately shifting the lagoons seaward and landward. If the depositional basin was shallow (less than approximately 10 metres), and had a gentle bottom slope, a large lateral shift could be caused by a relatively small water level change. Thin, faint laminations are evident in these units suggesting that the material was deposited in a slow, calm, rhythmic fashion (ie. lagoonal environment) (Heckel, 1972, p.242-243, 252-253). The lack of fauna and presence of only minor bioturbation probably resulted from high salinity and/or the subaerial exposure of the lagoonal areas (Blatt *et al.*, 1972, p.209 & 446; Heckel, 1972, p.239 & 244; Selley, 1970 p.97).

The major deposit of dolomite at the top of the Rockcliffe Formation probably occurred as the sea began its final regression at the end of Chazy time. The ellipsoids **were formed** by unknown circumstances or they could possibly be due to the subaerial exposure and resultant weathering of the dolostone sediments along fracture systems. When broken open, the concretions fracture like a weathering rind on an exposed boulder.

In summary, the dolomitic sediments are considered to be representative of a high salinity lagoonal environment along a sea coast with slight, irregular water level fluctuations. The final dolostone deposit probably underwent considerable subaerial exposure and weathering.

7.3 DEPOSITIONAL ENVIRONMENT FOR THE SHALE MICROFACIES:

The shale microfacies is thought to be a deposit of fluviially-transported or wind blown clay particles brought into an environment of relatively shallow water, with areas intermittently exposed to the air. The type of environment envisioned is a lagoonal, to intertidal flat area.

The thin, 7.5 cm. to 0.6 m. shale beds dispersed throughout the Rockcliffe Formation could either represent contemporaneous occurrence of the suggested environment and that of the subfeldsarenite or, as Hoskin (1974) and Rosenstein (1973) suggest, "flocculated particles deposited in a calm, slack-water situation between subarkosic banks or dunes" or be a combination of both situations.

The thick shale sequence at the top of the Rockcliffe is most likely lagoonal or intertidal. The thin, flat, rhythmic interbeds of fine silt and dark shale (flaser bedding), the near-shore, shallow water fauna (ie. Lingula and pelecypods), the horizontal and vertical bioturbation tubes, the minor occurrence of ripple marks in the shale (ie. occasionally stronger current action due to winds or tides), the "mud cracks" (ie. subaerial exposure), the thin carbonate interbeds, the scoured tops of some beds (ie. from tidal or storm currents), and the convoluted silt/shale beds caused from differential dewatering and movement of the sediments all appear to point to a very shallow water, sporadically exposed depositional environment (Evans, 1965; Fuchtbauer, 1974; Hatch and Rastall, 1971; Heckel, 1972; Klein, 1971; Reineck, 1972; Selley, 1970). Minor occurrences of red-coloured shale strengthen the suggestion of subaerial exposure.

The thick shale sequence, therefore, was probably deposited before lagoonal conditions became favourable for deposition of the overlying dolomite.

7.4 DEPOSITIONAL ENVIRONMENT FOR THE SUBFELDSARENITE MICROFACIES:

The depositional environment for the subfeldsarenite microfacies is seen as one of migrating submarine sandbars or dunes elongate

parallel to the shoreline, occurring below low tide water level and rarely, if ever subaerially exposed. The environment was affected by currents, tides and wave action and, due to the shifting nature of the substrate, organic remains are absent except for those transported into the area of deposition from other environments (Heckel, 1972, p.244).

The source area for the detritus was likely a low, flat, weathered land mass on the north and west sides of the basin. The paleocurrent directions, attitudes of the channels in the mixed microfacies (p.103), and microfacies changes found by the present author are comparable with the paleogeography suggested by other authors.

The present author agrees with both Hoskin (1974) and Rosenstein (1973) that "the original sediment size distribution rather than the transporting mechanism governed the size range of the final deposit" (Rosenstein, 1973, p.31). As cited earlier (p.96), the original sediment size range was a result of aeolian sorting. Therefore, it is postulated that the wind-sorted material was fluvially transported into the sea where the current, tidal and wave action redistributed it; leaving the coarse sizes close to the fluvial outlet, later to be brought further into the basin by stronger-than-normal current action, and removing the fine sizes to form the subaqueous dunes.

With the material now in the basin, the individual or variously combined effects of waves, currents and tidal action could have re-distributed it and eventually deposited it as lenticular, elongate dunes, parallel to the shoreline, which exhibit flat-bedding, lenticular bedding, ripple bedding or cross-bedding, depending on the location of deposition, the type and strength of water movement, and subsequent depositional or erosional forces (Heckel, 1972, p.243; Pettijohn et al., 1973, p.477, 487, 494).

The position of the Chazy shoreline (Fig. 14) is inferred from relationships of Precambrian and Paleozoic outcrops, isopachs, facies changes and other data (Wilson, 1946; Hofmann, 1963; Rosenstein, 1973; Hoskin, 1974). The paleocurrent directions obtained from the Rockcliffe (Table 2, Fig. 10) show four directions; two

indicate a north-northeastward on shore and a south-southwestward off-shore movement of sediment, while the other two exhibit opposing directions more or less parallel to the presumed shoreline (north-west and southeast). The majority of directions recorded show one of the longshore directions suggesting that a longshore current, in one of the two directions, played an important role in depositing the sandstone into subaqueous dunes. However, the opposing directions might be explained by strong tidal current action moving back and forth in the narrow, northwest arm of the Embayment. Tidal action is also suggested by abundant interference ripples and the herringbone cross-bedding (Klein, 1971, p.2586; Reineck, 1969, p.737).

Taking the above information into account, the author believes that a major river system transporting terrigenous sediment from the source area entered the sea at the northern end of the narrow northwest-trending arm of the sea (Fig. 14); out-flowing tidal and longshore currents distributed the bulk of the fine sediment within the basin.

The thin laminae of shale, separating the rippled beds or found only in the ripple troughs, suggest a slack-water stage (ie. minimal wave or current action) of the pulsating currents, which allowed the finer clay particles to settle out. The thicker laminae are probably residues of storm/high tide activity; such activity would have brought more clay into suspension or increased the influx of clay from the fluvial system. These features again suggest tidal dominated sediments (Hatch and Rastall, 1971, p.405; Hoskin, 1974, p.62; Reineck, 1969, p.737).

Evidence of organisms in the subfeldsarenite is minimal. This can likely be explained by the constantly shifting sediments within the dunal complex (Heckel, 1972, p.244).

Finally, Wilson (1946, p.18) noted a red-coloured outcrop of the subfeldsarenite further up the arm, at MacLaren Landing

toward the assumed fluvial source. This usually implies subaerial exposure, possibly associated with fluctuating water levels:

7.5 DEPOSITIONAL ENVIRONMENT FOR THE COARSE QUARTZARENITE MICROFACIES:

The quartzarenite microfacies is thought to represent, in general terms, trough (interbar depression) deposits of storm/high tide origin. Such units have a maximum thickness of 0.3 to 0.6 metres of cross-bedded, coarse sand, overlying a scoured base.

The coarse sediments were fluvially transported into the environment, distributed by storm/high tide action and deposited between the subaqueous fine sand bars where further sorting by removal of fines and concentration of coarse fraction could have occurred. The irregular dunal topography could produce the channel-like areas, through which the storm/high tide currents swept scouring the bottom and washing out the fines (Selley, 1970, p.129-130).

Orientation of the interbar depression cross-bed directions in the assumed troughs are at right angles to the shoreline and would suggest subaqueous bars parallel to the shore. The cross-beds could also result from longshore currents and/or tidal surge up the narrow arm at the northwest end of the embayment (Selley, 1970, p.130).

Further suggestion of a storm/high tide deposit are the associated coarse phosphatic shell fragments (ie. transported quickly, a short distance, and only once) and the three types of phosphatic clasts, all of which are indicative of previous primary phosphatic sedimentation (Bushinski, 1964; Mesolella, 1966, p.260-262; Williams et al., 1954, p.375-379). The clasts are likely a result of strong current action similar to that which ripped-up the intraformational shale clasts found in the mixed microfacies. The phosphatic material probably formed as thin beds in a shallow, nearshore, restricted environment of highly saline water normally the site for carbonate deposition (ie. lagoonal or intertidal areas) where occasionally phosphate was deposited. The phosphate was most likely derived from the dissolution of phosphatic shells (Blatt et al., 1972, p.547-556; Gulbrandsen, 1969, p.379-380; Krauskopf, 1967, p.92). The conditions for phosphate deposition, however, would have lasted only a short period allowing but a thin phosphatic deposit to develop before it was ripped-up by strong current activity, leaving no trace of the beds

other than the clasts. The circular phosphatic grains, some of which may be oolites, were a result of nearshore currents while silty quartz/feldspar-rich clasts formed when fine sand was blown, or carried by currents, into the phosphate depositional environment before it was disturbed by strong currents.

Another plausible explanation for the cross-bedded, coarse calcareous quartzarenite with its bipolar current directions, shell fragments, phosphatic clast content, and trough configuration is an estuarine environment subject to fast flowing, ebbing and flooding tidal currents (Selley, 1970, p.128-130). This environment also fits the depositional sequence already described for the preceding microfacies. The fluvial source for most of the terrigenous detritus entering the Embayment lay at the north end of the "arm", imposing an estuarine-type setting on the arm. The phosphate would then have been deposited in the shallow, restricted north end of the estuary where the conditions of high biological productivity, warm, nutrient-rich water with high phosphate content, high pH and high salinity, and nearshore downwelling (from the intermixing of fresh river and saline sea water) would be met (D'anglejan, 1967, p.15-44; Gulbrandsen, 1969, p.379-380; McKelvey, 1967, p.D8). Two additional factors in phosphate deposition, low continental runoff and low detritus influx, would be met infrequently, and for only short periods, resulting in only minor, thin beds of phosphate. Storm activity flushed the coarse grained sediment from the craton into the estuary, at the same time ripping-up the phosphate deposits, and then transported the sediment out of the arm (parallel to the shore) depositing it between the sand banks. When no phosphate deposition had occurred, the resulting coarse-grained deposit would be devoid of phosphatic clasts.

The preceding explanation may prove the most realistic since cross-bed directions perpendicular to the shore were seldom found suggesting that the majority of the material was not washed in from the adjacent shore but from a source to the west-northwest. However, minor influence by the adjacent shoreline deposits cannot be totally absent.

7.6 DEPOSITIONAL ENVIRONMENT OF THE MIXED MICROFACIES:

All three submicrofacies of the mixed microfacies are probably indicative of channel deposits (Bosence, 1973, p.66-67; Hatch and Rastall, 1971, p.397-404; Klein, 1971, p.2586-2587; Pettijohn et al., 1973, p.476-478; Reineck, 1969, p.737, 1972, p.147; Selley, 1970, p.97, 128-130; Van Straaten, 1959); however, the three types are not believed to define the same kind of channel. In most cases, the three sediment types occur in wedge-shaped, cross-bedded deposits that have deeply scoured the underlying material. The major direction of cross-bed dips and imbricate-upstream shale clasts indicate a landward (north) derivation of the deposited material.

Mixed submicrofacies 1 is thought to resemble a tidal channel, most probably in the area of ebb current activity between close-to-shore bars. The soft, transported shale clasts were ripped-up as the tide rose onto the tidal flats and then carried along with the ebbing water into channels between the bars where they (the clasts) were mixed with subfeldsarenite. The clasts are usually seen at the bottom of the channels as a lag deposit and from there the sediment fines-upward. This fining-upward sequence is due to the waning competency of the current. The waning current also brings rippling of the finer material, rather than cross-bedding (Fuchtbauer, 1974, p.73-79, 87-90).

Mixed submicrofacies 2 and 3 probably result from storm/high tide activity and the accompanying increased wave activity

and current action. Again, these two sediment types could have been deposited in tidal channels between bars or where channels broke through bars. The coarse sand was derived from the coarse fraction on the exposed, weathered terrain, above normal high-tide level. This material was transported into the sea, where it was mixed with the other components. The coarse shell fragments show only minor evidence of transport and were likely washed from the faunal communities on the tidal flats, in the lagoons, and other near-shore environments. The deformed shale clasts were derived from tidal flats. The differences between submicrofacies 2 and 3 likely result from the current competencies. Submicrofacies 2 lacks fine material which was washed further out to sea, suggesting this to be a nearshore channel deposit. Submicrofacies 3 has a mixture of coarse and fine sand but no shale clasts which suggests it was deposited farther from shore where the waning current could not carry the shale clasts and coarse shells; the coarse sand being spherical and well-rounded, could roll along the bottom as traction load.

A number of exposures (eg. Stations 48 and 60) revealed mixed submicrofacies 2 and 3 as thin, wide sheets with cross-bed directions varying from the perpendicular-to-shoreline norm for this microfacies. These are seen to typify fans spreading out seaward of the bars after the detritus escapes through the channels between the bars. Thus, a thinning of the beds seaward from the channel mouth in all directions would be produced, giving the beds their thin lenticular appearance rather than that of a U-shaped scour channel.

Storm/high tide deposits such as submicrofacies 2 and 3 are probably the results of sporadic and inconsistently spaced events. Submicrofacies 1 deposits depend on the strength and height of the tides, and the proximity to the shore. Hence, all three mixed submicrofacies show localized occurrences consistent with these interpretations.

7.7 SUMMARY OF THE OVERALL ENVIRONMENT OF DEPOSITION FOR THE ROCKCLIFFE FORMATION:

The suggested depositional environment for the five microfacies of the Rockcliffe Formation is a very shallow tidally dominated shoreline. A possible fluvial inlet into the basin, northwest of the study area at the north end of the narrow arm (ie. estuary? Fig. 14), is suggested.

A barren, wind-swept source area with sand dunes of intermediate grain size and interdunal sand of the very fine and coarse sizes has been postulated for the area landward (north) of the basin edge. Intertidal flats, where the thick shale sequences formed, were cut by tidal channels. Seaward of the tidal flats, very shallow lagoonal regions were perhaps occasionally formed, where dolostone and shale with thin layers of siltstone and limestone accumulated. Further offshore were wide, subaqueous dune/bank complexes, elongate parallel to shore. During storms or extremely high tides, channels from the tidal flat areas would cut through the sand banks distributing the sudden surge of coarse material (shell fragments, shale clasts, and coarse sand from the source area) out amongst the dunes. At the same time, the storms would flush coarse material into the north end of the narrow arm (estuary?) to be later redistributed by longshore and tidal currents to the subaqueous dunal area. As a result of the configuration of the basin, with its long, narrow arm (estuary?) to the northwest, the dominant sediment distribution mechanism was the pulsating, back and forth tidal flow in the arm. The NW-SE tidal current effects apparently partially masked the longshore currents and on/off shore movement. Phosphatic sediment possibly originated to the northeast, when conditions were suitable, and removed and carried southeast into the study area probably during storms or high tides.

7.8 DEPOSITIONAL ENVIRONMENT COMPARISON TO THE CORNWALL AREA:

The four points listed below summarize the relationships between the depositional environment in the Cornwall area (Rosenstein and Hoskin) and the Ottawa area:

1. Cornwall area was more basinward, in a quieter environment, as evidenced by more abundant limestone and shale.
2. Mainly finer sands and silts were transported to the Cornwall area.
3. The coarse quartz sand and mixed facies of the Cornwall area, along with much of the finer sediment, could have been derived from a closer source, such as the Frontenac

Axis to the west of Cornwall, rather than the north shore of the basin (Fig. 14). The transported detritus from either source area would be very similar.

4. Since the water was still relatively shallow in the Cornwall area, waves and currents would still be able to rework the detritus, forming ripples, cross-beds and sand banks.

In summary, it appears that the major differences in the depositional environments were the result of the Cornwall area being located further seaward (south) into the basin than the Ottawa area, which was virtually a shoreline environment, and being partially influenced by the Frontenac Axis.

CHAPTER VIII

CONCLUSIONS

When the study of the petrology and paleoenvironment of the Rockcliffe Formation was conceived, the author set out a number of objectives (p.4). The following conclusions illustrate the degree to which these objectives were attained and summarize the new information and knowledge gained:

1. New information includes locations and detailed descriptions of the outcrops in the Ottawa-Hull area, a list of the sedimentary structures and petrographic features observed in the formation, a detailed study of the rock samples in thin section, a stratigraphic compilation from well cores and outcrop sections, and a paleoenvironmental model for the deposition of the Chazyan sediments.
2. In general, the Rockcliffe Formation in the Ottawa-Hull area is dominated by terrigenous sediments characterized by lenticular bedding. The composition of the sediments is mainly quartz and feldspar fine sand, with clay-size material dominant in some areas. Minor coarse-grained clastics are also present.
3. Five microfacies are defined which, in decreasing order of abundance are:
 - a) subfeldsarenite

- b) shale
- c) coarse quartzarenite - clean submicrofacies
 - phosphatic submicrofacies with phosphatic shell fragments, oolites and quartz/feldspar clasts
- d) mixed, with intraformational shale clasts present
- e) dolostone

The subfeldsarenite, shale and dolomite represent coexisting persistent environments while the quartzarenite and mixed microfacies resulted from sporadic storm activity.

4. Diagenetic changes include overgrowths on coarse quartz grains, dolomitization of calcitic ooze, and cementation of the subfeldsarenite and quartzarenite with calcite.
5. The general stratigraphy of the Rockcliffe can be summarized as follows: basal 40 metres subfeldsarenite with scattered occurrences of quartzarenite and mixed microfacies, middle 7.5 metres shale, upper 2 metres dolostone. The lensing habit of the stratigraphic units make a regional as well as local correlation between wells and between wells and outcrops very difficult.
6. The Chazyan Rockcliffe Formation of the Ottawa-Hull area probably represents deposits of a very shallow, tidally influenced sea with tidal flats, lagoonal areas and subaqueous sandbars supplied with clastic material from a low, wind-swept land mass to the north. A long, narrow estuarine-type arm of the sea, which most likely extended to the northwest, played a marked rôle in the deposition of phosphate as well as influencing the deposition of the other sediment types in the embayment. Frequent storms are also suggested in the form of thin coarse lenses and layers.
7. Correlation with the Cornwall area shows that in that area more carbonate (biosparite) is present, and the shale is scattered throughout the stratigraphic sequence

MICROFACIES LEGEND FOR
APPENDIX B

BEDDING SYMBOLS:

- X — Cross
- F — Flat
- M — Massive
- R — Ripple
- ↑ — Direction of decreasing bed thickness
- L — Lenticular

OTHER SYMBOLS:

- A — Algal mounds
- C — Concretions
- f — Fossils
- m — Mud cracks
- S — Scoured
- E — Ellipsoid

SCALE (in m.):

* Section excluded from Rockliffe Formation after detailed examination (see p. 16, p. 78).

BIBLIOGRAPHY

- Baird, D.M., (ed.), 1972, Geology of the National Capital Region: 24th Int. Geol. Congr., Guidebook Excursions B23-27.
- Baldwin, E.J., 1973, The Moenkopi Formation of North-Central Arizona: An Interpretation of Ancient Environments Based Upon Sedimentary Structures and Stratification Types: Jour. Sed. Petro., V.43, No. 1, pp.92-106.
- Blatt, H., Middleton, G. and Murray, R., 1972, Origin of Sedimentary Rocks: Prentice-Hall Inc., New Jersey, 634 pp.
- Bolton, T.E. and Liberty, B.A., 1972, Geology of the National Capital Area in 24th Int. Geol. Congr., Guidebook, Excursions B23-27, Baird, D.M. (ed.), p.15-33.
- Bosence, D.W.J., 1973, Facies Relationships in a Tidally Influenced Environment: Geologie en Mijnbouw, V.52, pp.63-67.
- Bromley, R.G., 1967, Marine Phosphorites as Depth Indicators: Marine Geology, V.5, pp.503-509.
- Bushinski, G.I., 1964, On Shallow Water Origin of Phosphorite Sediments: Developments in Sedimentology, Deltaic and Shallow Marine Deposits, V.I, L.M.J.V. Van Straaten (ed.), Elsevier Publ. Co., New York, pp.62-69.
- Compton, R.R., 1962, Manual of Field Geology: John Wiley & Sons, Inc., New York, 378 pp.
- Crosby, E.J., 1972, Classification of Sedimentary Environments: Soc. Econ. Paleont. Mineral, Spec. Publ. 16, pp.4-11.
- D'anglejan, B.F., 1967, Origin of Marine Phosphates off Baja Calif., Mexico: Marine Geol., V.5, pp.15-44.
- Degens, E.T., 1965, Phosphates: Geochemistry of Sediments, Prentice-Hall Inc., New Jersey, pp.141-153.

- Douglas, R.J.W. (ed.), 1970, ¹¹²Geology and Economic Minerals of Canada: Dept. Energy, Mines and Resources, Geol. Surv. Can., Econ. Geol. Rept. No. 1, Ottawa, pp.228-250.
- Evans, G., 1965, Intertidal Flat Sediments and their Environments of Deposition in the Wash: Quart. Jour. Geol. Soc. London, V. 121, pp.209-245.
- Fuchtbauer, H., 1974, Sedimentary Petrology Pt. II, Sediments and Sedimentary Rocks: Halsted Press, John Wiley & Sons Inc., Toronto, pp.72-123.
- Govt. of Ontario, Dept. Mines and Northern Affairs, Supplement to Catalogue of Ontario Well Samples at the Geol. Surv. of Can., Paper 70-4.
- Gulbrandsen, R.A., 1969, Physical and Chemical Factors in the Formation of Marine Apatite: Econ. Geol., pp.365-382.
- Hatch, F.H. and Rastall, R.H., 1971, Deposits of Modern Seas and Oceans: Petrology of the Sedimentary Rocks, V.2, Hafner Publ. Co., New York, pp.395-411.
- _____, 1971, Phosphatic Deposits: Petrology of the Sedimentary Rocks, V.2, Hafner Publ. Co., New York, pp.331-337.
- Heckel, P.H., 1972, Recognition of Ancient Shallow Marine Environments: Soc. Econ. Paleont. Mineral., Spec. Publ. 16, pp.226-286.
- Hofmann, H.J., 1963, Ordovician Chazy Group in Southern Quebec: Amer. Assoc. Petro. Geol., V.47, No. 2, pp.270-294.
- Hoskin, R.J.R., 1974, Petrologic Description and Lateral Correlation of the Chazy sandstone, shale and limestone of the Cornwall Dyke Area: unpubl. B.Sc. Thesis, Queen's Univ., Kingston.
- Johnson, H.D., 1975, Tide-and Wave-dominated Inshore and Shoreline Sequences from the Late Precambrian, Finnmark, North Norway: Sedimentology, V.22, pp.45-74.

- Kay, M., 1942, Ottawa-Bonnechere graben and Lake Ontario homocline: Bull. Geol. Soc. Am., V.57, p.585-646.
- Kerr, P.F., 1959, Optical Mineralogy, 3rd. edition, McGraw-Hill Book Company, Toronto, 442 pp.
- Klein, G. de Vries, 1970, Tidal Origin of a Precambrian Quartzite-The lower fine-grained quartzite (Middle Dalradian) of Islay, Scotland: Jour. Sed. Petro., V.40, No. 3, pp.973-985.
- _____, 1971, A Sedimentary Model for Determining Paleo-tidal Range: Geol. Soc. Amer. Bull., V.82, pp.2585-2592.
- Krauskopf, K.B., 1967, Calcium Phosphate: Introduction to Geochemistry, McGraw-Hill Book Company, Toronto, pp.88-93.
- Krumbein, W.C. and Sloss, L.L., 1963, Stratigraphy and Sedimentation, 2nd. edition, W.H. Freeman & Co., San Francisco, 660 pp.
- Lane, D.W., 1963, Sedimentary Environment in the Cretaceous Dakota Sandstone in North-western Colorado: Amer. Assoc. Petro. Geol. Bull., V.47, pt. 1, pp.229-256.
- Liberty, B.A., 1971, Paleozoic geology of Wolfe Island, Bath, Sydenham and Gananoque map-area, Ontario: Geol. Surv. Can., Paper 70-35.
- Matthews, R.K., 1974, Dynamic Stratigraphy, Prentice-Hall Inc., New Jersey, 370 pp.
- McKelvey, V.E., 1967, Phosphate Deposits: U.S.G.S. Bull. 1252-D, pp.D2-D13.
- Mesolella, K.J., 1966, Collophane association with the unconformity at the base of the Devonian Onondaga limestone in New York State: Jour. Sed. Petro., V.36, No.1, pp.260-262.
- Pettijohn, F.J. et al., 1972, Sand and Sandstone, Springer-Verlag, New York, 618 pp.
- Pevear, D.R., 1967, Shallow Water Phosphorites: Econ. Geol., V.62, pp.562-575.

- de Raaf, J.F.M. and Boersma, J.R., 1971, Tidal Deposits and their Sedimentary Structures: Geol. en Mijnbouw, V.50, pp.479-504.
- Reineck, H.E., 1969, Tidal Flats: Amer. Assoc. Petro. Geol. Bull., V.53, p.737 (Abstr).
- _____, 1972, Tidal Flats: Soc. Econ. Paleont. Mineral., Spec. Publ. 16, pp.146-159.
- _____ and Singh, I.B., 1973, Depositional Sedimentary Environments, Springer-Verlag, New York.
- Rosenstein, E.S., 1973, The Chazy and Black Riveran Formations of the Cornwall Area, South-east Ontario - A paleoenvironment reconstruction and diagenetic study: unpubl. M.Sc. Thesis, Queen's Univ. Kingston, Ont.
- Sanford, B.V., 1963, Catalogue of Ontario Well Samples at the Geol. Surv. Can.: G.S.C. Paper 63-46, Ottawa, 415 pp.
- _____, 1970, in Douglas, R.J.W. (ed.), Geology and Economic Minerals of Canada: Geol. Surv. Can., Econ. Geol. Rept. No. 1, p.228-260.
- Selley, R.C., 1970, Ancient Sedimentary Environments, Chapman and Hall Ltd., London, England, pp.95-183.
- Sheldon, R.P., 1964, Paleolatitudinal and Paleogeographic distribution of Phosphorite: U.S.G.S. Prof. Paper 501-C, p.110.
- Twenhofel, W.H., 1961, Phosphatic Sediments: Treatise on Sedimentation, V.2, Dover Publ. Inc., New York, pp.546-560.
- Van Straaten, L.M.J.U., 1959, Minor Structures of Some Recent and Littoral Sediments: Geol. en Mijn., V.38, p.197-216.
- Vos, R.G., 1977, Sedimentology of an Upper Paleozoic River, Wave and Tidal Influenced Delta System in Southern Morocco: Jour. Sed. Petro., V.47, No. 3, pp.1242-1260.
- Williams, A. et al., 1965, Brachiopoda: Treatise on Invertebrate Paleontology, R.C. Moore (ed.), pt. H, 2 vols., Geol. Soc. Amer., Boulder Colorado, and Univ. of Kansas Press, Lawrence, Kansas, pp.H75-78 and H260-262.

- Williams, H., Turner, F.J., and Gilbert, C.M., 1954, Sedimentary Rocks: Petrography, W.H. Freeman & Co., San Francisco, pp. 251-384.
- Wilson, A.E., 1937, Erosional intervals indicated by Contacts in the vicinity of Ottawa, Ontario: Trans Roy. Soc. Can., Ser. III, V.31, Section IV, pp.45-60.
- _____, 1946, Geology of the Ottawa-St. Lawrence Lowland, Ontario and Quebec: G.S.C. Memoir 241, Ottawa, 66 pp.
- _____, 1956, A Guide to the Geology of the Ottawa District: Can. Field Naturalist, V.70, pp.1-68.
- _____ et al., 1936, Contributions to the study of the Ordovician of Ontario and Quebec: G.S.C. Memoir 202, Ottawa.
- _____ et al, 1941, Sources of oil and gas in central Ontario: Trans. Roy. Soc. Can., V.35, Section 4, pp.167-185.
- Youssef, M.I., 1965, Genesis of bedded phosphates: Econ. Geol., V.60, pp.590-600.

APPENDIX

A

2

THESES OUTCROP DESCRIPTION

117

Description No. _____

Location _____

Formation _____

Rock Name _____

Outcrop Description _____

Colour _____

Induration _____ Fissility _____

Texture: 1

Grain Size: Range _____ to _____

Modes _____

Sorting _____ Porosity _____

Orientation _____

Framework: Sand Phenoclasts

Roundness _____

Sphericity _____

Composition _____

Composition %:

Phenoclasts _____%; Sand _____%; Matrix _____%; Cement _____

Fossils _____
_____Lithologic Description _____

Primary Structures:

Bedding: Type _____ Sharpness _____

Character _____

Grain Segregation _____

Median Thickness _____

Thickness Range _____ to _____

Strike _____ Dip _____

Cleavage or Joints:

Strike _____ Dip _____

Strike _____ Dip _____

Other Structures: _____

Directional Data: _____

Other Remarks: _____

APPENDIX .

B

(NOT ALL OF THE SECTIONS REVEAL
THE ROCKCLIFFE FORMATION)

MICROFACIES LEGEND FOR
APPENDIX B

BEDDING SYMBOLS

- X — Cross
- F — Flat
- M — Massive
- R — Ripple
- ↑ — Direction of decreasing bed thickness
- L — Lenticular

OTHER SYMBOLS

- A — Algal mounds
- C — Concretions
- f — Fossils
- m — Mud cracks
- S — Scoured
- E — Ellipsoid

SCALE (in m.):

* Section excluded from Rockliffe Formation after detailed examination (see p. 16, p. 78).

STN. NO. 1

STN. NO. 2

STN. NO. 3

STN. NO. 6

STN. NO. 7

STN. NO. 8

STN. NO. 10

STN. NO. 11

STN. NO. 12

STN. NO. 13

STN. NO. 14

STN. NO. 16

STN. NO. 18

STN. NO. 19

STN. NO. 20

STN. NO. 21

STN. NO. 22

STN. NO. 25

STN. NO. 26*

STN. NO. 27*

STN. NO. 28*

STN. NO. 41

STN. NO. 42

STN. NO. 43

STN. NO. 45

STN. NO. 46

STN. NO. 47

STN. NO. 48

STN. NO. 50

STN. NO. 51

STN. NO. 52

STN. NO. 53

STN. NO. 54

STN. NO. 55A*

STN. NO. 55

STN. NO. 56

STN. NO. 57

STN. NO. 58

STN. NO. 59

STN. NO. 60

STN. NO. 61

STN. NO. 62

STN. NO. 63

STN. NO. 64

STN. NO. 65

STN. NO. 66

STN. NO. 67

STN. NO. 68

STN. NO. 69

STN. NO. 70

STN. NO. 71

STN. NO. 72

APPENDIX

C

Field description sections. Lithologies modified after microscopic examination in some cases (cf. Figure 12, Appendix B, and text).

Sections 4, 5, 9, 15, 39, 49 omitted because thicknesses exposed insufficient for plotting at this scale.

2.09 [

Photograph

01

Lithologic sample

STATION NO - 75-BT-01

LOCATION - N of Britannia infiltration plant

HEIGHT OF SECTION - 6"

2-09 [

01

6" - 14 gn with rusty spots, fn ss in $\frac{1}{4}$ - $\frac{1}{2}$ " undulatory beds
- thin shale wisps show ripples

STATION NO - 75-BT-02

LOCATION - NW of Britannia infiltration
plant

HEIGHT OF SECTION - 6"

2-10 [02 6" - lt gn with rusty spots, fn ss in $\frac{1}{4}$ - $\frac{1}{2}$ ", undulatory beds
- thin shale wisps show ripples

STATION NO - 75-BT-03

LOCATION - 100 yds W of 75-BT-02

HEIGHT OF SECTION - 6"

- 6 - lt. gn, fn ss in $\frac{1}{4}$ ", undulatory beds
- thin shale wisps show ripples

STATION NO - 75-BT-06

LOCATION - SW corner of Regina + Britannia St

HEIGHT OF SECTION - 2' 3"

03

- gy. gn, med ss with oxide grain stringers
- 27" - 1/2-1", undulatory beds with stringers showing ripples and x-beds

STATION NO. - 75-BT-07

LOCATION. - CORNER OF HOWE & POULIN ST.

HEIGHT OF SECTION - 3' 6"

STATION NO. 75-BT-08

LOCATION - At east end of Britannia
yacht club

HEIGHT OF SECTION - 1'

- lt. gn, fm-med. ss with flat, $\frac{1}{2}$ -2" beds

STATION NO. 75 BT-10 132

LOCATION - SW corner of Zephyr + Don St

HEIGHT OF SECTION - 2' 2 1/2"

STATION NO.- 75-BT-H 133

LOCATION- Tennis club, Britannia Park

HEIGHT OF SECTION- 1' 4"

- lt. gn, fm-med ss in $\frac{1}{2}$ -1", undulatory beds

STATION NO. - 75 BT-12

LOCATION - NW corner of Britannia & Don St

HEIGHT OF SECTION - 1'

2-4 [2-5]

- lt gn, fn ss with $\frac{1}{4}$ - $\frac{1}{2}$ " undulatory beds
- dip 5° in a 330° direction
- crescent trains give 90 - 100° direction

STATION NO - 75-BT-13

LOCATION - Corner of Regina & Britannia Rd

HEIGHT OF SECTION - 3' 8"

STATION NO - 75-BT-14

LOCATION - SE corner of Britannia & Priscilla St

HEIGHT OF SECTION - 1' 4"

16" - lt. gn, med ss in $\frac{1}{2}$ - $1\frac{1}{4}$ ", undulatory beds with oxide grains in wisps

STATION No. - 75-BT-16

LOCATION - Along bike path, W of Britannia

HEIGHT OF SECTION - 6"

2-15 [

07

6" - gg-gn, med. ss, in 1/2-2" beds with crescent structures showing 85° direction
 - get oxide grain stringers

STATION NO - 75-BT-17

LOCATION - On river, N of Woodroffe

HEIGHT OF SECTION - 6" + 6"

2-16
2-17

6" - gy. gn, med ss in $\frac{1}{2}$ -1", undulatory beds with worm tracks on bedding surface and $\perp$ to it
- top cap is dk. bn with $\frac{1}{16}$ - $\frac{1}{8}$ ", rd, spher qtz grs.

2-18

6" - bn, fn. gr, thinly bedded, undulatory ss.

STATION NO - 75-87-18

LOCATION - On river, N of Woodroffe Ave

HEIGHT OF SECTION - 1'

- gy-gr, med ss in $\frac{1}{4}$ -1", undulatory beds
- dip is 10° in a 140° direction.

STATION NO - 75-BT-19

LOCATION - E. of 75-BT-18

HEIGHT OF SECTION - 3'

- 1 ft. gn-gy, med, rippled and x-bedded ss interbedded with $\frac{1}{4}$ -1", vfn. ss.

- 1 ft. gn, coarse, x-bedded ss interbedded with $\frac{1}{4}$ - $\frac{1}{2}$ " layers of fn, undulatory ss; coarse beds = 1-1 $\frac{1}{2}$ "

- 70% fn ss increases toward base and coarse incr. in gr. size

STATION NO - 75-BT-20

141

LOCATION - E side of Pooler St

HEIGHT OF SECTION - 2' 6"

- dk. gn, thinly bedded, fissile shale with areas of large shells
and thin beds of broken shell fragments
- bedding slightly undulatory

142

STATION NO - 75-BT-21

LOCATION - NE of 75-BT-19

HEIGHT OF SECTION - 2' 3"

STATION No - 75-BT-22

LOCATION - On river, E of Woodroffe Ave

HEIGHT OF SECTION - 6'

3-3 [

13A

13B(2)

6'

- gn-gy, fn-med, undulatory ss with shaly lenses which contain small, soft, white xtls
- beds are $\frac{1}{2}$ -1"

STATION NO. - 75-BT-23

144

LOCATION - SW of Westboro Beach

HEIGHT OF SECTION - 30'

STATION NO - 75-BF-24

LOCATION - Below parking lot at Wistaro

HEIGHT OF SECTION - 13'

STATION No - 75-BT-25

146

LOCATION - N. of Westboro Beach

HEIGHT OF SECTION - 4'

STATION NO. - 75-BT-26

LOCATION - Near bike path, S of Champlain Bridge

HEIGHT OF SECTION - 5'

3-16
3-17 {
3-15 {
3-14 {

- dk gy, algal mounded ls
- ls right now fn ss and just under mounds appears ripped up
- in between the two ripped up areas get banded ls (thin sh layers)

- gn., fn, non-fossilif dol. with small ball + pillow struct at base and larger ball + pillows at top; rock breaks into square pieces
- small ball + pillows separated from large by $1\frac{1}{2}$ ", fossilif ls bed

3-12
3-13
3-19 {

- dk gy, massive, burrowed, minor algal mound ls.

STATION NO.- 75-BT-27

LOCATION- S of Champlain Bridge

HEIGHT OF SECTION- 6' 7"

STATION NO- 75-BT-28

LOCATION- N. of Champlain Bridge

HEIGHT OF SECTION- 4'

STATION NO. - 75-BT-29

LOCATION - NW of Briardcliffe Dr. + NE of Blair Rd

HEIGHT OF SECTION - 22'

LOCATION- Ski slope at Rockcliffe airport

HEIGHT OF SECTION- 25' 6"

LOCATION - S. side of dump, Rockcliffe airport

HEIGHT OF SECTION - 59' 8"

STATION NO. - 75-BT-32

LOCATION - SE. of Hwy. 17, at Orleans

HEIGHT OF SECTION - 18' 6"

STATION NO. 75-BT-33

154

LOCATION - SE of Hwy 17, at Orleans

HEIGHT OF SECTION - 15' 10"

STATION NO - 75-BT-34

LOCATION - SW side of Haysback

HEIGHT OF SECTION - 15' 10"

STATION NO. - 75-BT-35(1)

LOCATION - NE side of Hogsback

HEIGHT OF SECTION - 33'

5-10-

5-7

5-6

5-5

STATION NO - 75-BT-35(2)
(fault between 1 & 2)

LOCATION - NE side of Hoysback

HEIGHT OF SECTION - 17' 6"

STATION NO. - 75-BT-36

LOCATION - Below Rockcliffe Pt lookout

HEIGHT OF SECTION - 31'-10"

STATION NO - 75-BT 37

LOCATION: Along road down to Rockcliffe
boat club

HEIGHT OF SECTION - 20' 3"

STATION NO - 75-BT-38.

LOCATION - Across road from Rockcliffe
lookout

HEIGHT OF SECTION - 12'

STATION NO - 75-BT-40

LOCATION - AT ACACIA RD FORKS

HEIGHT OF SECTION - 25'

STATION NO - 75-BF-41

LOCATION - Corner of Mariposa and Landsdowne
Rd 5

HEIGHT OF SECTION - 1'

- dk. gm, $\frac{1}{8}$ " bedded, wipply, silty shale
- coarse ss lense in middle

STATION NO - 75-BT-42

LOCATION - Richmond St overpass, Quesada Hwy

HEIGHT OF SECTION - 10'

STATION NO- 75-QF-43

LOCATION- E of Garden Rd, in Quebec

HEIGHT OF SECTION- 6'

-lt. gn, fm, $\frac{1}{8}$ -1" (mainly $\frac{1}{2}$ -1") ripple bedded ss with thin shale wisps along bedding

STATION NO - 75, BT-44

LOCATION - Maple Rd just N of Evelyn Rd

HEIGHT OF SECTION - 12'

- gn, $\frac{1}{16}$ - $\frac{1}{8}$ " ripple and minor x-bedded, fissile shale with white lenses of fn. ss
- minor tracks
- x-beds give 0° direction
- beds dip 5° SW

2' - # gn - rusty, med, 1-3" lenticular bedded ss

STATION No. - 75-BT-45

LOCATION - E of Grimes Rd.

HEIGHT OF SECTION - 4'

STATION NO. - 75-BT-46

LOCATION - Fraser Rd just S of Lucerne Blvd

HEIGHT OF SECTION - 3'

lt. gn, med, $\frac{1}{2}$ -1 $\frac{1}{2}$ " rippled ss with rusty grains showing ripples

STATION NO - 75-87-47

LOCATION - Corner of Eardley & McConnell Rd

HEIGHT OF SECTION - 2'

STATION NO. - 75-BT-48

LOCATION - Corner of Eardley and Front St

HEIGHT OF SECTION - 9' 1"

STATION NO - 75-BT-50

LOCATION - W. of Du Portage Rd

HEIGHT OF SECTION - 6"

40

- 6
- 14 gr-rusty, fn-med, 8-12" undulatory bedded ss with minor tracks
 - crescent struct. give ~ 225° direction

STATION NO - 75-BT-51

LOCATION - N end of Hemlock Rd

HEIGHT OF SECTION - 6'

STATION NO - 75-BF-52

LOCATION - Along Du Lac Rd

HEIGHT OF SECTION - 6'

- lt. gy. gn, med. ss with rusty spots from top to base
- $\frac{1}{2}$ - $1\frac{1}{2}$ " beds with slightly rippled bedding surfaces
- tracks, burrows and crescent marks on surfaces
- crescent struct give 110° direction

STATION NO. - 75-BT-53

LOCATION - W. of Bellvue

HEIGHT OF SECTION - 6"

6-17 [

43

6"

- lt. gn, fn-med, slightly rippled ss. in $\frac{1}{2}$ -1" beds
- surfaces show basin and dome struct.
- ripples seen due to shale wisps

STATION NO - 75 BT-54

LOCATION - Along Railway, W of Vanier St

HEIGHT OF SECTION - 6'

- lt gn-rusty, med, rippled ss in $\frac{1}{2}$ -1 $\frac{1}{2}$ " beds
- fossil tracks and crescents very minor
- areas of $\frac{1}{2}$ " beds very broken
- get lens of lenticular bedding near base

STATION NO - 75-BF-55A

LOCATION - ISLANDS UNDER CHAMPLAIN
BRIDGE

HEIGHT OF SECTION - 10'

STATION NO - 75-87-55

LOCATION - Along Railway tracks at Jubilee St

HEIGHT OF SECTION - 4'

STATION NO - 75-BT-56

LOCATION^{re} Along river at base of Jubilee & James
Sts.

HEIGHT OF SECTION - 6'

STATION NO - 75-BT-57

LOCATION - E. end of Arbutus St.

HEIGHT OF SECTION - 3'

- lt. gy-gr, med, $\frac{1}{2}$ -1" undulatory bedded ss

STATION NO - 75-BT-36

LOCATION - S. end of Lortie Rd.

HEIGHT OF SECTION - 6' 6"

OF / DE

STATION NO 75 B-59

LOCATION - On shore W of Hamlet RI.

HEIGHT OF SECTION - 6'

STATION NO. - 75-BT-60

LOCATION - Along N side of Glenholm Rd

HEIGHT OF SECTION - 4'

STATION NO - 75-BT-61

LOCATION - Corner of Lortie & Ellesmere Rd

HEIGHT OF SECTION - 4'

STATION NO. - 75-BT-62

LOCATION - Lake St just N of Ellesmere

HEIGHT OF SECTION - 3'

6" - lt. gy, fn, $\frac{1}{2}$ -1" rippled ss with shale wisps

30" - gy, med, 2" rippled ss with shale wisps

STATION NO. - 75-BT-63

184

LOCATION - Corner of Forest & Arbutus Rd

HEIGHT OF SECTION - 2'

1' - lt. gy. dk. gn, $\frac{1}{16}$ - $\frac{1}{8}$ " rippled interbedded fn ss and shale; fissile
1' - lt. gy, fn, $\frac{1}{2}$ - 1" rippled ss with shale wispr

STATION NO - 75-BT-64

LOCATION - E. side Mountain Rd, N of Ellesmere

HEIGHT OF SECTION - 5'

STATION NO - 75-BT-65

LOCATION - Corner of Arbutus + Butternut St

HEIGHT OF SECTION - 3'

STATION NO - 75-87-66

187

LOCATION - Corner of Janiger & Pine St

HEIGHT OF SECTION - 2' 2"

STATION NO. - 75-BT-67

188

LOCATION - Corner of Cedar & Photos Rd.

HEIGHT OF SECTION - 1' 6"

7-9 [

55

18"

- H. gy-gn with rusty spots, fm-med, rippled, $\frac{1}{16}$ - $\frac{1}{2}$ " ss with shale wisps
- friable; tracks; fluting

STATION NO - 75-BT-68

LOCATION - Corner of Hemlock + Juniper St

HEIGHT OF SECTION - 6'

STATION NO.- 75-BT-69

LOCATION- On shore, S of Montcalm, W of Lowel

HEIGHT OF SECTION- 3'

STATION No. - 75-BT-70

191

LOCATION - At Deschenes' Filtration Plant

HEIGHT OF SECTION - 8'

STATION NO. - 75-BT-71

LOCATION - Along shore E. of Deschenes F. Irrigation

HEIGHT OF SECTION - 9' 9"

STATION NO - 75-BT-72

LOCATION - Just E of 75-BT-71

HEIGHT OF SECTION - 11'

APPENDIX

D

OBSERVATORY CORE, CARLIN
AVE

Rig base - 274' above S.C.

OTTAWA FM

- basal 2' 4" are gn sh with thin wavy of 1/4" gy, fn ss every 1/8"
- next 2" is black shelly ss with coarse, white g/c grs with a basal crystal like in lmg
- top 8" is gy gn (m. red), contorted and swirled sh & ss with small pellet structure

- 90% dk gn-gy (varren), dol sh with small contorted, 1/4" gy, fn ss layer
- at 280' set 1/2" of black, rd, phosph ss
- dk gy areas seem more silty and massive
- 7' missing

- basal 6" is gy-1/4" gy, fn ss with black flecks; 9" of massive dk gn sh with minor ss concretionary
- 6" like basal 6" only top 2" highly contorted & has ripped up sh

- thin, contorted, interbeds of 1/4" gy ss and dk gn sh

314'

- massive, fm, lg ss with thin shell frag and very minor, thin sh comp.
- basal 1' shows faint ss
- get sh + ss interbeds with sh pieces at locations, 1' sh, 1' (bioturbated sh?)
- top 1' is med, extra pepper ss with oriented shell frag
- get minor 1' beds of this med ss throughout

320'

- to 8" interval of dk gn sh and fm, salt + pepper ss
- get minor 1' beds ss
- get beds of dk gn, dk sh at locations p' bed
- at base get 2" sh with thin ss wisps overlain by 5" coarse, black, oriented ss (like at Orleans) overlain by 2" of sh with thin ss wisps
- get minor 1' beds of this coarse layer

321'

- H gy, fm ss with abundant shell frag and no thin sh wisps

322'

- base is ang and scoured with ripped 1' ss pieces
- a mixture of fine-course, lg ss with abundant fresh fine ss and sh wisps

324'

- H gy, fm ss with minor shell frag and thin sh wisps
- get coarse layers and sh to pass where planned

332'

- dk gn sh with contorted H gy, fm ss layers
- base is scoured and angular and overlain by 3" coarse, wh & g's gr in a sh + stars
- top has 2" of same coarse material

333'

- fm, lg ss with minor shell frag; massive
- basal 3" is interbed sh comp in ss
- thinly interbedded, contorted fm, H gy, ss and dk gn sh

336'

- bottom fm is H gy, fm ss with minor wisps and minor shell frag
- next 1' has 2" base of dk gn sh with minor ss wisps overlain by 10" of fm and white ss with oriented shell frag and minor sh wisps
- top 3 1/2' is like basal 8 1/2' only get more sh in contorted beds, toward top

20F

344'

- basal contact is angular and undulatory overlain by 1' dk gn sh with g's gr + sh
- next 6" is fm, H gy, ss with oriented, abundant small frag; 6" of med, white ss with oriented shell frag; 6" like bottom of only white, not gy
- H gy, fm ss with thin sh wisps

348'

353'

- 1' beds of H gy, fm ss with 8-12" interbeds of sh (these sh beds usually have thin, fm ss streaks)

355'

- bottom 1' is 2' of dk gn sh overlain by dk gn sh with fine ss interbeds overlain by 1' of coarse, white qtz ss with abundant shell frag + phos. pieces
- top 2 1/2' is mainly dk gn sh with some contorted, fn ss interbedded and a top 3" layer of the coarse ss
- basal contact is angular and high in sh and sh pieces
- next 2 1/2' is 1/2" interbed. of lg gy, fn ss and dk gn sh with contorting; 3" of large ss + sh contorting; 3" lg gy, fn ss with small, minor sh twigs; 3" dk gn sh with minor contorted ss; top 6" is same as basal 2 1/2'
- lg gy, fn med ss with thin sh beds (these sh beds more abundant in basal 1')
- get 1" white, med coarse ss bands with black shell frag every 4" or so
- bottom 4 1/2' is dk gn, dol sh with interbeds of white, fn coarse ss
- top 1 1/2' is same only flat bedded
- bottom 3 1/2' is lg gy, fn med ss with sh wisps every 1/2' and med coarse, shelly ss every 1'
- within 1 1/2' is white, fn med ss with shell frag and very minor wisps
- top 1' is thin, contorted but not contorted lg gy, fn med ss
- bottom 1' is gn, massive, fn dol sh overlain by 6" like 397-399; 1 1/2' like bottom 1' of this section;
- 3" white, coarse ss in carb cement with minor sh + abundant shell frag; top 1 1/2" like base of this section
- base has 1/2" coarse, white qtz ss overlain by the rest which is 1/2" interbedded sh + lg gy, fn ss
- minor contorted beds in interbedded ss + sh.
- bottom 6" like basal 1 1/2' in 403-401'
- top 2 3/4' like 410-408'
- lg gy-white, coarse, qtz ss in carb cement with black, shell frag throat
- basal 1 1/2' is like underlying material only fn ss and wisps every 1/2"-1"
- over this get 1" dk gn sh overlain by 1/2" coarse ss + interbedded sh
- top 8" not sharp lower contact with bottom 1' of lg gy, massive, fn ss grading up to 2" of 1/2"-1" interbedded fn ss + sh
- lg gy-white, med ss with sh wisps every 1/2"-1"
- minor black shell frag scattered throat

- bottom 1' is gn, massive, fm dol sh overlain by 6" like 397-401'; 1 1/2' below 1' of this section;
 - 3" white, coarse ss in carb cement with minor sh + abundant shell frag; top 1 1/2" like base of this column

- bottom 6" like basal 1 1/2' in 401-405'
 - top 2 1/2' like 410-403'

- lt gy-white, coarse, qtz ss in carb cement with black, shell frag throat
 - basal 1 1/2' is like underlying material only fm ss and wipe every 1/2-1"
 - over this get 1" of gn sh overlain by 6" coarse ss + interbedded sh
 - top 6" not sharp lower contact with bottom 1' of lt gy, massive, fm ss grading up to 2" of 1/2-1" interbedded fm ss + sh

- lt gy-white, med ss with sh wipe every 1/2-1"
 - minor black shell frag scattered throat

- lt gy-gn, fm, massive ss with sharp, erosional-looking basal contact

- basal 6" is flat, interbedded lt gy, fm med ss and gn sh, with top 2" of lenticular sh + sh pieces
 - top 6" is lt ss, fm, massive ss with top 1 1/2" of ripple up sh pieces
 - ss like 424-422 only more cement + lt gy in color
 - minor thin sh wipe and abundant sh pieces in top 2" (med, lt gy ss)
 - lt gn, med ss with sh wipe (more abundant in lower 1")
 - get minor 1/2-1" bands of med-coarse ss

- basal contact sharp and overlain by 6" of lt gn, fm, flat ss; 1' like 424-422; 2" ripple-interbedded fm, lt gn ss + lt gn sh; 6" like 424-422 with sh pieces; 4" med ss like 424-422 with highly undulatory sh layers; 6" like 424-422 with abundant ripped up sh pieces.

- white, coarse qtz ss with minor shell frag in a carb cement
 - thin (1/2-1") bands of fm ss + gn, carb sh

OXFORD FM.

KILBORN AVE SCHOOL,
BILLINGS BRIDGE

848'

844'

CORE LOST

845 1/2'

853'

- lt. gy. fn ss with no phos shells with abundant wavy sh wisps and 8' sh beds
- sh dominant in a couple of areas
- two areas 1' thick have contorted bedding

- med. fn, abundant phos flecks, massive ss

- lt. gy. fn ss with no phos flecks
- a couple of 3" areas of sh or swirled ss and sh
- 852' = 1" of white, coarse, gtz ss

- very broken up core, part of which is lost
- beds show vertical (or close) bedding
- 869 1/2 - 864 = swirled ss + sh
- 864 - 860 1/2 = fn ss with minor sh lenses and wisps
- 860 1/2 - 853 = very broken up, mixed ss like at top of Westboro Beach

869 1/2'

CORE LOST

819'

- fn. to med. fn, lt. gy. ss with very thin sh. wisps scattered
- at 2 areas indicated get sh. rich beds with balls of ss
 > 3" thick

20F

806 1/2'

806'

- 3 sequences of sh with ss beds (thin) at base(?) overlain by 1' coarse, white, gtz ss.
- sh with ss increases in ss toward top sequence

- fn. to med. fn, lt. gy. ss with very thin sh. wisps scattered

815 1/2'

- very coarse, white, gtz ss with abundant phos. shell frag. and very little sh.

$$L \geq 3' + 4\omega$$

6487

is over. In by it some, while, 213

11. *Al. ...*

196

phos shell frag. and very little s.

in abundant ill clay matrix
as shown by clay to surface etc.

848

els of f is every 3^k ; only minor ph. iers

0327

104,

$$a^{\dagger} + c_f$$

str upper contract

937'

with wisps overlain by 1" of char. etc ss with

and wisps with interbedded shales and for

1

1

of ss at top

9.6

well.

423' L.

3053

RIG. BASE - 251' above SL

- 101

- lt. gy. ss, fossiliferous ss with varying amounts of shell frags
- interbedded are 1/2" to 1" dk. gy. sh. whips, some contorted
- some areas seem sh. rich, others ss. rich however ss. predominates in all except top 3 1/2'
- top 3 1/2' = interbedded, contorted ss. & sh.

- base is straight with 2' of black shell frag with minor gy. sh. lenses and gr. ss
- top 5' is massive, lt. gy. ss, fossiliferous ss with minor shell frag and minor whips
- 1/2" sh. piece layer ~ 1' up from base

- got 4" at base of material like 1739-1740' over an angular contact
- got 3 1/2' over this of lt. gy. ss with minor shell frag
- got 2" of sh. pieces & gr. ss. in ss. at transition point
- got 3 1/2' of massive, lt. gy. ss with minor shell frag over this

- massive, lt. gy. ss, fossiliferous ss with minor sh. frags
- coarse, white gr. ss with abundant sh. lenses & pieces and phosph. shell & pieces in a carb. content; basal contact undulating
- lt. gy. ss with minor sh. shell frag and thin sh. whips
- ss. massive looking (sh. very minor)

basal contact is slightly undulating, but not sharp, with a large amount of phosph. in the ss. above it is lt. gy. ss with minor shells & whips

- lt. gy. ss, fossiliferous ss. with varying amounts of shell material
- sh. whips from 1/2" to 1" thickness are interbedded every 4-5'
- where more sh. present got contorted bedding with ss.
- top 3' is sh. rich and contorted
- where sh. abundant got pyrite

17612'		- bottom 1" has 4 cycles of coarse, white qtz ss with sh lumps & ripped up sh. contain by med gy ss with abundant shells oriented by 1" interbedded ss & sh
17610'		- top has 2" of coarse at base grading up to massive, lt gy, gn, fm med ss with abundant shells
17608'		- gy, fm med ss with shell trains which show laminations
17606'		- top gets abundant thin wisps of sh
17604'		- lowest 1" is same as underlying and has sharp contact
17602'		- rest is fm, gy ss with 1" wisps of sh every 1" and minor shell frag
17600'		- same as below only minor wisps and shell frag remain abundant throat
17598'		- fm, gy, fm med ss with abundant sh, shell frag which decrease toward top
17596'		- base is angular and has 1" of coarse, white qtz, gy ss in the sh
17594'		- lt gy, fm med ss with minor shells and wisps; top 2" sorted
17592'		- med, lt gy ss with abundant oriented, shell frag, minor wisps; 2-4" coarse, white
17590'		- lt gy, fm med ss with sh, shell, a lt some wisp of gy sh showing ripple
17588'		- 2-4" zone of oriented sh pieces and coarse, white qtz, gy, fm med ss with small brack
17586'		- massive, coarse white ss with black shell
17584'		- lt gy, fm ss with minor sh frag and coarse thin sh wisps
17582'		- got coarse white ss and shell and fm piece but 2" from base
17580'		- got 2" of 1" 1/2" interbedded ss & sh not laminar pitted
17578'		- 1" interbedded, lt gy, fm, fm med & lt gy, sh, undulating
17576'		- same as 17578' 17582'
17574'		- fm med, lt gy ss with minor shell frag
17572'		- sh wisps scattered throat
17570'		
17568'		- black shell frag with white, coarse qtz, gy and ripped up sh
17566'		- basal contact sharp with underlying 1" of coarse, white qtz ss and phosph shell frag and
17564'		- ripped up sh pieces
17562'		- rest is fm, lt gy-gn ss with fm, black shell oriented ss show ripples & small knts
17560'		- lt gy, med ss with rounded, black, and frag with thin lt gy, sh wisps every 1-4"
17558'		- got ripped up sh pieces at localities pointed
17556'		
17554'		- fm med, lt gy ss with fm, coarse, black, and
17552'		- 1-2" beds of sh lenses & sh pieces at localities pointed
17550'		
17548'		- coarse, white, qtz ss with oriented, large, phosph shell frag in carb cement
17546'		- gy, fm med, dol ss with oriented, fm, sh shells and some pyrite
17544'		- top 1" more thin bedded with wisps of gy dol and gn, sh
17542'		
17540'		- lt gy, massive, fm, dol ss with fm, black shell frag, oriented 1" to bedding
17538'		
17536'		- coarse, white qtz ss with black phosph shell frag and ripped up dol pieces in a dol cement
17534'		- got coarse grading up into med, then 4" of coarse, then 1" fm, then 2" coarse
17532'		
17530'		- same as below only thin, gy dol wisps
17528'		
17526'		- massive, lt gy, fm med, dol ss with fm, black shells
17524'		- basal contact sharp but irregular and 1/2" of pyritic, dol sh
17522'		

APPENDIX
E

Tabulated Textural and Compositional Properties of Selected Samples Studied in Detail

Sample No.	Grain Type %										Mean Grain Size (mm)		
	Quartz	Feldspar	Phos. Clasts	Phos. Shells	Calcite	Dolomite	Micrite	Clay Matrix	Shale Clasts	Other	Quartz	Feldspar	Phos. Shells
17B	4	1			15	50	25			5			
22E	10	1		1		82				6			
23F	9	1		1		40	40			9			
23G	2	1		2		90				5			
24K	12					84				4			
11A	10	3		15	10			55		7			
02	47	18		7	5			17		6			
04A	55	25		9				5		6			
10C	38	17		6	19	1		15		4			
13A	44	20		3	15	3		15		m			
13B	40	15		15	24	1		5		m			
14C	38	10		3	40			m		9			
15C	25	15		1	40	m		15		4			
16C	40	15		m	40	m		m		5			
21E	50	20		5				17		8			
23L	35	10		7	25			15		8			
23N	30	10		5	30			25		m			
23O	55	20		5				12		8			
23P	45	20		5		8		10		12			
24D	40	15		9	25			10		1			

Tabulated Textural and Compositional Properties of Selected Samples Studied in Detail (continued)

Sample No.	Grain Type %										Mean Grain Size (mm)			
	Quartz	Feldspar	Phos. Clasts	Phos. Shells	Calcite	Dolomite	Micrite	Clay Matrix	Shale Clasts	Other	Quartz	Feldspar	Phos. Shells	Shale Clasts
24E	46	17		7	13	1		12		4	0.07	0.07	0.25	
38A	52	19		7				15		7	0.09	0.09	0.1	
58C	43	19		8				18		12	0.07	0.06	0.24	
21B	60	5		3	27			3		2	(0.5)	0.06	3.0	
23N	40	7	P	15	20			15		3	(0.1)	0.1	1.3	
24G	50	m	P	11	35			3		1	(0.07)	0.04	1.1	
23H	45	m	P	15	15			7	18	m	(0.05)	0.04	1.1	0.8
31D	37	7	P	13	18	10		5	10	m	0.07	0.07	2.6	3.0
14B	22	10	18	5	30			15		m	(1.7)	0.07	0.08	
59E	40	7	P	15	10			18		10	(2.0)	0.07	(2.5)	
23J	35	15	P	15	25			7		3	0.07	0.07	1.9	
21F	45	15		7				12	13	8	(1.3)	0.06	0.1	
21G	40	10		5	20			10	15	m	0.07	0.06	0.29	3.6
59F	40	9		11	15			8	10	7	(0.5)	0.06	0.29	5.0
											(0.3)	0.09	0.28	8.1

p = present; m = minor; () = minor

END

201280

FIN