

THESE TERMS GOVERN YOUR USE OF THIS DOCUMENT

Your use of this Ontario Geological Survey document (the “Content”) is governed by the terms set out on this page (“Terms of Use”). By downloading this Content, you (the “User”) have accepted, and have agreed to be bound by, the Terms of Use.

Content: This Content is offered by the Province of Ontario’s *Ministry of Northern Development and Mines* (MNDM) as a public service, on an “as-is” basis. Recommendations and statements of opinion expressed in the Content are those of the author or authors and are not to be construed as statement of government policy. You are solely responsible for your use of the Content. You should not rely on the Content for legal advice nor as authoritative in your particular circumstances. Users should verify the accuracy and applicability of any Content before acting on it. MNDM does not guarantee, or make any warranty express or implied, that the Content is current, accurate, complete or reliable. MNDM is not responsible for any damage however caused, which results, directly or indirectly, from your use of the Content. MNDM assumes no legal liability or responsibility for the Content whatsoever.

Links to Other Web Sites: This Content may contain links, to Web sites that are not operated by MNDM. Linked Web sites may not be available in French. MNDM neither endorses nor assumes any responsibility for the safety, accuracy or availability of linked Web sites or the information contained on them. The linked Web sites, their operation and content are the responsibility of the person or entity for which they were created or maintained (the “Owner”). Both your use of a linked Web site, and your right to use or reproduce information or materials from a linked Web site, are subject to the terms of use governing that particular Web site. Any comments or inquiries regarding a linked Web site must be directed to its Owner.

Copyright: Canadian and international intellectual property laws protect the Content. Unless otherwise indicated, copyright is held by the Queen’s Printer for Ontario.

It is recommended that reference to the Content be made in the following form:

Wolf, R.R. 2006. Paleozoic geology of Cockburn Island, Manitoulin area; Ontario Geological Survey, Open File Report 5424, 55p.

Use and Reproduction of Content: The Content may be used and reproduced only in accordance with applicable intellectual property laws. *Non-commercial* use of unsubstantial excerpts of the Content is permitted provided that appropriate credit is given and Crown copyright is acknowledged. Any substantial reproduction of the Content or any *commercial* use of all or part of the Content is prohibited without the prior written permission of MNDM. Substantial reproduction includes the reproduction of any illustration or figure, such as, but not limited to graphs, charts and maps. Commercial use includes commercial distribution of the Content, the reproduction of multiple copies of the Content for any purpose whether or not commercial, use of the Content in commercial publications, and the creation of value-added products using the Content.

Contact:

FOR FURTHER INFORMATION ON	PLEASE CONTACT:	BY TELEPHONE:	BY E-MAIL:
The Reproduction of Content	MNDM Publication Services	Local: (705) 670-5691 Toll Free: 1-888-415-9845, ext. 5691 (inside Canada, United States)	Pubsales@ndm.gov.on.ca
The Purchase of MNDM Publications	MNDM Publication Sales	Local: (705) 670-5691 Toll Free: 1-888-415-9845, ext. 5691 (inside Canada, United States)	Pubsales@ndm.gov.on.ca
Crown Copyright	Queen’s Printer	Local: (416) 326-2678 Toll Free: 1-800-668-9938 (inside Canada, United States)	Copyright@gov.on.ca



**Ontario Geological Survey
Open File Report 5424**

**Paleozoic Geology of
Cockburn Island,
Manitoulin Area**

2006



ONTARIO GEOLOGICAL SURVEY

Open File Report 5424

Paleozoic Geology of Cockburn Island, Manitoulin Area

by

R.R. Wolf

2006

Parts of this publication may be quoted if credit is given. It is recommended that reference to this publication be made in the following form:

Wolf, R.R. 2006. Paleozoic geology of Cockburn Island, Manitoulin area; Ontario Geological Survey, Open File Report 5424, 55p.

Open File Reports of the Ontario Geological Survey are available for viewing at the John B. Gammon Geoscience Library in Sudbury, at the Mines and Minerals Information Centre in Toronto, and at the regional Mines and Minerals office whose district includes the area covered by the report (see below).

Copies can be purchased at Publication Sales and the office whose district includes the area covered by the report. Although a particular report may not be in stock at locations other than the Publication Sales office in Sudbury, they can generally be obtained within 3 working days. All telephone, fax, mail and e-mail orders should be directed to the Publication Sales office in Sudbury. Use of VISA or MasterCard ensures the fastest possible service. Cheques or money orders should be made payable to the *Minister of Finance*.

Mines and Minerals Information Centre (MMIC) Macdonald Block, Room M2-17 900 Bay St. Toronto, Ontario M7A 1C3	Tel: (416) 314-3800
John B. Gammon Geoscience Library 933 Ramsey Lake Road, Level A3 Sudbury, Ontario P3E 6B5	Tel: (705) 670-5615
Publication Sales 933 Ramsey Lake Rd., Level A3 Sudbury, Ontario P3E 6B5	Tel: (705) 670-5691(local) 1-888-415-9845(toll-free) Fax: (705) 670-5770 E-mail: pubsales@ndm.gov.on.ca

Regional Mines and Minerals Offices:

Kenora - Suite 104, 810 Robertson St., Kenora P9N 4J2
Kirkland Lake - 10 Government Rd. E., Kirkland Lake P2N 1A8
Red Lake - Box 324, Ontario Government Building, Red Lake P0V 2M0
Sault Ste. Marie - 70 Foster Dr., Ste. 200, Sault Ste. Marie P6A 6V8
Southern Ontario - P.O. Bag Service 43, 126 Old Troy Rd., Tweed K0K 3J0
Sudbury - Level A3, 933 Ramsey Lake Rd., Sudbury P3E 6B5
Thunder Bay - Suite B002, 435 James St. S., Thunder Bay P7E 6S7
Timmins - Ontario Government Complex, P.O. Bag 3060, Hwy. 101 East, South Porcupine P0N 1H0
Toronto - MMIC, Macdonald Block, Room M2-17, 900 Bay St., Toronto M7A 1C3

This report has not received a technical edit. Discrepancies may occur for which the Ontario Ministry of Northern Development and Mines does not assume any liability. Source references are included in the report and users are urged to verify critical information. Recommendations and statements of opinions expressed are those of the author or authors and are not to be construed as statements of government policy.

If you wish to reproduce any of the text, tables or illustrations in this report, please write for permission to the Team Leader, Publication Services, Ministry of Northern Development and Mines, 933 Ramsey Lake Road, Level A3, Sudbury, Ontario P3E 6B5.

Cette publication est disponible en anglais seulement.

Parts of this report may be quoted if credit is given. It is recommended that reference be made in the following form:

Wolf, R.R. 2006. Paleozoic geology of Cockburn Island, Manitoulin area; Ontario Geological Survey, Open File Report 5424, 55p.

Contents

Abstract	ix
Introduction	1
Location	1
Access	1
Topography and Drainage.....	1
Previous Geological Studies	1
Present Geological Study	4
Drilling Operations	6
Structural Geology.....	6
Stratigraphy	9
Introduction.....	9
Precambrian	9
Paleozoic	12
Ordovician	12
Prairie du Chien Formation.....	12
St. Peter Formation	14
Glenwood Formation	15
Undifferentiated Strata.....	16
Collingwood Member of the Lindsay Formation.....	17
Blue Mountain Formation.....	18
Georgian Bay Formation.....	19
Silurian	20
Manitoulin Formation	22
Cabot Head Formation.....	23
Dyer Bay Formation	23
Wingfield Formation.....	24
St. Edmund Formation.....	25
Fossil Hill Formation	26
Amabel Formation	28
Quaternary.....	29
Economic Geology	29
Acknowledgements	31
References	31
Appendix 1. Geochemical Analysis of Selected Surface and Drill Hole Samples from Cockburn Island	37
Appendix 2. Geological Log of Drill Hole OGS-85-7 Cockburn Island	43
Appendix 3. Geophysical Wire-Line Logs of Drill Hole OGS-85-7 Cockburn Island.....	53
Metric Conversion Table	55

FIGURES

1.	Map of Ontario showing the location of Cockburn and neighbouring islands, in northern Lake Huron	2
2.	Geographic map of Cockburn Island.	3
3.	Geological map of Cockburn Island.....	5
4.	Aeromagnetic map of Cockburn Island showing the location of drill hole OGS-85-7	7
5.	Map of the Lake Huron area showing the general geology of the exposed Precambrian rocks and the inferred geology of the subsurface Precambrian rocks	8
6.	Summary of the geological log from drill hole OGS-85-7, Cockburn Island	13
7.	Quaternary geology of Cockburn Island	30
8.	Vertical variations in SiO ₂ content in the Precambrian rocks and formations exposed at surface on Cockburn Island	39
9.	Vertical variations of MgO and CaO contents in the Precambrian rocks and formations exposed at surface on Cockburn Island.....	40
10.	Vertical variations of Al ₂ O ₃ and Fe ₂ O ₃ contents in the Precambrian rocks and formations exposed at surface on Cockburn Island.....	41
11.	Gamma ray and bulk density geophysical log of drill hole OGS-85-7 Cockburn Island.....	54
12.	Gamma ray, bulk density and caliper log, drill hole OGS-85-7 Cockburn Island	back pocket
13.	Gamma ray and focussed electric log, drill hole OGS-85-7 Cockburn Island	back pocket
14.	Gamma ray and neutron porosity log, drill hole OGS-85-7 Cockburn Island.....	back pocket

TABLES

1.	Lithologic units of Cockburn Island.....	10
2.	Comparison between the North American and European classifications of the Silurian System	21
3.	Geochemical data for surface samples and selected drill hole samples	38

MAP

Map P.2987	Paleozoic geology of Cockburn Island, District of Manitoulin.....	back pocket
------------	---	-------------

CHART

A.	Stratigraphic nomenclature of Silurian rocks in the northern Lake Huron area.....	back pocket
----	---	-------------

Abstract

Cockburn Island is located in northern Lake Huron and is underlain by Silurian carbonate strata, which is exposed at the surface only in the northern part of the island. Detailed surface mapping delineated the distribution of the Middle Silurian Dyer Bay, Wingfield, St. Edmund, Fossil Hill, and Amabel formations (in ascending stratigraphic order) on the island. Of these units only the 3 upper formations are well exposed. Individual outcrops seldom exceed 2 m in thickness. Thick Quaternary deposits cover most of the island; in places, over 100 m of unconsolidated sediment overlies the bedrock surface.

To assist in interpreting the bedrock geology on the island, a deep diamond-drill hole was cored through the Paleozoic succession at the southern end of the island. Located near an intense magnetic anomaly, this drill hole terminated in a Precambrian magnetite-rich amphibolite. The lower Paleozoic strata intersected in the drill hole include conglomerates, sandstones, shales, dolostones, and limestones, ranging in age from the Cambro-Ordovician to the Middle Silurian.

Selected surface samples of dolostones on Cockburn Island, which were geochemically analyzed, are similar in composition to stratigraphically equivalent dolostones that occur on nearby Manitoulin Island. Lafarge Canada Inc. currently operates a large quarry in the Amabel Formation near Meldrum Bay, on Manitoulin Island, just east of Cockburn Island.

Paleozoic Geology of Cockburn Island, Manitoulin Area

R. R. Wolf¹
Ontario Geological Survey
Open File Report 5424
2006

¹Formerly of the Ontario Geological Survey.

Introduction

LOCATION

Cockburn Island, in northern Lake Huron, is situated between Manitoulin Island to the east and Drummond Island (Michigan, United States of America) to the west (Figure 1). The island is bounded approximately by latitude 45°50'N and 46°00'N, and by longitude 83°15'W and 83°30'W. The Township of Cockburn Island includes all of Cockburn Island (Figure 2), an area of approximately 175 km². The centre of the island is approximately 40 km south of the north shore of Lake Huron.

ACCESS

Cockburn Island has no direct access to the mainland and has had no regular ferry service since the 1960s. A commercial barge was hired to transport the Ontario Geological Survey (OGS) field crew and its equipment to Cockburn Island. At the village of Cockburn Island, Fisheries and Oceans Canada maintains a small boat harbour which provides sheltered docking facilities. On Cockburn Island, itself, the Township maintains approximately 45 km of gravel road (Figure 2). The remaining portions of the island are easily accessible from abandoned logging roads and hunting trails, most of which are passable only by four-wheel drive vehicles. The only exception is in the southwestern part of the island, where extensive swamps cover most of the area.

TOPOGRAPHY AND DRAINAGE

The topography of Cockburn Island is dominated by a large morainic hill, named McCaigs Hill, in the centre of the island, which stands approximately 120 m above the lake level, and is enhanced by 30 m high bluffs. To the north and west a gentle slope, with low gravel and bedrock terraces, extends to the lake level. To the south and east a gradual slope extends to another 30 m high bluff that parallels the shoreline. The present-day Lake Huron shoreline consists of cobble and gravel beaches with scattered bedrock exposures. Only along the bays on the southern shore have sandy beaches developed. During the field season (1985) the water level in Lake Huron was near or at its highest ever recorded level, thus some bedrock exposures that would normally have been exposed were under water.

Drainage of the central portion of the island is controlled by the Sand Creek–Sand Lake system, flowing south, and an unnamed creek flowing north through Robb Lake (Figure 2). The western part of the island contains extensive swamps around Wagosh Lake. There are numerous fresh-water springs and areas of standing water in low-lying areas.

PREVIOUS GEOLOGICAL STUDIES

The first geological reports of Cockburn Island were presented by Bigsby (1821, 1824), in the papers of his exploration through northern Lake Huron. He recorded the presence of limestone and shaly limestone at various sites along the shoreline, and also collected fossils from some localities on Cockburn Island

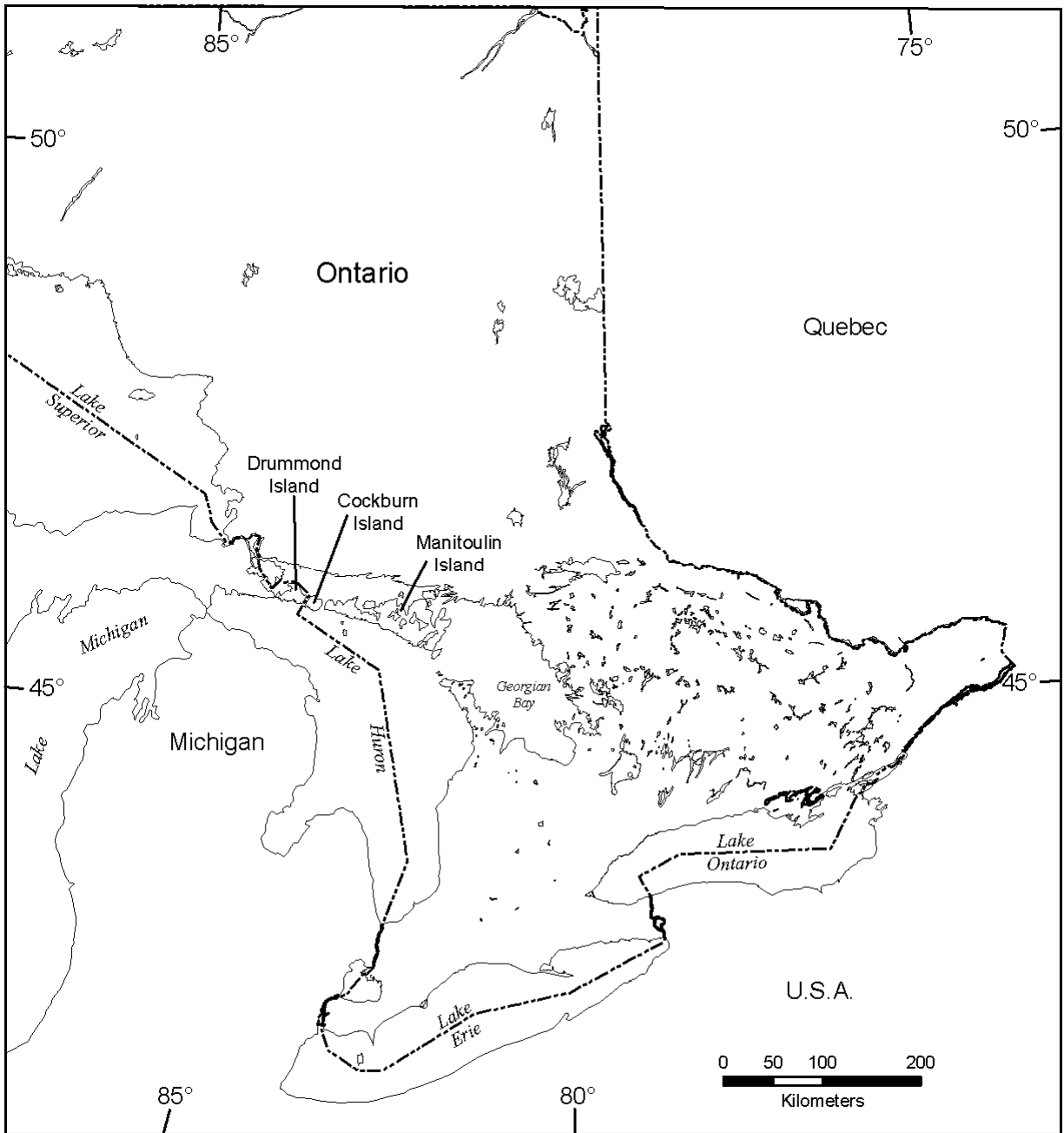


Figure 1. Map of Ontario showing the location of Cockburn and neighbouring islands, in northern Lake Huron.

(Bigsby 1824, p.200). The next visit to the island was by Alexander Murray (1849), who also examined the shoreline exposures, identifying them as Niagaran limestones, a designation subsequently supported by Logan (1863).

The first detailed geological examination of the island's interior was undertaken by Bell (1870). In addition to briefly describing the scattered outcrops of Niagaran limestone, he also referred to the extensive areas of swamps, boulders and sand terraces (Bell 1870, p.110).

The work of Williams (1916, 1919) was the most comprehensive up to that time. Extending the classification scheme he developed for Manitoulin Island, the bedrock strata of Cockburn Island were assigned to the Dyer Bay dolomite "lentile" (Cabot Head Member, Medina-Cataract Formation) and the Lockport Formation; although on the accompanying geological map (GSC Map 1715 in Williams 1919) Cockburn Island was mapped entirely as the Lockport Formation. Williams (1919, p.36) was aware that this error had occurred because of his misidentification of *Virgiana* sp. as *Pentamerus* sp., but he was

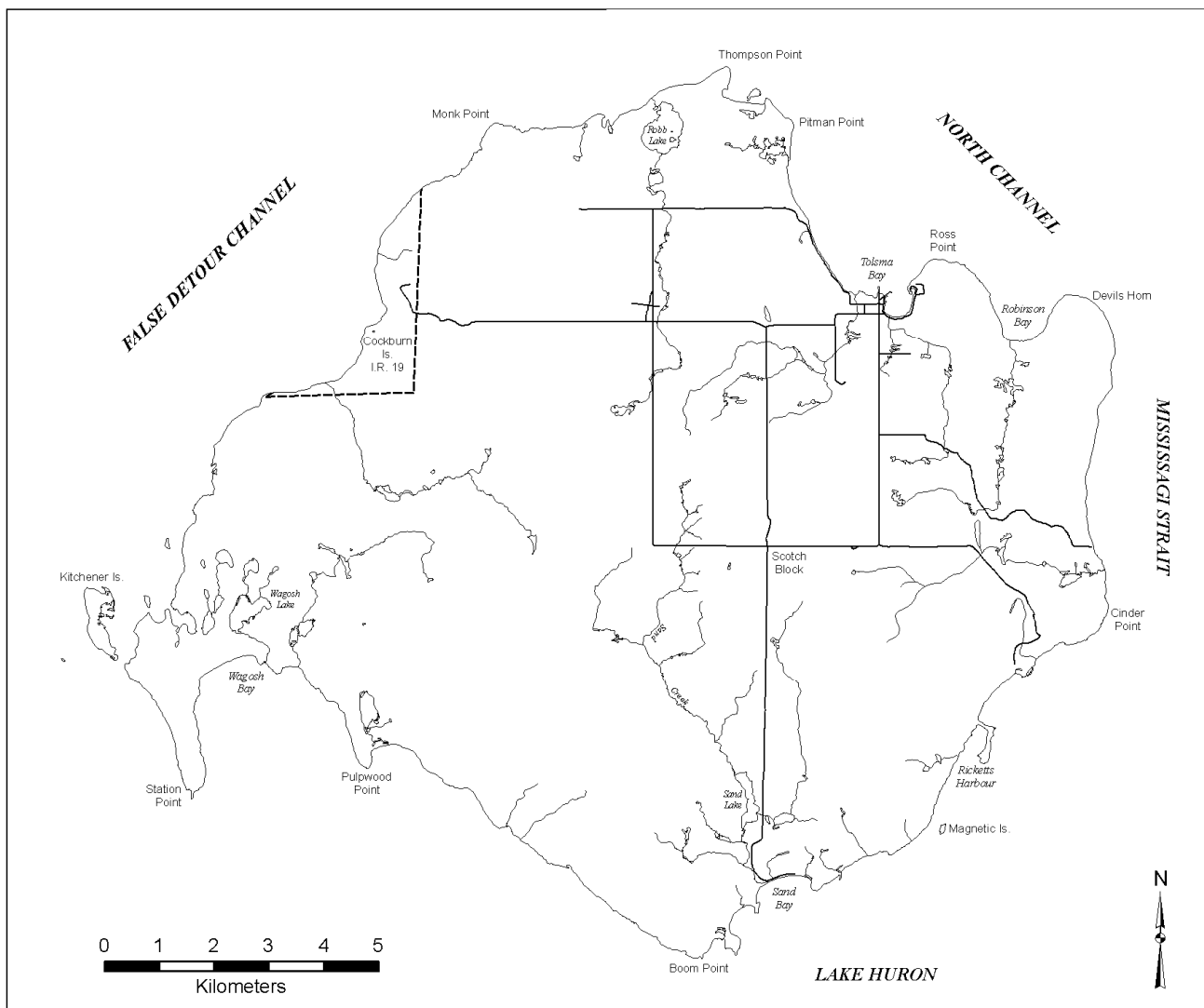


Figure 2. Geographic map of Cockburn Island.

unable to make the correction on the map. Argillaceous dolostones at Pitman Point were assigned to the “Dyer Bay dolomite beds” of the Cabot Head Member (Medina-Cataract Formation; Williams 1919, p.36). The remaining dolostone outcrops were all mapped as the undivided Lockport dolomite, although the “Fossil Hill Coral Horizon” was mentioned as being present on Cockburn Island (Williams 1919, p.61).

Williams (1936, 1937) later re-examined the strata on Cockburn Island. The outcrops of shaly dolostone of the Dyer Bay Formation on the northern shore of the island were again described. Green calcareous shale and dolostone, which are exposed south of the Dyer Bay dolostone, were assigned to the Wingfield shale (Williams 1919, p.16). The dolostones of the Lockport Formation were also briefly described again.

Kelley (1949), in an unpublished MSc thesis, examined the geology of Cockburn Island. Using nomenclature developed in northern Michigan (Chart A, back pocket), the strata of Cockburn Island was correlated to the Medinan and Niagaran series of Drummond Island, Michigan. The correlation was based primarily on faunal evidence, supported by insoluble residue and microscopic analyses.

The most recent investigations on Cockburn Island were undertaken by B.A. Liberty, who first examined the Paleozoic rocks during 1954 to 1957 (Liberty 1957). A coloured version of the map, at a 1 inch to 1 mile scale, was subsequently released (Liberty 1972). The stratigraphic nomenclature used by Liberty on Cockburn Island followed the scheme established earlier (Liberty 1966, 1968; Liberty and Bolton 1971) for Manitoulin Island and the Bruce Peninsula (Chart A, back pocket).

PRESENT GEOLOGICAL STUDY

Recent revisions to the geological maps of Manitoulin Island (Johnson and Telford 1985a-f) indicated the need to re-examine the Paleozoic rocks on Cockburn Island. The OGS field party of the author and assistants examined the bedrock geology during July and August of 1985. The field mapping was controlled by using airphotos, at a scale of 1:10 000, supplemented by topographic maps at a scale of 1:50 000. Outcrops were reached primarily by foot traverses using pace and compass to maintain geographical control. Detailed lithological descriptions were recorded, including data on rock type; bedding thickness and lateral variability; grain or crystal size; colour; fossil content; mineralization; and any other pertinent information. The location of each outcrop examined was recorded directly onto an overlay on the airphoto. This data was then transferred to a base map (scale 1:50 000) prepared by the Cartography Section, Surveys and Mapping Branch, Ministry of Natural Resources. This preliminary geological map (Figure 3) was then subsequently published (Wolf 1986: Map P.2987, back pocket of this report). In addition, a preliminary discussion of the geology of Cockburn Island was presented by Wolf (1985).

The Paleozoic carbonates in this region could be a potential source for aggregate, cement and flux for the steel industry. On nearby Manitoulin Island, Lafarge Canada Inc. ship high-quality dolostone from its large quarry near Meldrum Bay to several different markets in southern Ontario and the United States. Samples collected during the bedrock mapping were submitted for geochemical analyses (Appendix 1) to provide a preliminary assessment of the quality of similar dolostone on Cockburn Island.

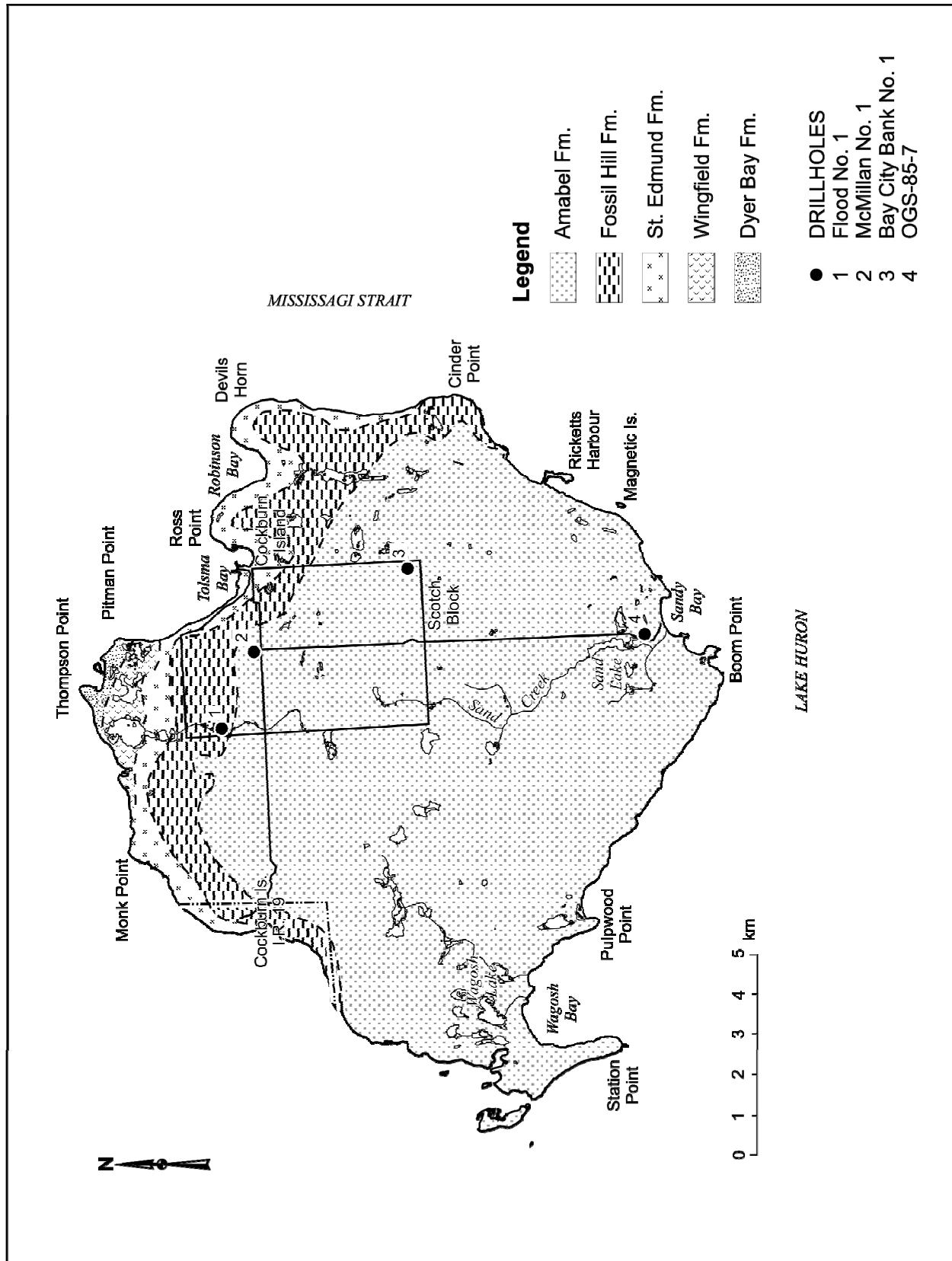


Figure 3. Geological map of Cockburn Island (after Wolf 1986).

DRILLING OPERATIONS

To supplement the surface data collected during the bedrock mapping, a drilling firm was contracted to drill a deep diamond-drill hole (OGS-85-7 Cockburn Island) at the southern end of the island (Figure 3). The site was chosen so as to provide the most complete Paleozoic section. In addition, it was hoped that the source of the magnetic anomaly underlying the southeast corner of the island (Figure 4) could be identified (Ontario Department of Mines and Geological Survey of Canada 1963). Also influencing the decision for site location were a minimum overburden thickness, constant water supply, and good road access.

The drilling operation was completed in just over a week of non-stop drilling, with an average drilling rate of 65 m per 24 hours. Surface casing (HW size) was cemented into bedrock at a depth of 34.5 m. Intermediate casing (NW size) was reamed down to 43 m and was left hanging. A continuous core (NQ size) was recovered from near the bedrock surface down to a depth of 521.0 m. A detailed log of the core is presented in Appendix 2. Only the cemented surface casing was not recovered at the end of the operations. At the completion of the drilling operations, the drill hole was plugged with cement.

Upon completion of the drilling, several wire-line geophysical tools were run down the open, water-filled drill hole. The wire-line logs used included gamma ray, focussed electric, neutron porosity (limestone matrix), bulk density and caliper. A copy of these logs is appended to this report (Figure 11, Appendix 3; Figures 12 to 14, back pocket). It should be noted that even though the drill hole was not cased below a depth of 43 m, the caliper log clearly shows that the drill hole walls remained stable throughout the drilling operation, even through the shale strata.

The entire core is stored at the Drill Core Library of the Ministry of Northern Development and Mines office in Sault Ste. Marie. Inquires regarding access to the core should be directed to the:

District Geologist, Sault Ste. Marie Office
Ministry of Northern Development and Mines
Suite 200, Roberta Bondar Place
70 Foster Drive
Sault Ste. Marie, Ontario, P6A 2B3
or call (705) 945-6931

Structural Geology

The rocks underlying Cockburn Island consist of Paleozoic sedimentary strata that were deposited on a relatively stable, Precambrian-aged, cratonic shelf. During an Early Proterozoic episode of compressional deformation (the Penokean Orogeny), the Huronian supracrustal wedge was overridden by an allochthonous terrane from the south (the Manitoulin Island Igneous Zone, Figure 5), the remainder of which now lies south of the Manitoulin Island Discontinuity (MID) (Zolnai, Price and Helmstaedt 1984). The MID, which trends eastward across the centre of Cockburn and Manitoulin islands (*see* Figure 5), delineates the southern boundary of the Huronian strata, and apparently had no influence on the subsequent deposition of Paleozoic strata.

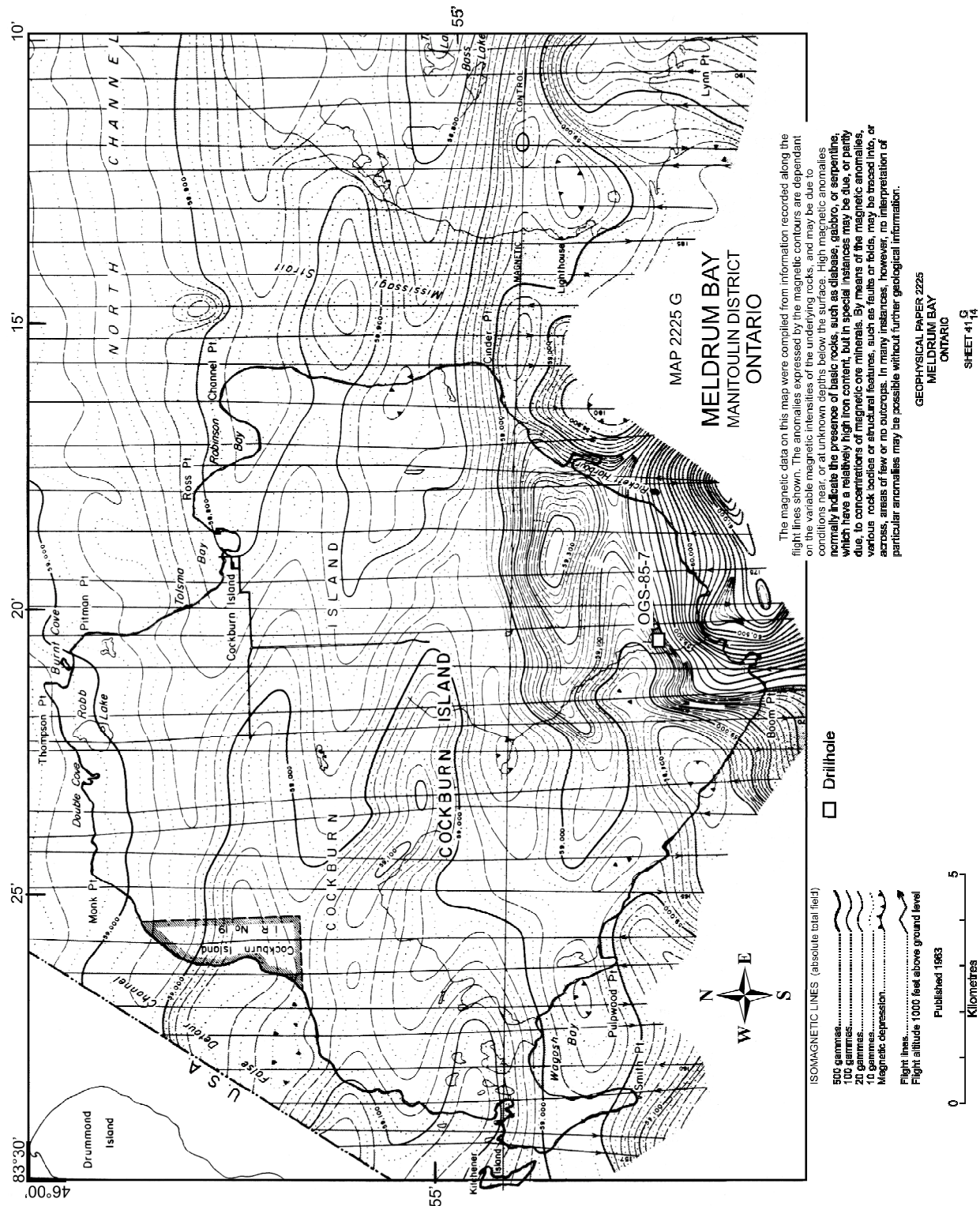


Figure 4. Aeromagnetic map of Cockburn Island showing the location of drill hole OGS-85-7 (after Ontario Department of Mines and Geological Survey of Canada 1963).

The Paleozoic rocks of Cockburn Island lie along the northern rim of the Michigan Basin, an oval-shaped intracratonic basin. Tectonic subsidence curves for the Michigan Basin indicate that the basin formed initially at about 1100 Ma by Middle Proterozoic (Keewenawan) fault-controlled, mechanical subsidence (Sleep and Sloss 1978). Subsequently, following the breakup of the Late Proterozoic supercontinent (about 580 to 500 Ma), anorogenic granites intruded into shallow crustal levels (de V. Klein and Hsui 1987). This led to thermal subsidence of the overlying crustal rock around 520 to 460 Ma (Nunn, Sleep and Moore 1984; Nunn 1986). The depression was then filled with a succession of Paleozoic sedimentary rocks, of which a maximum stratigraphic thickness of 4500 m is still preserved on the subsurface Precambrian rocks (Van Schmus, Card and Harrower 1975; O'Hara and Hinze 1980).

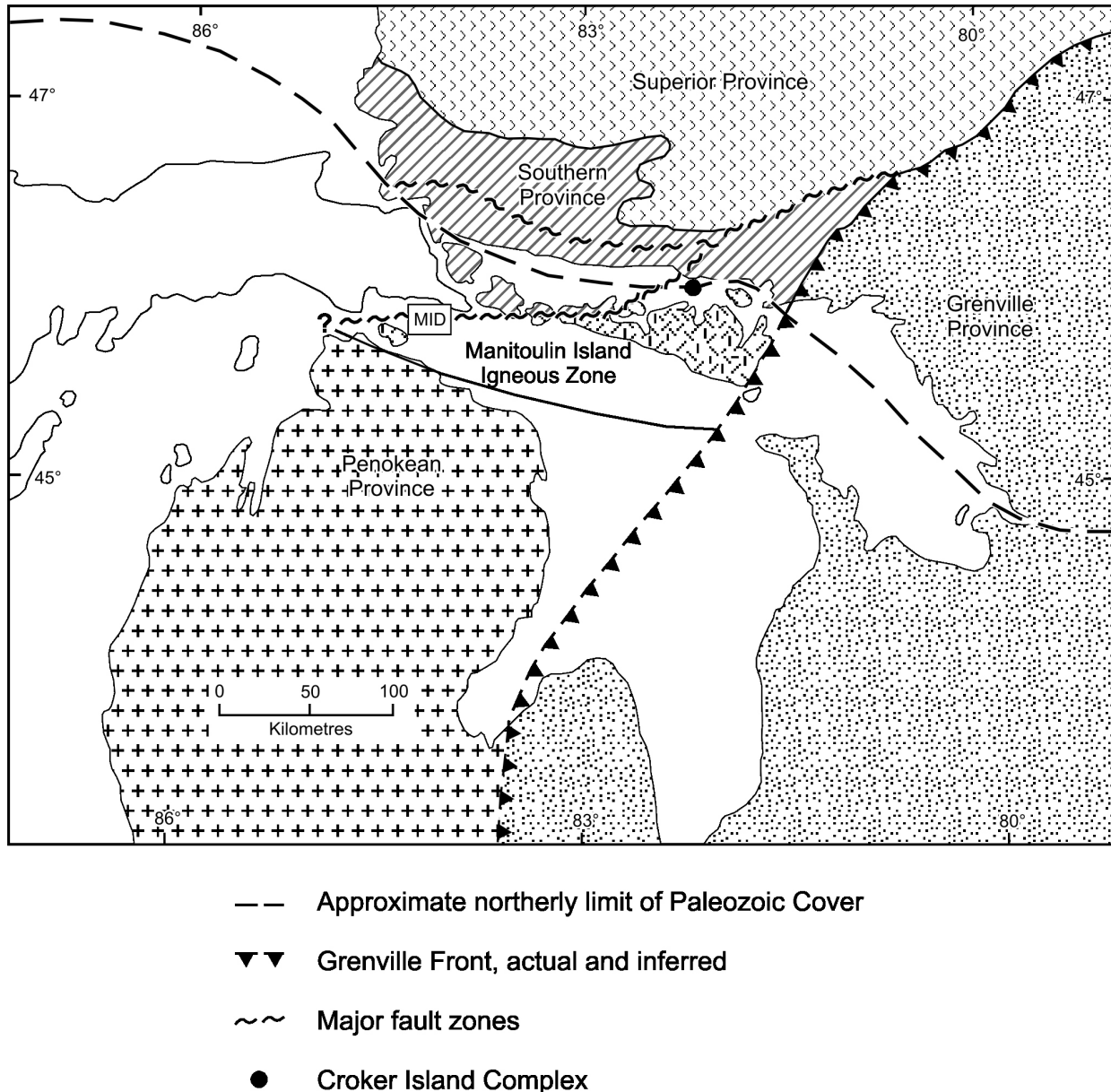


Figure 5. Map of the Lake Huron area showing the general geology of the exposed Precambrian rocks and the inferred geology of the subsurface Precambrian rocks (*after* Van Schmus, Card and Harrower 1975; O'Hara and Hinze 1980).

In northeastern North America several major orogenic episodes affected the deposition of Paleozoic sedimentary rocks. Of these the Late Ordovician Taconic Orogeny may have been the source of very fine-grained terrigenous material which suppressed calcium carbonate-producing organisms. This terrigenous material is now represented by the shales of the Blue Mountain Formation and the lower part of the Georgian Bay Formation. The late Paleozoic orogenic events (Acadian and Alleghanian) apparently did not have any major impact in the Cockburn Island area.

The Paleozoic strata underlying Cockburn Island are essentially flat lying, with only a shallow regional dip to the south into the Michigan Basin. Based on the distribution of bedrock exposures on Cockburn Island the dip of these strata is estimated to be less than 1° to the south.

Almost every exposure of bedrock on Cockburn Island exhibits joints and fractures. The jointing is best developed in exposures of the St. Edmund and Amabel formations. For both units the dominant joints trend at 140°, with a less significant trend at 050°; the joints are usually spaced about 1 m apart. On exposed bedding plane surfaces of the Amabel Formation, the joints and fractures are commonly enlarged and deepened by dissolution, in what appears to be the initial stages of karstification.

Stratigraphy

INTRODUCTION

The bedrock of Cockburn Island consists of Middle Silurian strata (*see* Figure 3), but unlike adjacent areas on Manitoulin and Drummond islands, the usually prominent Niagara Escarpment is greatly subdued. On Cockburn Island the bedrock is commonly overlain by thick glacial and post-glacial deposits, over 100 m thick in places. The scattered bedrock exposures are concentrated along the shoreline of the island. Additional stratigraphic information was obtained from old petroleum exploration wells (Sanford 1964) and drill hole OGS-85-7 Cockburn Island (OGS-85-7).

Only the formations overlying the Dyer Bay–Cabot Head Formation contact (Table 1) outcrop on Cockburn Island. The underlying Precambrian to Lower Silurian succession occurs only in the subsurface and the detailed description presented here is based on core retrieved from the OGS-85-7 drill hole (*see* Appendix 2). The geology of the stratigraphic succession will be discussed in ascending order, beginning with the Precambrian.

PRECAMBRIAN

On Cockburn Island, the Precambrian rocks only occur deep in the subsurface, underlying the Paleozoic strata. Along the northern shore of Lake Huron, however, a wide variety of lithologies are present in the Proterozoic Huronian rocks of the Southern Province (*see* Figure 5).

Under northern Lake Huron the subsurface geology of the Precambrian (*see* Figure 5) has been inferred primarily by aeromagnetic and gravity data (Ontario Department of Mines and Geological Survey of Canada 1963; O'Hara 1981), supplemented to a minor degree by diamond-drill holes (Van Schmus, Card and Harrower 1975).

Table 1. Lithologic units of Cockburn Island. (Thickness of units in parentheses.)

PHANEROZOIC	
CENOZOIC	
QUATERNARY	
PLEISTOCENE and RECENT (30 m)	
Glacial, glacio-lacustrine, and organic-rich deposits	
	<i>MAJOR UNCONFORMITY</i>
PALEOZOIC	
MIDDLE SILURIAN	
Amabel Formation (45.5 m)	
Dolostone	
Fossil Hill Formation (33.2 m)	
Dolostone, chert-rich, fossiliferous	
St. Edmund Formation (39.6)	
Dolostone, limestone	
Wingfield Formation (13.1 m)	
Shaly dolostone, shale	
Dyer Bay Formation (4.4 m)	
Dolostone	
LOWER SILURIAN	
Cabot Head Formation (20.2 m)	
Shale, gypsum, shaly dolostone	
Manitoulin Formation (15.9 m)	
Dolostone	
	<i>UNCONFORMITY</i>
UPPER ORDOVICIAN	
Georgian Bay Formation (58.8 m)	
Dolostone, shaly dolostone	
Blue Mountain Formation (66.95 m)	
Shale	
Lindsay Formation	
Collingwood Member (5.05 m)	
Calcareous, organic-rich shale	
MIDDLE ORDOVICIAN	
Undifferentiated limestone, shale, and dolostone (100.3 m)	
Glenwood Formation (8.5 m)	
Shale, shaly dolostone	
	<i>UNCONFORMITY</i>
St. Peter Formation* (12.1 m)	
Quartz arenite	
	<i>UNCONFORMITY</i>
LOWER ORDOVICIAN	
Prairie du Chien Formation* (30.95 m)	
Dolostone, sandy dolostone, conglomerate	
	<i>MAJOR UNCONFORMITY</i>
PRECAMBRIAN	
Magnetite-rich amphibolite (37.45 m)	

* These units are tentatively assigned to the indicated formations. A more precise determination awaits more detailed lithological, sedimentological and paleontological analysis.

NOTE: Only the MIDDLE SILURIAN formations are exposed on the surface of Cockburn Island.

The southernmost boundary of the Huronian rocks is considered to be represented by the east-trending Manitoulin Island Discontinuity, or MID (Zolnai, Price and Helmstaedt 1984). South of the MID the Manitoulin Island Igneous Zone (O'Hara and Hinze 1980), a complex of anorogenic plutons, emplaced about 1500 Ma ago, are characterized by strong positive magnetic anomalies (Van Schmus, Card and Harrower 1975). These plutons are part of a continent-wide suite of contemporaneous intrusions (Anderson 1983). The strong positive magnetic anomaly centred off the southeastern shore of Cockburn Island (*see* Figure 4; Ontario Department of Mines and Geological Survey of Canada 1963), near Magnetic Island, was the target of drill hole OGS-85-7.

Of the 4 drill holes previously completed on Cockburn Island (*see* Figure 3) only OGS-85-7 definitely penetrated the Precambrian. Beards (1967) and Van Schmus, Card and Harrower (1975), using data from Nwachukwu (1964), suggested that one of the drill holes had reached a Precambrian quartzite. Re-examination of the original driller's log by the author, and a comparison with the core of drill hole OGS-85-7, suggests that this "quartzite" may actually be a basal Paleozoic sandstone. Sanford (1964), in his examination of well cuttings from drill holes on Cockburn Island, indicated that the oldest rocks penetrated by the Flood No.1, McMillan No.1 and Bay City Bank No.1 drill holes are Lower to Middle Ordovician in age.

The 34.5 m of Precambrian rock in drill hole OGS-85-7 (between a depth of 483.5 and 521.0 m) can be subdivided into 2 units based on its lithological characteristics (*see* Appendix 2) and its signature on the wire-line geophysical logs (*see* Figures 11 to 14). The lower unit, 24 m thick, consists of a black, fine-crystalline, magnetite-rich amphibolite, which exhibits a faint banding in some intervals. Thin quartz veins are common throughout. This rock is considerably heavier than an equal length of core from the upper Precambrian unit.

The 13.5 m thick upper unit in the Precambrian interval of the core is characterized by a deep reddish-brown colour that obscures any potential small-scale features. The lower contact is gradational with the black lower unit, and contains a considerable number of quartz veins. The upper unit is considered to be an intensely altered zone of the underlying unit. The upper contact with the Paleozoic strata is very sharp and irregular.

Geochemical analyses of a sample of core from each of the 2 units (*see* Appendix 1) reveal that there are only minor variations between the 2 units for most elements. The unaltered rock only differs from the overlying unit in that it contains more calcium and manganese and less aluminum and carbon dioxide. The high iron levels (34 to 36%) reflect the presence of abundant magnetite. The focussed electric and neutron porosity logs provide the best signatures for separating the lower and upper units (*see* Figures 13 and 14).

Based on the core and wire-line logs of drill hole OGS-85-7, the Precambrian rocks in the subsurface of the southeastern part of Cockburn Island are considered to be a magnetite-rich amphibolite which has an intensely altered upper zone. The timing of this alteration is unclear. It may be a deep-weathered zone representing Precambrian weathering or it may have formed much later by diagenesis. The nature of the overlying unconformity and the lack of significant alteration in the overlying Paleozoic strata suggest that this zone of alteration may have formed before the Paleozoic sediments were deposited.

The magnetite-rich amphibolite is probably responsible for the strong positive magnetic anomaly which occurs at the southeastern corner of the island (Figure 4). The Crocker Island Complex (Figure 5), which displays a similar positive magnetic anomaly to that seen at Cockburn Island, is a roughly circular intrusion consisting of concentric zones, to the interior, of syenodiorite, diorite, and gabbro (Card 1965). The Precambrian rock recovered from drill hole OGS-85-7 thus may be a metamorphosed equivalent of the central gabbroic zone of the Crocker Island Complex.

PALEOZOIC

The Paleozoic strata that have been mapped at surface on Cockburn Island consist of several formations of Middle Silurian carbonates (*see* Table 1). In ascending order they are the Dyer Bay, Wingfield (which is not exposed), St. Edmund, Fossil Hill, and Amabel formations (Wolf 1986: Map P.2987, back pocket).

The subsurface stratigraphy of Cockburn Island has been ascertained from deep drill holes. Overlying the Precambrian surface is a complex sequence of clastic and carbonate sedimentary rocks ranging in age from Cambro-Ordovician to the Middle Silurian (Figure 6). These strata can be correlated lithologically with similar units in southern Ontario and northern Michigan.

Ordovician

A comprehensive litho- and biostratigraphic synthesis of the Ordovician strata in this region will not be included with this report. The following discussion briefly describes each formation and its lithological correlation to other regions.

PRAIRIE DU CHIEN FORMATION

The oldest Paleozoic formation in drill hole OGS-85-7 is provisionally assigned to the Lower Ordovician Prairie du Chien Formation. A complex sequence, 30.95 m thick, of interbedded dolostones, shales, sandstones, and conglomerates occurs between a depth of 452.6 and 483.55 m in the Cockburn Island drill hole (*see* Appendix 2). Dolostones and shales are more abundant in the upper part of the formation while sandstones and conglomerates dominate the lower portion (*see* Figure 6).

The base of the formation is characterised by a thick conglomerate consisting of pebbles and cobbles of Precambrian quartzites and mafic rocks, and clasts of apparently Paleozoic sedimentary rocks, including quartz sandstones and sandy dolostones. The clasts generally decrease in size (up to 20 cm in diameter) and abundance upwards. The conglomerate is generally clast supported with a poorly sorted, fine- to coarse-grained quartz sandstone matrix. Significant amounts of light green glauconite are present throughout the matrix. The lower contact of the formation marks a major erosional unconformity between the red, altered Precambrian amphibolite and the light brown conglomerates of the Lower Ordovician Prairie du Chien Formation. The contact with the Precambrian surface is very sharp and irregular and is delineated by a very thin band of dark grey-red residual material.

In the lower part of the formation, interbedded with and overlying the conglomerates, light green sandstones are common (*see* Appendix 2). These sandstones are well sorted, contain well-rounded quartz grains, range from fine to coarse grained, and are commonly cemented by dolomite. Variable amounts of light green glauconite are present in most of these sandstone intervals. Thin horizons of shale and shaly dolostone also occur in the sandstones, some of which are incorporated into the sandstones as rip-up clasts. No obvious burrows or fossils were observed.

The dolostones in the upper part of the formation range from a clean, light grey, fine-crystalline variety to intervals containing mud to sand-sized terrigenous material. The clastic components include significant amounts of coarse-grained, well-rounded quartz grains, commonly associated with light green glauconitic clays. Interbedded with the dolostones are thin-laminated, red and green, noncalcareous shales and thin beds of medium-grained, brown to light green quartz sandstones. Rarely, small white chert nodules are present in the clean dolostones.

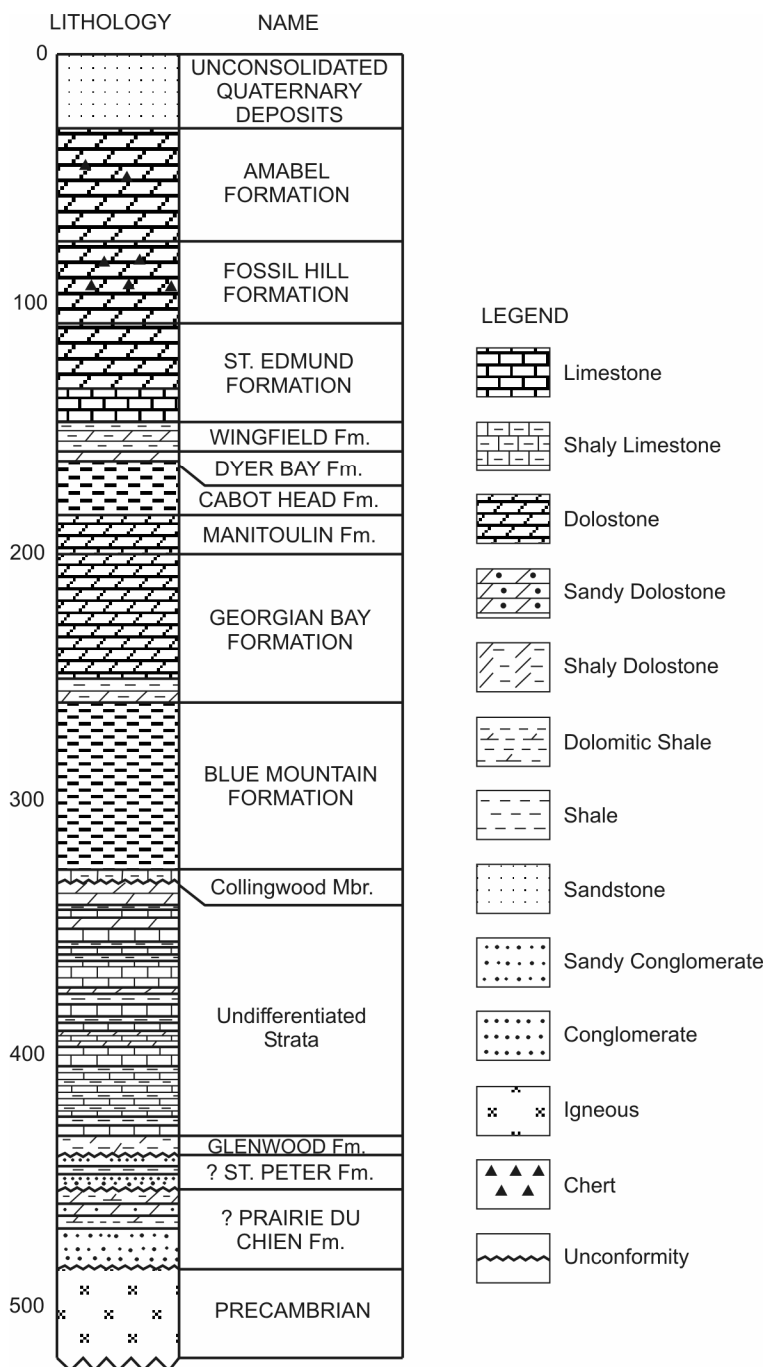


Figure 6. Summary of the geological log from drill hole OGS-85-7, Cockburn Island. See Appendix 2 for a detailed log of the hole.

Intervals in the upper part of the formation, composed predominantly of shale, are characterised by green-grey and red, thin-laminated, noncalcareous shale with thin horizons of shaly and sandy dolostone, and medium- to coarse-grained dolomitic quartz sandstone. Thin intervals of fine-grained, ripple cross-laminated sandstones occur rarely within the shales.

The geophysical wire-line logs of this interval (*see* Figures 11 to 14) clearly show the complex interbedding of these rock types. The gamma ray and neutron porosity logs clearly delineate the shale and carbonate components. The unconformity at the base of the formation is well defined on the focussed electric log.

The exact age of the strata assigned to the Prairie du Chien Formation is unknown as a result of the absence of both micro- and megafossils. An additional complication is the presence of an apparent disconformity at the top of the formation. Based on comparisons with deep drill hole geophysical and geological logs from northern Michigan (Bricker, Milstein and Reszka 1983), the Lower Ordovician Prairie du Chien Formation is the most similar unit to the basal unit in drill hole OGS-85-7. It may be possible, however, that these dolostones may also be correlative with the recently described Lower to Middle Ordovician Foster Formation of Michigan (Fisher and Barratt 1985). Also possible is that the strata of this interval is older, possibly even Cambrian in age. Examination of insoluble residues from some of the dolostone intervals did not yield any microfossils, which might have provided a more accurate age for these rocks. A similar sequence of dolostone and clastic strata was encountered at the base of the Paleozoic sequence in a drill hole on St. Joseph Island to the northwest (Johnson, Russell and Telford 1985).

The highly variable depositional environments of the formation are reflected in the complex interbedded nature of the lithologies. Initial high-energy conditions dominated by clastic sedimentation, were gradually replaced by carbonate-dominated processes operating under quieter conditions. The influence of the nearby Precambrian shoreline is seen in the continued presence of clastic sediments even in the upper part of the formation. The basal clastic sediments may be either fluvial or marine, or both, in origin, whereas the dolostones almost certainly are marine in origin. The presence of older sedimentary rocks in clasts of the basal conglomerates suggests that several cycles of sedimentation and erosion may have occurred before the final episode of sedimentation.

ST. PETER FORMATION

The dominantly fine-grained quartz sandstones that disconformably overlie the Prairie du Chien Formation are provisionally assigned to the St. Peter Formation. The sandstones of the 12.1 m thick St. Peter Formation, with thick intervals of quartz pebble conglomerates and rare, thin intervals of shale, occur between a depth of 440.5 and 452.6 m in drill hole OGS-85-7 (*see* Appendix 2).

The quartz pebble conglomerates, which occur predominantly in the lower part of the formation, consist primarily of quartz and quartzite pebbles in a matrix of coarse-grained, well-sorted quartz sandstone. At the base of the formation is a 40 cm thick intraformational conglomerate of fine-grained, muddy sandstone rip-up clasts, similar in lithology to some of the intervals of the underlying Prairie du Chien Formation.

The quartz sandstones assigned to the St. Peter Formation in the drill hole are characterized by very well-sorted, well-rounded quartz grains ranging in size from medium to coarse grained. The quartz grains are well cemented by either quartz overgrowths or by a dolomitic cement. The sandstones range in colour from light grey to light brown, with intervals of pink and light red, and of light green. The red colouration is probably the result of trace amounts of hematite, while the light green is probably caused

by glauconitic clays. Some of the sandstone intervals are moderately burrowed, although no discrete burrows could be distinguished.

The rare shale intervals within the St. Peter Formation are characterized by a grey, noncalcareous shale that is commonly intensely bioturbated. A shell of the brachiopod *Lingula* sp. was recovered from a 30 cm thick shale interval, 1.5 m below the top of the formation. Thin layers of dolomitic shale and sandy shale may also be present within the shale intervals.

The lower contact of the formation is disconformable, reflected by the sharp, irregular surface on the underlying dolostone. The abrupt change from a clean dolostone of the Prairie du Chien Formation to the intraformational conglomerates of the St. Peter Formation is a striking contrast in lithologies.

The wire-line geophysical logs through the St. Peter Formation reflect the dominant quartz sandstone lithology (see Figures 11 to 14). The abrupt lithological change at the lower contact is clearly revealed in the gamma ray log, primarily the result of the high shale content in the upper part of the Prairie du Chien Formation. The focussed electric log also shows the influence of the increased porosity in the sandstones of the St. Peter Formation. The upper contact of the formation is partially obscured by the presence of the 30 cm thick shale interval near the top of the formation.

The lack of any diagnostic fossils from the strata assigned to the St. Peter Formation makes it difficult to ascertain the precise age of this unit. Also, the presence of a disconformity at both the upper and lower contacts of the formation further complicates the age determination. Based on lithological comparisons to deep drill holes in central Michigan (Bricker, Milstein and Reszka 1983), these quartz sandstones are thus tentatively correlated with the quartz sandstones of the Middle Ordovician St. Peter Formation of Michigan. However, it may be possible that the strata assigned to the St. Peter Formation in the OGS-85-7 drill hole may be correlative with the Middle Ordovician Bruggers Formation of northern Michigan described by Fisher and Barratt (1985). A similar quartz sandstone interval was also intersected in the St. Joseph Island drill hole (Johnson, Russell and Telford 1985). Examination of insoluble residues from the rare dolomitic shale and shale intervals did not yield any microfossils, which might have provided further insight on the age of this unit.

The presence of extensive burrows and a brachiopod shell within the strata of the St. Peter Formation indicate that most of these sediments are marine in origin. The basal intraformational conglomerate apparently resulted from the reworking of the underlying dolostones of the Prairie du Chien Formation, whereas the quartz pebbles in the conglomerates were probably derived from nearby Precambrian sources. The clean, well-sorted, coarse-grained, quartz-rich sandstones reflect high-energy conditions in which quiescent intervals resulted in the deposition of shales or carbonates. Based upon comparisons with studies of surface exposures in Wisconsin (Mai and Dott 1985), the quartz sandstones are considered to have been deposited in a shallow marine shelf environment. Whether this strata underlying Cockburn Island was deposited on a tidal-, wave-, or storm-dominated shelf cannot be determined at this time.

GLENWOOD FORMATION

The complex succession of sandstones, shales, shaly dolostones and dolostones (see Figure 6) disconformably overlying the quartz sandstones of the St. Peter Formation is assigned to the Glenwood Formation. The 8.5 m thick interval occurs between a depth of 432.0 and 440.5 m in drill hole OGS-85-7 (see Appendix 2). The sandstones occur at the base of the formation and are overlain by the shales and dolostones.

The dominant lithology in the Glenwood Formation is a noncalcareous shale, which is commonly interbedded with other lithologies, including dolostone, sandy dolostone, shaly dolostone, sandstone, and sandy shale. Most intervals are dark grey in colour, with the sandier intervals light brown. Most of the shales and interbedded lithologies are extensively burrowed, the burrow fills commonly a different lithology than the surrounding rock. Disarticulated and abraded fossil fragments are common in some of the dolostones; some fossils have also been pyritized.

The disconformable lower contact of the formation occurs where dolomitic sandy shales abruptly overlie the clean quartz sandstones of the St. Peter Formation. This contact is very sharp and irregular.

The wire-line geophysical logs reflect the complex interbedded lithologies (*see* Figures 11 to 14). The lower contact is placed at the second (i.e., the upper) shale spike on the gamma ray log because the geological log of the core (*see* Appendix 2) reveals the presence of a shale bed in the upper St. Peter Formation, 1.5 m below the disconformity. Without a continuous sequence of core to examine, the base of the Glenwood Formation would probably have been set at the lowest shale spike on the gamma ray log. The other wire-line logs also reflect the rapid succession of lithologies, although the neutron porosity log suggests there is a gradual increase in carbonate content in the upper part of the formation.

The Glenwood Formation is Middle Ordovician in age and can be correlated by its lithology and stratigraphic position to a similar sequence of shale-dominated strata in deep drill holes across Michigan (Bricker, Milstein and Reszka 1983). The lithology and stratigraphic position of these strata in drill hole OGS-85-7 are similar to strata in the same position in the drill holes at Little Current and St. Joseph Island (Johnson, Russell and Telford 1985). Further south and east in Ontario the Glenwood Formation can be similarly correlated to the Shadow Lake Formation (Liberty 1969; Williams 1991), a dominantly terrigenous unit, which also occupies a similar stratigraphic position.

The Glenwood Formation represents the initial sediments deposited after a major regression at the end of the deposition of the St. Peter Formation. The lack of coarse-grained clastic rocks in the Glenwood Formation indicates either an absence of sources of such sediment or else the presence of very low energy depositional processes during the transgression. The presence of extensive burrows and fossil debris indicates these rocks were deposited in a marine environment, probably a shallow carbonate shelf. Rare, nonburrowed, shale intervals suggest that, at times, more restricted conditions may have prevailed. The influence of clastic sediments gradually decreased with time and carbonate sedimentation dominated in the upper part of the Glenwood Formation.

UNDIFFERENTIATED STRATA

A 100 m thick sequence of interbedded limestone, dolostone and shale (*see* Figure 6) occurs between a depth of 331.7 and 430.6 m in drill hole OGS-85-7 (*see* Appendix 2). The strata of this interval can be correlated to the Black River and Trenton groups of Michigan and to the Simcoe Group of south-central Ontario (Liberty 1969), but further subdivision into formations remains unresolved.

The dominant lithologies throughout this unit are alternating intervals of limestone and calcareous shale. Dolostone occurs sporadically throughout the sequence and is predominant at the top of the formation, forming a thick cap to the limestone and shale sequence. The light grey limestones range between 2 extremes in lithology, which also are the 2 most common varieties. At one end of the spectrum is a very fine-crystalline limestone, sometimes with a lithographic texture, and commonly containing scattered fossil debris. The second major type of limestone is a medium- to usually coarse-crystalline limestone, which may be bioclastic or even calcarenitic in places. Fossils are very abundant in the second type of limestone and are commonly fragmented and abraded. Interbedded with the limestones, and

comprising 30 to 50% of the sequence, are dark grey calcareous shales, commonly intensively burrowed. The limestone varieties and shales generally alternate every 20 to 50 cm, up to a maximum of 1.0 m. The upper and lower contacts between the limestones and shales range from sharp, erosional and burrowed to gradational. Nodular limestone intervals rarely occur in the sequence.

The dolostones are predominant in the upper part of the sequence and also form a thick cap to the limestone and shale. A porous, very coarse-crystalline dolostone in the uppermost part of the sequence contains 2 thin, 10 cm thick, intervals that are stained black, probably by hydrocarbons. Generally, the dolostones are medium brown, medium crystalline, and have sharp lower and upper contacts with the under and overlying strata, respectively.

The lower contact of this interbedded limestone and shale interval with the Glenwood Formation is apparently conformable and is placed at the base of the lowest limestone bed. Some thin interbeds of shaly dolostone occur just above the contact.

The wire-line geophysical logs of this interval (*see* Figures 11 to 14), especially the gamma ray log, suggest that the lithology referred to as a calcareous shale may not be a shale but a carbonate which has shale-like fissility. The low gamma ray and higher neutron porosity signatures suggest a high carbonate content throughout the sequence. The lower contact reflects the decrease in shale and increase in carbonate content at the top of the Glenwood Formation.

The stratigraphic position of these strata and approximate correlation to surface exposures north of Manitoulin Island suggest a Middle Ordovician age. Specific correlation on a formational level to adjacent regions proved to be very difficult because of the lithological dissimilarity of these strata to stratigraphically and temporally equivalent rocks in Michigan and Ontario. Only the nearby OGS drill holes at Little Current and St. Joseph Island (Johnson, Russell and Telford 1985) intersected a similar succession of limestones and shales. Correlation on a group scale indicate that these strata in northern Lake Huron are equivalent to the Black River and Trenton groups of Michigan (Hussey 1952) and to the Simcoe Group of south-central Ontario (Liberty 1969). The uppermost part of the sequence in drill hole OGS-85-7 is probably equivalent to the lower member of the Lindsay Formation (Russell and Telford 1983), as the overlying strata in the drill hole can be assigned to the Collingwood Member of the Lindsay Formation (Russell and Telford 1983).

The depositional environment throughout the time this interval of limestones, shales and dolostones was deposited appears to have fluctuated between quiet to energetic carbonate-producing conditions and quiet noncarbonate producing conditions. Post-depositional diagenesis included local dolomitization and migration of hydrocarbons into the dolostone. A shallow carbonate shelf depositional environment is envisioned, with a variety of processes active across the shelf producing the various types of limestone.

COLLINGWOOD MEMBER OF THE LINDSAY FORMATION

Disconformably overlying the dolostone cap of the undifferentiated Middle Ordovician limestones and shales is a 5.05 m thick interval of black, organic-rich, calcareous shale (*see* Figure 6) that is assigned to the Upper Ordovician Collingwood Member, Lindsay Formation, as defined by Russell and Telford (1983). This unit, between a depth of 326.65 and 331.7 m in drill hole OGS-85-7 (*see* Appendix 2), can be correlated to black shales of similar age in Michigan and Ontario.

The strata of the Collingwood Member in the drill hole core are characterized by a nonfissile, black, organic-rich, calcareous shale which exudes a strong petroliferous odour from freshly broken surfaces. However, by its strong effervescent reaction to dilute hydrochloric acid, these shales could easily be

classified as limestones. The strata of the Collingwood Member (in the drill hole) yielded several fossils, including cephalopods, conularids, trilobites (including *Triarthrus* sp.) and graptolites (including *Climacograptus* sp.).

The lower contact of the member with the underlying dolostone is very sharp and erosional with a thin layer resembling a residue of insoluble material, which suggests that this contact is disconformable.

The wire-line geophysical signatures through the Collingwood Member (*see* Figures 11 to 14) were affected by the high organic content of the shales. This is especially reflected by the elevated gamma ray log values. The high carbonate content of these strata significantly increased the response on the neutron porosity log (*see* Figure 14). The lower contact of the member is indicated by the sharp changes in the log signatures across the contact.

The distinctive black shale lithology of this unit provides an excellent horizon for regional correlation across Ontario and into Michigan. Russell and Telford (1983) describe the equivalent strata in southern Ontario. Churcher et al. (1991) examines the distribution, stratigraphy and resource potential of the Collingwood Member in southwestern Ontario.

In an examination of the organic geochemistry of the Collingwood Member across Ontario, Macauley (1987) found that the black shales in drill hole OGS-85-7 had lower Total Organic Carbon values, lower Hydrogen Indices, and higher Production Indices than anticipated from regional trends (Macauley 1987, p.14). This was attributed to an increased maturation level of these strata in the Cockburn Island area relative to the maturation levels of these strata in the adjacent areas. The discrepancy between the thickness of the Collingwood Member in drill hole OGS-85-7 reported by Macauley (1987) of 6.83 m and that reported in this study of 5.05 m is attributed to the inclusion of the overlying organic-rich, noncalcareous shales in the Collingwood Member by Macauley (1987, p.13). These noncalcareous shales have been assigned to the overlying Blue Mountain Formation in this report.

The black shale of the Collingwood Member reflects a drastic change in the depositional environment, from an open, shallow water shelf, oxygen-rich marine setting to an apparently deeper, oxygen-poor, marine basin. The high organic content of the shales probably resulted from high organic production and/or the restriction of biodegrading organisms from at least part of the water column. The fossil material recovered from these shales was either carried in by currents or more likely settled down from near surface, oxygenated waters.

BLUE MOUNTAIN FORMATION

The 67 m of grey shales of the Upper Ordovician Blue Mountain Formation (Russell and Telford 1983) overlie the black shales of the Collingwood Member and occur between a depth of 259.7 and 326.65 m in drill hole OGS-85-7 (*see* Appendix 2). The medium to dark grey, noncalcareous shales (*see* Figure 6) are very uniform throughout the formation. A few, very thin laminae of silt or thin mud-flake conglomerates occur scattered throughout the shales. In the basal 0.5 m of the unit the colour gradually lightens upward from black to grey. Very thin and sporadic laminae of shaly dolostone occur in the uppermost 2 m of the formation. A few graptolites were recovered from around the 300 m depth.

The lower contact with the Collingwood Member is sharply delineated when using dilute hydrochloric acid to test for calcium carbonate. The change from the calcareous black shale to the dark grey, noncalcareous shale is very sharp and planar. The absence of any sedimentary or bedding features at this contact suggests that either the contact represents a conformable surface or else the calcium carbonate edge represents a diagenetic feature. The lack of any obvious sedimentological break above or

below the abrupt decrease in carbonate-rich shale reinforces the interpretation of this as the lower contact of the Blue Mountain Formation.

The wire-line geophysical logs strongly reflect the continuous shale sequence, with the gamma ray signature displaying especially high values. The lower contact of the formation is very noticeable on the neutron porosity log that shows the abrupt change in calcium carbonate content at the base of the Blue Mountain Formation.

The sparsely fossiliferous Blue Mountain Formation contains graptolites of Upper Ordovician age and is bracketed by fossiliferous Upper Ordovician strata. The shales can be correlated to the lithologically similar Blue Mountain Formation in southern Ontario (Russell and Telford 1983) and the Utica Shale in Michigan (Hussey 1952).

The oxygen-poor conditions that had prevailed during the deposition of the Collingwood Member apparently changed to slightly more oxygenated waters during the deposition of the Blue Mountain Formation. However, the massive influx of very fine-grained clastic material from the developing Taconic Orogeny, the ancestral Appalachian Mountains to the east, suppressed carbonate production.

GEORGIAN BAY FORMATION

The 59 m thick Upper Ordovician Georgian Bay Formation in drill hole OGS-85-7 consists primarily of dolostone with some thin shale intervals near the base (*see* Figure 6). The formation occurs between a depth of 200.9 and 259.7 m in the drill hole (*see* Appendix 2). The dolostones encountered in this drill hole are quite different from the limestones which usually occur in this formation in southern Ontario (Liberty 1969).

The dolostones of the Georgian Bay Formation are medium grey in colour, range from fine to medium crystalline and commonly contain abundant burrows, fossils and fossil debris. A rich and diverse fauna includes brachiopods, bryozoans, gastropods and corals. Some of the dolostones contain vugs, many of which are lined or filled with dolomite crystals. The interbedded shales occur only in the lowest 10 m of the formation.

The lower contact of the Georgian Bay Formation with the shales of the Blue Mountain Formation is placed at the base of the lowermost dolostone bed. The contact itself is sharp and planar, and displays no erosional features.

The geophysical wire-line logs, especially the gamma ray, focussed electric and neutron porosity logs, reflect the gradual upward shift to carbonates in the lowermost Georgian Bay Formation (*see* Figures 11 to 14). The lower contact is placed at the beginning of this gradual change.

The fossils observed in the core of the Georgian Bay Formation indicate an Upper Ordovician age for the dolostones. The presence of dolostones in this formation in the Cockburn Island drill hole is a major change in lithology compared to southern Ontario, where the Georgian Bay Formation is an interbedded limestone (minor dolostone and sandstone/siltstone) and shale (Liberty 1969). Even so, these strata can be correlated with the Georgian Bay and Queenston formations in southern Ontario (Liberty 1969) and to Upper Ordovician strata in Michigan (Hussey 1952).

The presence of a diverse marine fauna indicates that these carbonates were deposited in open shallow marine waters beyond the influence of prodeltaic processes of the Queenston Delta, a thick clastic wedge derived from the mountains of the Taconic Orogeny to the east. The subsequent dolomitization of

these strata has obscured some of the finer sedimentary structures but most large fossils are still well preserved.

Silurian

Two separate stratigraphic classifications for the Silurian System have developed over the years (Table 2), one for North America and one for Europe. North American geologists have primarily used a three-fold subdivision for the Silurian, based upon the New York succession (Fisher 1960). The subdivisions were based on predominantly carbonate formations, some of which contained diagnostic shelly faunas and some which did not. The European classification has developed into a four-fold subdivision based primarily on graptolite-bearing shales and carbonates (Holland 1985).

The limitations and drawbacks of the North American classification were discussed by Berry and Boucot (1970), who recommended that “the New York terminology be restricted to that area in which the units can be physically traced on a lithological basis” (Berry and Boucot 1970, p.15). Furthermore, it was recommended that the New York succession should no longer be used as a standard for correlation (Berry and Boucot 1970, p.16). In place of the New York standard Berry and Boucot (1970, p.14-15) suggested that the European classification be applied to North American strata because the graptolite and shelly faunas of the United Kingdom, Scandinavia and Czechoslovakia can be compared directly to similar North American faunas. The European classification for the Silurian has been adopted by the Decade of North American Geology (DNAG) and has been applied to the Silurian strata of Manitoulin Island (M.E. Johnson 1981).

The Ontario Geological Survey used the New York (North American) standard (*see* Table 2) during its geological mapping of Manitoulin Island (Johnson and Telford 1985a-f) following historical practice (Williams 1919; Liberty 1972) and because of its relatively close proximity to the New York standard section. This report continues the OGS practise of using the New York standard but supplements it, where possible, by correlation to the European classification.

The stratigraphic nomenclature of the Silurian rocks in the northern Lake Huron area has had a complex history (*see* Chart A, back pocket). Among the many geologists who have studied the rocks in this region, several were prominent in their influence upon subsequent workers. The first to subdivide the Niagara Limestone, as used by the initial explorers (Bigsby 1821, 1824; Murray 1849; Logan 1863; Bell 1870), was Williams (1919), who based his subdivisions primarily on natural cliff exposures on the Bruce Peninsula. In a subsequent study of Manitoulin Island (Williams 1936, 1937) this classification was further refined (*see* Chart A, back pocket). The subdivision of the Lockport Formation by Bolton (1953, 1957) basically completed the nomenclatural classification for the Manitoulin Island area, although several variations of this scheme have been proposed (Liberty 1966, 1968; M.E. Johnson 1981) (*see* Chart A, back pocket).

A different stratigraphic classification has been proposed for the Silurian strata of northern Michigan. Based primarily on the early work of E.H. Ehlers, the terminology was formalized in the guidebook of the Michigan Basin Geological Society’s Annual Fieldtrip in 1957 (Ehlers and Kesling 1957). The criteria for these subdivisions was presented in a posthumous publication of Ehlers’ early work, which was edited by R.V. Kesling (Ehlers 1973). The nomenclature, as it is used today by the Michigan Geological Survey, was finalized with the further subdivision of the Engadine Dolostone (Johnson et al. 1979) (*see* Chart A, back pocket).

Table 2. Comparison between the North American and European classifications of the Silurian System (*after* Fisher 1960; Holland 1985).

NORTH AMERICAN STANDARD (after FISHER 1960)		EURPOEAN STANDARD (after HOLLAND 1985)			
	SERIES		SERIES	STAGES	
UPPER SILURIAN	Cayugan	UPPER SILURIAN	Pridolian	Not yet subdivided	
			Ludlowian	Ludfordian	
				Gorstian	
		MIDDLE SILURIAN	Niagaran	LOWER SILURIAN	Wenlockian
LOWER SILURIAN	Alexandrian	Llandoveryian	C ₆		
					C ₅
				C ₄	
				C ₂₋₃	
			C ₁	Aeronian	
			B ₃		
			B ₂		
			B ₁	Rhuddanian	
			A ₄		
			A ₃		
A ₂					

In the recent examination of the bedrock of Manitoulin Island, the Ontario Geological Survey initially used the nomenclature proposed by Liberty (1966, 1968), as it was based primarily upon lithological criteria (M.D. Johnson 1979, 1980, 1981). The detailed geological and geochemical data collected from both surface and subsurface samples clearly revealed that a modification of Liberty's

(1966, 1968) classification was necessary. The classification proposed by Johnson and Telford (1985a-f) (*see* Chart A, back pocket) resembles that which had been developed by Bolton (1953, 1957) with only some minor changes in re-defining some of the formational contacts (Johnson and Telford 1985a-f).

On Cockburn Island the exposed strata is restricted to the Middle Silurian formations (*see* Table 1), whereas the Lower Silurian units occur only in the subsurface.

MANITOULIN FORMATION

The oldest Silurian strata underlying Cockburn Island, the 15 m of dolostones assigned to the Manitoulin Formation, occur at a depth of 185.0 to 200.9 m in drill hole OGS-85-7 (*see* Appendix 2). The lowermost 2 m of the Manitoulin Formation consists of noncalcareous shale and shaly dolostone (*see* Figure 6), which overlie the Ordovician–Silurian contact at the base of the Manitoulin Formation.

The dolostones of the Manitoulin Formation are similar to those of the underlying Georgian Bay Formation. They are characterized by light grey to light brown, fine- to medium-crystalline dolostones which contain scattered fossil fragments, including crinoidal debris, corals, brachiopods and stromatoporoids. Thin interbeds of shale and shaly dolostone occur throughout the formation. The basal 2 m consists of dark grey, noncalcareous shale with thin, fine-crystalline dolostone interbeds.

The lower contact of the formation was not recovered in the Cockburn Island drill hole because of grinding of the core at that horizon. However, based on the Kagawong West Quarry exposure on Manitoulin Island (Johnson and Telford 1985a), this contact is assumed to be sharp and erosional.

The contact between the Manitoulin and Georgian Bay formations is also the boundary between the Ordovician and Silurian Systems. Conodont studies (Barnes, Telford and Tarrant 1978) on Manitoulin Island and the Bruce Peninsula suggest that the latest Ordovician stage is missing from the Paleozoic succession in the northern Lake Huron area. The regression at the end of the Ordovician was caused by a major glacial episode that resulted in a significant lowering of sea level around the globe (Dennison 1976). The initial Silurian sediments, which consist of shale both in the Cockburn Island drill hole and at the Kagawong West Quarry, suggest that the transgressing marine waters were initially low in energy and probably did not erode much of the weathered Ordovician sediments, but instead reworked the sediments into the basal Silurian shale.

The Manitoulin Formation contains Early Silurian (early Llandoveryan: Berry and Boucot 1970) fossils immediately above the lower contact and throughout the formation. On Manitoulin Island numerous bioherms (small reef-like structures) have been identified (Fay and Copper 1982), but the Cockburn Island drill hole did not intersect any significant fossil accumulations that would indicate the presence of a bioherm.

The wire-line geophysical logs through the Manitoulin Formation interval (*see* Figures 11 to 14) clearly identify the basal shale unit and the overlying succession of nearly shale-free dolostone.

The depositional environment of the Manitoulin Formation was similar to that of the underlying Georgian Bay Formation except that the enclosed fauna reflect the evolutionary changes that resulted from the Late Ordovician glacial episode. The sediments of the Manitoulin Formation were probably deposited on a shallow marine shelf with patch reef-like accumulations of organisms scattered across the shelf.

CABOT HEAD FORMATION

Conformably overlying the dolostones of the Manitoulin Formation are the 20 m of shales, dolostones and evaporites (*see* Figure 6) of the Cabot Head Formation. This formation was intersected at a depth of 164.8 to 185.0 m in the OGS-85-7 drill hole (*see* Appendix 2).

The Cabot Head Formation consists of a complex sequence of interbedded shales, dolostones and evaporites. The shales are either brick red or green in colour and are commonly laminated. The dolostones occur as thin, light grey to light brown, fine-crystalline interbeds, commonly associated with numerous shale partings. The evaporites occur either as horizontal layers of white, fibrous gypsum, up to 2 cm thick, or as mottled gypsum and anhydrite replacing dolostone. In addition, thin fractures intersected by the drill hole in this formation are commonly filled with gypsum.

The lower contact of the Cabot Head Formation, although sharp, is considered to be conformable. The contact is placed at the base of the lowest shale bed.

The Cabot Head Formation contains very few fossils and none were observed in the Cockburn Island drill hole. Based on the sparse fauna recovered on nearby Manitoulin Island, and its stratigraphic position, the Cabot Head Formation is considered to be Early Silurian in age (early Llandoveryan: Berry and Boucot 1970).

The shales of the Cabot Head Formation are easily correlated across Ontario and into Michigan. The evaporites observed in the Cockburn Island drill hole are the eastern most occurrence within this formation, known to date. A similar sequence of shale, dolostone and evaporites has been reported from drill holes in northern Michigan (Lilienthal 1978).

The wire-line geophysical logs (*see* Figures 11 to 14) reflect the complex lithologies comprising the Cabot Head Formation intersected in the drill hole. On the gamma ray log the shale content is clearly visible, although the influence of the carbonates and evaporites produced a jagged signature. A similar jagged signature is present in the other logs.

The occurrence of shale in the Cabot Head Formation indicates there was a major change in the depositional environment from the open marine shelf of the Manitoulin Formation to one where carbonate production virtually ceased with the influx of terrigenous material and the initiation of partially hypersaline conditions.

DYER BAY FORMATION

The 4.4 m of dolostones (*see* Figure 6) of the Dyer Bay Formation, which occurs at a depth of 160.4 to 164.8 m in the OGS-85-7 drill hole (*see* Appendix 2), are also the oldest Silurian rocks exposed at the surface on Cockburn Island.

The Dyer Bay Formation is exposed in scattered bedding plane outcrops along the northern shoreline of Cockburn Island between Robb Lake (UTM co-ordinates 316650E 5095750N) and a position just south of Pitman's Point (UTM co-ordinates 318800E 5094900N) (*see* Figure 3). These horizontal bedding plane exposures are generally confined to the beach and are often obscured by extensive beach cobble accumulations. These beach berms are dominated by dolostone cobbles probably originating from underwater exposures of the Dyer Bay Formation just offshore. A dense, cedar-dominated forest extends inland from the shoreline and covers any further exposures of these dolostones.

The Dyer Bay Formation, where it is exposed, consists of blue-grey to grey-brown, thin-bedded, medium-crystalline dolostones, which weather to a light brown colour. Internal and external molds of the pentamerid brachiopod *Virgiana* sp. are abundant in both the surface exposures and in the OGS-85-7 drill hole at a depth of 161.0 to 163.0 m. A coral-bryozoan dominated fauna in the Dyer Bay Formation, described from exposures on Manitoulin Island (Bolton 1957, 1968), was not observed in the surface exposures or in the core from the drill hole.

The bedrock sample analyzed for major elements (*see* Appendix 1) yielded results that were similar to those obtained from samples of the Dyer Bay Formation on Manitoulin Island (Johnson and Telford 1981a; Johnson 1983).

The lower contact of the Dyer Bay Formation is not exposed in any of the surface exposures on Cockburn Island. In the Cockburn Island drill hole the conformable contact is placed at the base of the lowest occurring dolostone overlying the green shales of the Cabot Head Formation.

The brachiopod *Virgiana* sp. provides an excellent opportunity to precisely date the dolostones of the Dyer Bay Formation. This widely distributed brachiopod is confined to the narrow time interval between the late Early Llandovery and the end of the Middle Llandovery (Berry and Boucot 1970; Boucot 1972). A conodont fauna recovered from the Dyer Bay Formation on the Bruce Peninsula (Barnes, Telford and Tarrant 1978) can be correlated to Middle Llandoveryan age rocks in North America. Correlation to other regions of North America with the brachiopod *Virgiana* sp. indicates that the Dyer Bay Formation is early Middle Silurian in age (Bolton 1953, 1957).

The wire-line geophysical logs through the Dyer Bay Formation (*see* Figures 11 to 14) clearly reveal the influence of the carbonates on all of the signatures. Bracketed by shales below and above, the thin dolostone interval stands out clearly.

The presence of *Virgiana* sp. in such abundance in the dolostones of the Dyer Bay Formation suggests that a stable, shallow water, carbonate shelf had developed for a short time. The sea was probably too deep to support a coral-algal community but it was shallow enough for a brachiopod community. This community was either at or just below the fair-weather wave base (M.E. Johnson 1981).

WINGFIELD FORMATION

While the green shales (*see* Figure 6) of the Wingfield Formation are not exposed at the surface on Cockburn Island, an interval of 13.1 m was intersected at a depth of 147.3 to 160.4 m in the OGS-85-7 drill hole (*see* Appendix 2). The area on Cockburn Island underlain by the Wingfield Formation (Figure 3) consists predominantly of shallow lakes (like Robb Lake), large beaver ponds and swamps.

In drill hole OGS-85-7 the Wingfield Formation consists of light green shale and intensely burrowed shaly dolostone. Thin interbeds of grey-brown, fine-crystalline dolostone also occur throughout the formation. Between a depth of 150.5 and 157.0 m in the drill hole, white, fibrous gypsum occurs in thin interbeds, some up to 2 cm thick, along with mottled patches of light grey to white anhydrite which has replaced dolostone and shaly dolostone.

The lower contact of the green shales of the Wingfield Formation with the dolostones of the Dyer Bay Formation is very sharp, yet it is considered to be conformable. Elsewhere in southern Ontario this contact is more gradational, with interbedding of the dolostone and green shale (Bolton 1957).

The wire-line geophysical logs reflect the generally shale-rich character of the formation (*see* Figures 11 to 14), although the presence of the dolostone beds produce a slightly less elevated shale signature than the underlying shales of the Cabot Head Formation. The spike at the 150 m level on the neutron porosity log may reflect, in part, the evaporites which are present at that horizon in the drill hole.

The virtual absence of any diagnostic fossils in the strata of the Wingfield Formation makes it difficult to assign a precise age, as can be done with the underlying Dyer Bay Formation. However, based on its stratigraphic position and by its correlation to more fossiliferous units elsewhere in North America, an early Late Llandoveryan age was suggested by Berry and Boucot (1970). Bolton (1953, 1957) considered the Wingfield Formation to be of Middle Silurian age.

The presence of evaporites and shales in the Wingfield Formation indicates a return to hypersaline- and clastic-dominated environments after the brief interval of normal marine conditions during the deposition of the Dyer Bay Formation.

ST. EDMUND FORMATION

The dolostones assigned to the St. Edmund Formation (*see* Figure 6) are well exposed along the northern shoreline of Cockburn Island. In the OGS-85-7 drill hole 40 m of these dolostones was intersected at a depth of 107.7 to 147.3 m (*see* Appendix 2).

Surface exposures of the St. Edmund Formation range from small bedding plane exposures to shoreline bluffs up to 4 m high. Most exposures occur along the northern shoreline with only a few, poorly exposed outcrops discovered in the northwestern part of the island (*see* Figure 3).

The St. Edmund Formation consists of 2 varieties of dolostone and a microcrystalline limestone. The most abundant type of dolostone is pale grey in colour, weathering to white or cream, and is microcrystalline, producing a porcellaneous texture. In surface exposures it is commonly thin bedded (5 to 10 cm) with individual beds containing fine laminae. Alternating with this dolostone is a second variety which is medium brown in colour, weathering also to a medium brown, is medium bedded (10 to 25 cm), and is medium to coarse crystalline, commonly producing a sucrosic, or “sugary”, texture. The light grey, microcrystalline variety of dolostone is more abundant in the upper part of the formation, whereas the brown, medium- to coarse-crystalline variety is more common in the lower part of the formation. One outcrop in the northwestern part of the island consists of a coarse-crystalline dolostone that exhibits a striking vuggy texture, where the vugs are lined with dolomite and quartz crystals.

A light grey, microcrystalline limestone was observed along the northwestern shoreline of Cockburn Island (UTM co-ordinates 311950E 5093850N), along the western shoreline of Tolsma Bay (UTM co-ordinates 319000E 5093400N), and in 2 intervals near the base of the formation in drill hole OGS-85-7 (135.5 to 138.0 m and 142.5 to 145.0 m, Appendix 2). Displaying a lithographic texture, this medium- to light grey-weathering limestone forms 15 to 25 cm thick beds in surface exposures. Small colonial tabulate corals and stromatoporoids are scattered throughout the outcrops of this limestone and in the core of the drill hole.

The geochemical data of dolostones from some of the bedrock exposures (*see* Appendix 1) are similar to that reported for the same strata on Manitoulin Island (Johnson and Telford 1981a; Johnson 1983), except for the vuggy dolostone, which contains significantly higher levels of silica. The 3 samples of the microcrystalline limestone that were analyzed revealed it to be a very calcium-rich limestone with CaO values over 50% (*see* Appendix 1).

The lower contact of the St. Edmund Formation with the green shales and shaly dolostones of the Wingfield Formation is not exposed in any surface outcrops on Cockburn Island. In the Cockburn Island drill hole this contact, placed at the base of the lowest dolostone overlying the uppermost green shale or shaly dolostone, is sharp and is considered to be conformable.

The wire-line geophysical logs of the St. Edmund Formation (*see* Figures 11 to 14) reflect the shale-free, carbonate-rich character of this formation. The 2 limestone intervals at the base of the formation cause distinct, broad peaks in both the focussed electric and neutron porosity logs (*see* Figures 13 and 14). Also, the focussed electric log increases beyond the recording limit in the upper part of the formation.

The age assigned to the St. Edmund Formation is based upon a sparse fauna and its stratigraphic position. An early Late Llandoveryan age had been assigned to this formation by Berry and Boucot (1970), and was supported by M.E. Johnson (1981). Based on its stratigraphic position and its fauna, Bolton (1953, 1957) considered the St. Edmund Formation of Bruce Peninsula to be Middle Silurian in age.

The St. Edmund Formation was redefined by Johnson and Telford (1985a-f) when detailed mapping and subsurface studies on Manitoulin Island (Johnson and Telford 1981a, 1981b) indicated that the St. Edmund Member (Cabot Head Formation) and the overlying Mindemoya Formation of Liberty (1968, 1972; *see* Chart A, back pocket) constitute a single, mappable rock unit. The Cockburn Island drill hole confirms this revision, as it clearly reveals the interbedding of the 2 different dolostone varieties. Liberty (1968) had based his original definitions on the belief that the 2 different dolostone types were stratigraphically separate. The microcrystalline limestone interval in the St. Edmund Formation correlates well with the Fiborn Limestone Member of the Hendricks Dolomite (*see* Chart A, back pocket), which occurs to the west on Drummond Island, Michigan (Johnson and Sorensen 1978).

The depositional environment of the St. Edmund Formation was dominated by very quiet energy conditions as is reflected by the micritic muds observed in the limestones. Small colonies of corals and stromatoporoids developed but the presence of the mud inhibited their widespread growth. The variety of dolostone types probably reflects varying grades of diagenesis of these micritic limestones; there is a progression from the porcellaneous dolostone, to the medium-crystalline variety, to finally the vuggy dolostone, which exhibits the most complex sequence of diagenesis. Alternatively, the dolostone varieties may represent variations in grain size of the original limestones. Detailed petrographic studies are needed to clarify this issue.

FOSSIL HILL FORMATION

The chert-rich dolostones of the Fossil Hill Formation are well exposed across some parts of Cockburn Island (*see* Figure 3) often yielding rich, coral-dominated fossil collections. The formation occurs between a depth of 74.5 and 107.7 m in the Cockburn Island drill hole (*see* Appendix 2).

Bedrock exposures of the Fossil Hill Formation are common in the northeastern part of the island, east of the village of Cockburn Island (Tolsmaville on Map P.2987, back pocket) (*see* Figure 3). Scattered exposures were also identified across the northern part of the island and near the northwestern shoreline on Indian Reserve 19 (*see* Figure 3). Individual surface exposures usually did not exceed 2 m in thickness.

The Fossil Hill Formation consists of light brown to grey-brown, thin to medium (2 to 25 cm), irregularly bedded, fine- to coarse-crystalline, fossiliferous dolostone which weathers a light brown to cream colour. Most beds contain some chert, either a white, soft, chalk-like variety, or a light grey (or

rarely black), hard, flint-like variety. Almost all the fossils have been replaced by silica, so that upon weathering they stand out in relief. Several horizons within the formation are profusely fossiliferous, usually with numerous disarticulated and disoriented fragments. The most common fossils collected include pentamerid brachiopods, stromatoporoids and numerous species of tabulate and rugose corals. Other less common fossil types identified include gastropods, cephalopods and orthid brachiopods. Several, apparently persistent, coral-algal and brachiopod-rich horizons have been identified across the northern Lake Huron area in this formation (M.E. Johnson 1981).

Geochemical analyses of several bedrock samples from the Fossil Hill Formation (*see* Appendix 1) show a uniform trend in most elements throughout the formation. While only chert-free samples were selected, one silica-rich sample was inadvertently included. (Examination of the hand sample from which the analysis was done revealed the presence of what appears to be silicified stromatolite mats.) Comparisons with geochemical analyses of similar strata from Manitoulin Island (Johnson and Telford 1981a; Johnson 1983) indicate that the dolostones of the Fossil Hill Formation on Cockburn Island are similar to those on Manitoulin Island.

The informally named “False Mindemoya Bed” (Liberty 1968) is a 3 to 4 m thick interval of microcrystalline dolostone (similar in lithology to that of the underlying St. Edmund Formation) which occurs 5 m above the base of the Fossil Hill Formation. It was identified in several outcrops and occurs between a depth of 98.4 and 102.3 m in the OGS-85-7 drill hole (*see* Appendix 2).

The lower contact of the Fossil Hill Formation is exposed clearly at only one location on Cockburn Island. In the old quarry southeast of the village (UTM co-ordinates 321050E 5091200N) (*see* Figure 3), 3 m of very fine-crystalline dolostone of the St. Edmund Formation is overlain by 3 m of medium- to coarse-crystalline, fossiliferous, cherty dolostone of the Fossil Hill Formation. (It may be possible that this contact is the upper contact of the “False Mindemoya Bed”; however, based on the author’s mapping in the immediate area, it is more likely this is the contact between the St. Edmund and Fossil Hill formations.) In both the surface exposure and in the core of the Cockburn Island drill hole the lower contact of the Fossil Hill Formation is very sharp and irregular, suggesting the presence of a minor disconformity.

The wire-line geophysical logs of the Fossil Hill Formation (*see* Figures 11 to 14) reflect the totally shale-free nature of these dolostones. The chert-rich intervals decrease the otherwise highly elevated signature of the focussed electric log (*see* Figure 13).

The rich fossil content of the Fossil Hill Formation provides for a relatively precise age determination. Based on its brachiopod fauna (which includes *Pentamerus* sp. and *Pentameroides* sp.) a Late Llandoveryan age has been assigned to this formation (Berry and Boucot 1970; M.E. Johnson 1981). Bolton (1953, 1957) used the same fauna to assign a Middle Silurian age to these dolostones, by correlating the dolostones to equivalent strata in western New York.

Recently, M.E. Johnson and his associates (Johnson and Campbell 1980; M.E. Johnson 1981; Colville and Johnson 1982) have subdivided the Fossil Hill Formation in Ontario into 2 formations, by extending the Schoolcraft and Cordell Dolomites into Ontario from Michigan (*see* Chart A, back pocket). This subdivision appears to be based, in part, on the presence of fossil communities, which display evolutionary changes with time. However, both surface exposures and drill core samples from Cockburn Island (and Manitoulin Island) indicate that there is no significant lithological difference between these 2 suggested formations in Ontario. Thus the Fossil Hill Formation, as originally defined by Bolton (1953), was used in both this study and for the mapping on Manitoulin Island (Johnson and Telford 1985a-f).

The presence of apparently persistent coral-algal biostromes and brachiopod communities across North America and elsewhere (Johnson, Rong and Yang 1985), in units correlated with the Fossil Hill Formation, suggests that an extensive, shallow water, carbonate shelf existed across much of the North American craton at this time. While no large barrier-reef type accumulations developed in the northern Lake Huron area, coral-algal biostromes flourished several times throughout the time the sediments of the Fossil Hill Formation were deposited. When the water depth increased slightly, brachiopod-dominated communities were established.

AMABEL FORMATION

The Amabel Formation, the youngest Paleozoic strata exposed on Cockburn Island (and also the most widespread on the island), underlies nearly two-thirds of the island (*see* Figure 3). In the Cockburn Island drill hole, 45.5 m of this formation extends from the bedrock surface at a depth of 29.0 m down to a depth of 74.5 m (*see* Appendix 2).

Widespread exposures of the Amabel Formation occur along the eastern shoreline of the island. Additional exposures occur across the interior of the northern part of the island and for a short distance along the western shoreline (*see* Figure 3). South of the surface exposures, thick, unconsolidated Quaternary deposits, over 30 m thick in places, cover the bedrock surface. Bedrock exposures are commonly horizontal bedding plane surfaces, often dissected by solution-enlarged joints and fractures.

The Amabel Formation on Cockburn Island consists of white to blue-grey, thick-bedded to massive (40 cm to over 1 m thick), medium-crystalline dolostone, which weathers to a light or medium grey colour. Thin horizons contain a sparse fauna of pentamerid brachiopods. No chert was observed in any surface exposures, but rare chert nodules were encountered in the Cockburn Island drill hole (*see* Appendix 2). Stylolites, sometimes closely spaced, were observed in a few outcrops and in several intervals of core from the drill hole. Small, open vugs and large vugs filled with calcite, dolomite and quartz crystals were also observed in both surface exposures and in the core.

Geochemical analyses of several surface samples from the Amabel Formation (*see* Appendix 1) show a uniform range in the values of CaO and MgO. Other major element oxides, including SiO₂, Al₂O₃, and Fe₂O₃, appear to increase gradually upwards in the formation. These values are still well within the range of values obtained from analyses of dolostones from the Amabel Formation on Manitoulin Island (Johnson and Telford 1981a; Johnson 1983).

The lower contact of the Amabel Formation with the Fossil Hill Formation is sharp and irregular, based on the core of drill hole OGS-85-7. This lower contact is not exposed in any surface outcrop on Cockburn Island. While considered to be gradual and conformable in southern Ontario (Bolton 1953, 1957), on Cockburn Island this contact appears to represent a minor disconformity.

The wire-line geophysical logs of the Amabel Formation (*see* Figures 11 to 14) reflect its shale-free, carbonate lithology. On the focussed electric log (*see* Figure 13), below the casing level at a depth of 42 m, the chert in the dolostone reduces the signature. The other logs produced very uniform signatures throughout the formation. The lower contact of the Amabel Formation cannot be identified accurately on any of the geophysical logs and is based solely on the geological log. The bedrock surface, at a depth of 29.0 m, is indicated by the sharp decrease in the neutron porosity log (*see* Figure 14). The water table accounts for the sharp increase in the neutron porosity log at a depth of 8 m.

On Cockburn Island the Amabel Formation contains only a sparse brachiopod fauna. Based on this, and on correlation to adjacent regions by Berry and Boucot (1970), the Amabel Formation is assigned to

the Early Wenlockian. Bolton (1953, 1957) placed the Amabel Formation in the Middle Silurian because the formation can be directly correlated to the Middle Silurian Lockport Formation of western New York.

Detailed mapping on Manitoulin Island by Johnson and Telford (1985a-f) produced a fourfold subdivision of the Amabel Formation, based upon 4 major lithofacies. Only one of these facies, Facies III, has been identified on Cockburn Island. The Amabel Formation, in part, is equivalent to the Engadine Dolomite of Michigan and the Lockport Formation of Ontario and New York.

The depositional environment of the Amabel Formation appears to be similar in many ways to that of the underlying Fossil Hill Formation. However, extensive communities did not develop on the shallow water carbonate shelf, except for scattered brachiopod accumulations. Either the pervasive dolomitization obliterated the fossils, or else some other factor, maybe elevated salinities, inhibited the development of extensive communities.

QUATERNARY

While detailed mapping of the surficial deposits on Cockburn Island has not yet been done, the regional physiographic study of Chapman and Putnam (1984) provides some information, in addition to the author's observations. The central hill on Cockburn Island (Figure 7) may be composed of till, possibly of morainic origin. It is similar in geomorphology to a central topographic high on nearby St. Joseph Island (Karrow 1982). Well-developed bluffs, up to 30 m high, with associated terraces, extend around the hill. These appear to represent the later stages of glacial Lake Algonquin. Around the central hill on Cockburn Island, flat sand plains dominate, most likely shallow lacustrine and local beach deposits. Just west of the hill, several drumlins (*see* Figure 7) protrude through the sand plain (Chapman and Putnam 1984).

Around most of the island, parallel to the present day shoreline is a second 30 m high bluff, representing the former glacial Lake Nipissing shoreline (*see* Figure 7). The poorly drained area in the southwestern part of the island below these bluffs may be underlain by glaciolacustrine clays.

Deeply incised post-glacial streams dissect parts of the sand plain. Peat and other organic-rich deposits are located across the island. Several remnant beach ridges occur parallel to the present day shoreline. Record breaking high lake levels during 1985 resulted in much less shoreline exposures than would normally occur.

Economic Geology

There are currently no active quarries operating on Cockburn Island. A small abandoned quarry, located southeast of the village of Cockburn Island (*see* Figure 3), was worked for a short time at the turn of the century to supply stone for a sulphite-pulp mill in Sault Ste. Marie (Miller 1904; Goudge 1938). A narrow-gauge railway had transported stone from the quarry to a dock on Tolsma Bay.

Three petroleum exploration wells (Flood No.1, McMillan No.1 and Bay City Bank No.1) were drilled on Cockburn Island during 1936 and 1937 (*see* Figure 3). All 3 were thought to have penetrated into the Precambrian (*see* discussion in "Precambrian" section). All 3 wells were unsuccessful in locating commercial hydrocarbon deposits (Sanford 1964).

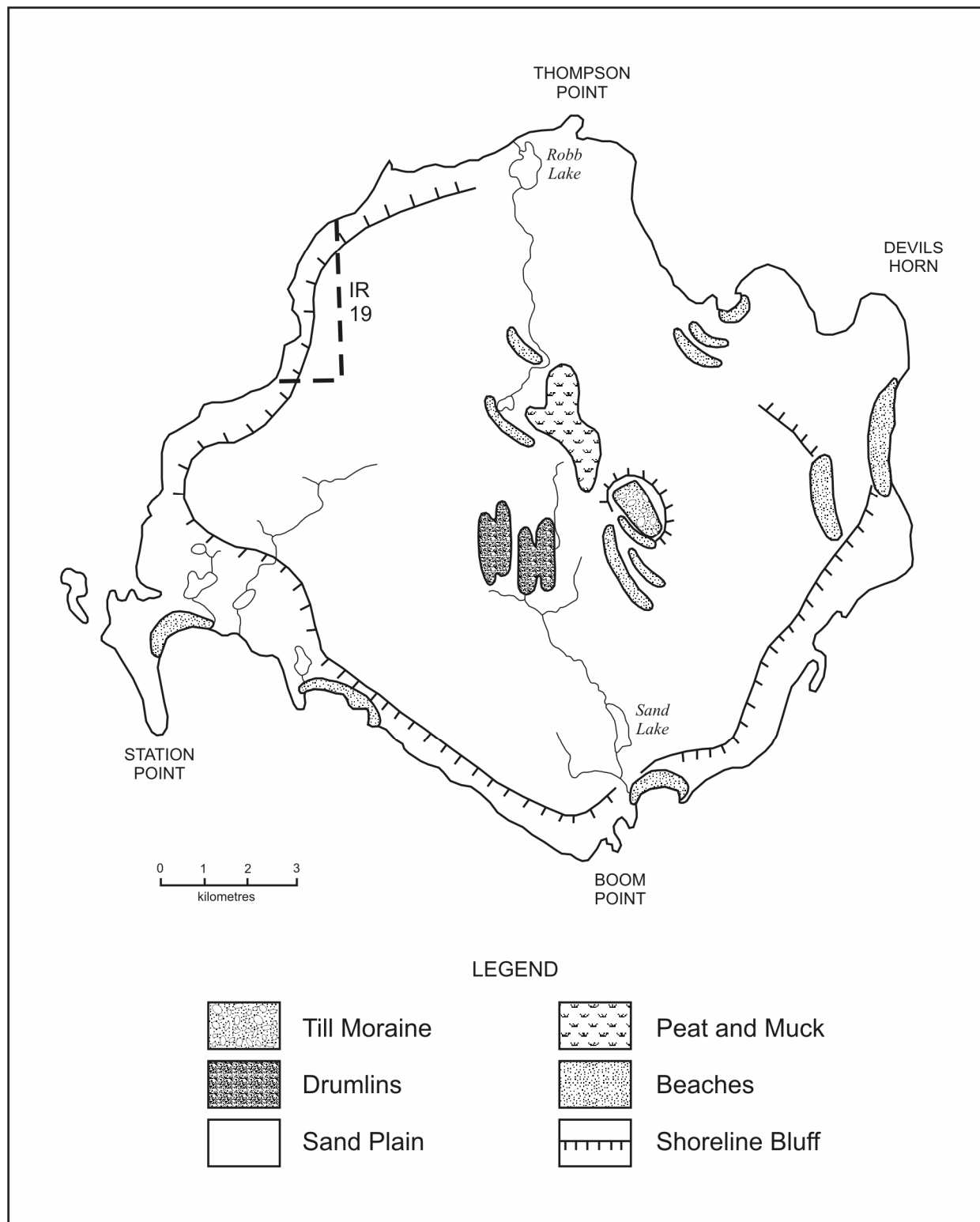


Figure 7. Quaternary geology of Cockburn Island (*after* Chapman and Putnam 1984).

Several small gravel and sand pits have been excavated by the Township of Cockburn Island to provide aggregate for the maintenance of the gravel roads on the island.

Lafarge Canada Inc. currently operates a large quarry near Meldrum Bay, on Manitoulin Island, which is located approximately 3 kilometres east of the eastern shoreline of Cockburn Island. Dolostone from the Amabel Formation, similar to that exposed on the eastern part of Cockburn Island, is crushed at the quarry and shipped by freighter to markets in Ontario and the United States.

Acknowledgements

The author was assisted in the field by George Flack, Glen Fernandes, and Dan Roumbanis. Accommodation on Cockburn Island was generously provided by the Ontario Paper Company.

The co-operation of the staff of the Township of Cockburn Island is gratefully acknowledged. The author would especially like to extend his appreciation to Rusty Gibbs of the Township of Cockburn Island, Jim Rayner and Lee Chapel of the Ontario Paper Company, and Bill Williams of Thessalon, Ontario, for their assistance while the OGS crew was on Cockburn Island.

Permission by the band chief to enter Cockburn Island Indian Reserve 19 is gratefully acknowledged.

The author also would like to thank Dr. P.G. Telford and M.D. Johnson, formerly of the Ontario Geological Survey, for their comments on regional geology and stratigraphy, and for reviewing this report. The report was also reviewed by Derek Armstrong, Frank Brunton and Dave Rowell of the Ontario Geological Survey.

References

- Anderson, J.L. 1983. Proterozoic anorogenic granite plutonism of North America; *in* Proterozoic Geology, Selected Papers from an International Proterozoic Symposium, Geological Society of America, Memoir 161, p.133-154.
- Barnes, C.R., Telford, P.G. and Tarrant, G.A. 1978. Ordovician and Silurian conodont biostratigraphy, Manitoulin Island and Bruce Peninsula; *in* Geology of the Manitoulin Area, Michigan Basin Geological Society, Special Paper 3, Guidebook to Annual Field Trip, p. 63-71.
- Beards, R.J. 1967. Guide to the subsurface Paleozoic stratigraphy of southern Ontario; Ontario Department of Energy and Resource Management, Paper 67-1, 19p.
- Bell, R. 1870. Report on the geology of the Grand Manitoulin, Cockburn, Drummond, and St. Joseph islands; Geological Survey of Canada, Report of Progress for 1866-1869, p.109-116.
- Berry, W.B.N. and Boucot, A.J. 1970. Correlation of the North American Silurian rocks; Geological Society of America, Special Paper 102, 289p.
- Bigsby, J.J. 1821. Geological and mineralogical observations on the northwest portion of Lake Huron; American Journal of Science, First Series, v.3, p.254-272.

- Bigsby, J.J. 1824. Notes on the geography and geology of Lake Huron; Transactions, Geological Society of London, 2nd Series, v.1, pt.2, p.175-208.
- Bolton, T.E. 1953. Silurian formations of the Niagara Escarpment in Ontario; Geological Survey of Canada, Paper 53-23, 19p.
- 1957. Silurian stratigraphy and paleontology of the Niagara Escarpment in Ontario; Geological Survey of Canada, Memoir 289, 145p.
- 1968. Silurian faunal assemblages, Manitoulin Island, Ontario; *in* The Geology of Manitoulin Island, Michigan Geological Society, Annual Field Trip Guidebook, p.38-49.
- Boucot, A.J. 1972. Correlation of the New York, Ontario, and northern Michigan Silurian by means of fossils, with the European standards; *in* Niagaran Stratigraphy: Hamilton, Ontario, Michigan Basin Geological Society, Annual Field Excursion Guidebook, p.66-67.
- Bricker, D.M., Milstein, R.L. and Reszka, C.R., Jr. 1983. Selected studies of Cambro-Ordovician sediments within the Michigan Basin; Michigan Geological Survey Division, Report of Investigations 26, 54p.
- Card, K.D. 1965. The Crocker Island Complex; Ontario Department of Mines, Geological Circular 14, 11p.
- Chapman, L.J. and Putnam, D.F. 1984. The physiography of southern Ontario (3rd Edition); Ontario Geological Survey, Special Volume 2, 270p., accompanied by Map 2715, scale 1:600 000.
- Churcher, P.L., Johnson, M.D., Telford, P.G. and Baker, J.F. 1991. Stratigraphy and oil shale resource potential of the Upper Ordovician Collingwood Member, Lindsay Formation, southwestern Ontario; Ontario Geological Survey, Open File Report 5817, 98p.
- Colville, V.R. and Johnson, M.E. 1982. Correlation of sea-level curves for the lower Silurian of the Bruce Peninsula and Lake Timiskaming District (Ontario); Canadian Journal of Earth Sciences, v.19, p.962-974.
- Dennison, J.M. 1976. Appalachian Queenston Delta related to eustatic sea-level drop accompanying late Ordovician glaciation centered in Africa; *in* The Ordovician System: Proceedings of a Paleontological Association Symposium, Birmingham, p.107-120.
- de V. Klein, G. and Hsui, A.T. 1987. Origin of cratonic basins; Geology, v.15, p.1094-1098.
- Ehlers, G.M. 1973. Stratigraphy of the Niagaran Series of the northern peninsula of Michigan; Michigan University Museum of Paleontology, Papers on Paleontology, no.3, 200p.
- Ehlers, G.M. and Kesling, R.V. 1957. Silurian rocks of the northern peninsula of Michigan; Michigan Basin Geological Society, Annual Field Conference Guidebook, 63p.
- Fay, I. and Copper, P. 1982. Early Silurian bioherms in the Manitoulin Formation of Manitoulin Island; Third North American Paleontological Convention, Proceedings, v.1, p.159-163.
- Fisher, D.W. 1960. Correlation of the Silurian rocks in New York State; New York State Museum, Science Service, Geological Survey, Map and Chart Series, no.1.
- Fisher, J.H. and Barratt, M.W. 1985. Exploration in Ordovician of central Michigan Basin; American Association of Petroleum Geologists, Bulletin, v.69, p.2065-2076.
- Goudge, M.F. 1938. Limestones of Canada - Part IV, Ontario; Canada Department of Mines and Resources, Bureau of Mines, Publication 781, 362p.

- Holland, C.H. 1985. Series and stages of the Silurian System; Episodes, v.8, p.101-103.
- Hussey, R.C. 1952. The Middle and Upper Ordovician rocks of Michigan; Michigan Geological Survey Division, Publication no.46, Geological Series 39, 89p.
- Johnson, A.M. and Sorensen, H.D. 1978. Drill core investigation of the Fiborn Limestone Member in Schoolcraft, Mackinac, and Chippewa Counties, Michigan; Michigan Geological Survey Division, Report of Investigations 18, 51p.
- Johnson, A.M., Kesling, R.V., Lilienthal, R.T. and Sorensen, H.D. 1979. The Maple Block Knoll Reef in the Bush Bay Dolostone (Silurian, Engadine Group), Northern Peninsula of Michigan; Michigan University Museum of Paleontology, Papers on Paleontology, no.20, 33p.
- Johnson, M.D. 1979. Limestone-dolostone assessment study of Manitoulin Island; *in* Summary of Field Work, 1979, by the Ontario Geological Survey, edited by V.G. Milne, O.L. White, R.B. Barlow, and C.R. Kustra, Ontario Geological Survey, Miscellaneous Paper 90, p.158-161.
- 1980. Limestone-dolostone assessment study of Manitoulin Island; *in* Summary of Field Work and Other Activities 1980, Ontario Geological Survey, Miscellaneous Paper 96, p.126-129.
- 1981. Limestone-dolostone assessment study of Manitoulin Island; *in* Summary of Field Work 1981, Ontario Geological Survey, Miscellaneous Paper 100, p.140-142.
- 1983. Geochemical analysis: Manitoulin Island limestone-dolostone assessment project; Ontario Geological Survey, Open File Report 5383, 86p.
- Johnson, M.D. and Telford, P.G. 1981a: Preliminary results of the 1978-1979 drilling program, Manitoulin Island limestone-dolostone assessment project; Ontario Geological Survey, Open File Report 5360, 81p.
- 1981b. Preliminary results of the 1980 drilling program, Manitoulin Island limestone-dolostone assessment project; Ontario Geological Survey, Open File Report 5364, 44p.
- 1985a: Paleozoic geology of the Kagawong area, District of Manitoulin; Ontario Geological Survey, Geological Series, Preliminary Map P.2669, scale 1:50 000.
- 1985b: Paleozoic geology of the Little Current area, District of Manitoulin; Ontario Geological Survey, Geological Series, Preliminary Map P.2270, scale 1:50 000.
- 1985c: Paleozoic geology of the Manitowaning area, District of Manitoulin; Ontario Geological Survey, Geological Series, Preliminary Map P.2672, scale 1:50 000.
- 1985d: Paleozoic geology of the Meldrum Bay area, District of Manitoulin; Ontario Geological Survey, Geological Series, Preliminary Map P.2667, scale 1:50 000.
- 1985e: Paleozoic geology of the Providence Bay area, District of Manitoulin; Ontario Geological Survey, Geological Series, Preliminary Map P.2671, scale 1:50 000.
- 1985f: Paleozoic geology of the Silver Water area, District of Manitoulin; Ontario Geological Survey, Geological Series Preliminary Map P.2668, scale 1:50 000.
- Johnson, M.D., Russell, D.J. and Telford, P.G. 1985. Oil shale assessment project, drill holes for regional correlation, 1983-84; Ontario Geological Survey, Open File Report 5565, 49p.
- Johnson, M.E. 1981. Correlation of lower Silurian strata from the Michigan Upper Peninsula to Manitoulin Island; Canadian Journal of Earth Sciences, v.18, p.869-883.

- Johnson, M.E. and Campbell, G.T. 1980. Recurrent carbonate environments in the lower Silurian of northern Michigan and their inter-regional correlation; *Journal of Paleontology*, v.54, p.1041-1057.
- Johnson, M.E., Rong Yia-Yu, and Yang Xue-Chang 1985. International correlation by sea-level events in the early Silurian of North America and China (Yangtze Platform); *Geological Society of America Bulletin*, v.96, p.1384-1397.
- Karrow, P.F. 1982. Quaternary geology of St. Joseph Island, Algoma District; Ontario Geological Survey, Geological Series, Preliminary Map P.2581, scale 1:50 000.
- Kelley, R.W. 1949. The geology of Cockburn Island, Ontario; unpublished MSc thesis, Wayne University, Detroit, Michigan, 81p.
- Liberty, B.A. 1957. Manitoulin Island, District of Manitoulin, Ontario; Geological Survey of Canada, Map 20-1957, scale 1 inch to 4 miles, or 1:253 440.
- 1966. Geology of the Bruce Peninsula, Ontario; Geological Survey of Canada, Paper 65-41, 8p., 13 maps.
- 1968. Ordovician and Silurian stratigraphy of Manitoulin Island, Ontario; *in* The Geology of Manitoulin Island, Michigan Basin Geological Society, Annual Field Excursion Guidebook, p.25-37.
- 1969. Paleozoic geology of the Lake Simcoe area, Ontario; Geological Survey of Canada, Memoir 355, 201p.
- 1972. Meldrum Bay area, Manitoulin District; Ontario Division of Mines, Map 2244, scale 1:63 360.
- Liberty, B.A. and Bolton, T.E. 1971. Paleozoic geology of the Bruce Peninsula area, Ontario; Geological Survey of Canada, Memoir 360, 163p.
- Lilienthal, R.T. 1978. Stratigraphic cross-sections of the Michigan Basin; Michigan Geological Survey Division, Report of Investigations 19, 36p.
- Logan, W.E. 1863. Geology of Canada; Geological Survey of Canada, Report of Progress for 1863, 938p.
- Macauley, G. 1987. Organic geochemistry of Ordovician Collingwood oil shales on Manitoulin, Drummond and St. Joseph islands, southern Ontario; Geological Survey of Canada, Open File Report 1496, 30p.
- Mai, H. and Dott, R.H., Jr. 1985. A subsurface study of the St. Peter Sandstone in southern and eastern Wisconsin; Wisconsin Geological and Natural History Survey, Information Circular 47, 26p.
- Miller, W.G. 1904. The limestones of Ontario; Ontario Bureau of Mines, Annual Report for 1904, v.XIII, pt.2, 143p.
- Murray, A. 1849. Report on Bruce Peninsula and Manitoulin Islands; Geological Survey of Canada, Report of Progress for 1847-48, p.81-121.
- Nunn, J.A. 1986. Subsidence and thermal history of the Michigan Basin; *in* Thermal Modeling in Sedimentary Basins, Editions Techip, Paris, France, p.417-436.
- Nunn, J.A., Sleep, N.H. and Moore, W.E. 1984. Thermal subsidence and generation of hydrocarbons in Michigan Basin; *American Association of Petroleum Geologists, Bulletin*, v.68, p.296-315.
- Nwachukwu, S.O. 1964. The geologic significance of geomagnetic measurements in the Lake Huron Basin and adjacent areas; unpublished PhD thesis, University of Toronto, Toronto, Ontario, 384p.

- O'Hara, N.W. 1981. Great Lakes region gravity and magnetic map sequence, MC-39, Lake Huron area; Geological Society of America, Map and Chart Series MC-39.
- O'Hara, N.W. and Hinze, W.J. 1980. Regional basement geology of Lake Huron; Geological Society of America Bulletin, v.91, p.348-358.
- Ontario Department of Mines and Geological Survey of Canada 1963. Meldrum Bay, Manitoulin District; Geological Survey of Canada, Aeromagnetic Map Series, Map 2225G, scale 1:63 360.
- Russell, D.J. and Telford, P.G. 1983. Revisions to the stratigraphy of the Upper Ordovician Collingwood beds of Ontario - A potential oil shale; Canadian Journal of Earth Sciences, v.20, p.1780-1790.
- Sanford, B.V. 1964. Catalogue of Ontario well samples at the Geological Survey of Canada, Ottawa; Geological Survey of Canada, Paper 63-46, 415p.
- Sanford, J.T. 1972. Niagaran-Alexandrian (Silurian) stratigraphy and tectonics; *in* Niagaran Stratigraphy: Hamilton, Ontario, edited by T.R. Segall and R.A. Dunn, Michigan Basin Geological Society, Annual Field Excursion Guidebook, p.42-56.
- 1978. The stratigraphy of the Manitoulin Island area; *in* The Geology of the Manitoulin Area, edited by J.T. Sanford and R.E. Mosher, Michigan Basin Geological Society, Special Paper 3, Guidebook to Annual Field Trip, p.31-41.
- Sleep, N.H. and Sloss, L.L. 1978. A deep borehole in the Michigan Basin; Journal of Geophysical Research, Volume B83, p.5815-5819.
- Swartz, C.K. (Chairman), Alcock, F.J., Butts, C., Chadwick, G.H., Cummings, E.R., Decker, C.E., Ehlers, G.M., Foerste, A.F., Gillette, T., Kindle, E.M., Kirk, E., Northrop, S.A., Prouty, W.F., Savage, T.E., Shrock, R.R., Swartz, F.M., Twenhofel, W.H., and Williams, M.Y. 1942. Correlation of the Silurian formations of North America; Geological Society of America Bulletin, v.53, p.533-538.
- Van Schmus, W.R., Card, K.D. and Harrower, K.L. 1975. Geology and ages of buried Precambrian basement rocks, Manitoulin Island, Ontario; Canadian Journal of Earth Sciences, v.12, p.1175-1189.
- Williams, D.W. 1991. Paleozoic geology of the Ottawa–St. Lawrence lowland, southern Ontario; Ontario Geological Survey, Open File Report 5770, 292p.
- Williams, M.Y. 1916. Formations adjacent to the Niagara Escarpment of southwestern Ontario; Geological Survey of Canada, Summary Report for 1915, p.139-142.
- 1919. The Silurian geology and faunas of the Ontario Peninsula, and Manitoulin Island and adjacent islands; Geological Survey of Canada, Memoir 111, 195p.
- 1936. Preliminary map showing geology, Manitoulin Island, Manitoulin District, Ontario; Geological Survey of Canada, Paper 36-21.
- 1937. General geology and petroleum resources of Manitoulin Island and adjacent islands, Ontario; Geological Survey of Canada, Paper 37-25, 57p.
- Winder, C.G. and Sanford, B.V. 1972. Stratigraphy and paleontology of the Paleozoic rocks of southern Ontario; 24th International Geological Congress, Montreal, Canada, Guidebook for Excursion A45-C-45, 73p.
- Wolf, R.R. 1985. Paleozoic geology of Cockburn Island, District of Manitoulin; *in* Summary of Fieldwork and Other Activities 1985, Ontario Geological Survey, Miscellaneous Paper 126, p.155-156.

——— 1986. Paleozoic geology of Cockburn Island, District of Manitoulin; Ontario Geological Survey, Geological Series, Preliminary Map P.2987, scale 1:50 000.

Zolnai, A.I., Price, R.A. and Helmstaedt, H. 1984. Regional cross-section of the Southern Province adjacent to Lake Huron, Ontario: implications for the tectonic significance of the Murray Fault Zone; Canadian Journal of Earth Sciences, v.21, p.447-456.

Appendix 1

Geochemical Analysis of Selected Surface and Drill Hole Samples from Cockburn Island

Explanatory Notes:

The geochemical analyses presented here were provided by the Geoscience Laboratories of the Ontario Geological Survey. The elements listed in the following table were determined by X-ray fluorescence spectroscopy and are reported as weight percent of their oxides. The samples are arranged in approximate stratigraphic order in the table.

The 3 accompanying graphs show the trends for some of the major elements, also with the samples arranged in approximate stratigraphic order.

Table 3 - Geochemical Data for Surface Samples and Selected Drill Hole* Samples
(In approximate stratigraphic order)

Formation	Sample No.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	P ₂ O ₅	MnO	CO ₂	LOI	Total
Amabel	69	1.56	0.34	0.50	22.00	28.90	0.00	0.12	0.01	0.01	0.01	44.9	46.0	99.5
Amabel	44	2.69	0.54	0.25	21.70	28.56	0.00	0.28	0.02	0.01	0.01	43.9	45.9	99.9
Amabel	17	2.37	0.43	0.22	21.80	28.80	0.00	0.17	0.01	0.02	0.01	44.0	46.2	100.0
Amabel	19	1.78	0.25	0.18	21.80	29.20	0.00	0.09	0.01	0.01	0.01	43.9	46.4	99.7
Amabel	61	2.24	0.39	0.24	21.60	28.90	0.00	0.20	0.01	0.02	0.01	44.4	46.1	99.7
Amabel	50	0.50	0.19	0.15	22.20	29.80	0.00	0.06	0.00	0.01	0.01	42.9	47.2	100.2
Amabel	40	0.56	0.21	0.14	22.20	29.80	0.00	0.06	0.00	0.02	0.01	43.1	47.1	100.0
Amabel	62	0.80	0.23	0.17	22.20	29.70	0.00	0.07	0.00	0.01	0.01	44.1	46.9	100.0
Amabel	64	0.39	0.14	0.20	22.20	29.80	0.00	0.00	0.00	0.01	0.01	44.9	47.2	99.9
Fossil Hill	15	3.28	0.64	0.33	21.50	28.10	0.00	0.38	0.03	0.02	0.01	44.8	45.2	99.5
Fossil Hill	16	1.53	0.27	0.26	21.90	29.50	0.00	0.15	0.01	0.02	0.01	44.8	46.6	100.2
Fossil Hill	8	0.95	0.22	0.16	21.90	29.90	0.00	0.04	0.00	0.02	0.01	45.2	46.8	100.0
Fossil Hill	36	0.97	0.20	0.17	21.90	29.90	0.00	0.07	0.00	0.02	0.01	44.8	46.7	99.9
Fossil Hill	12	55.30	0.62	0.00	10.00	12.30	0.00	0.00	0.00	0.02	0.02	22.2	20.9	99.1
Fossil Hill	20	3.39	0.14	0.17	21.70	28.60	0.00	0.00	0.00	0.02	0.01	42.8	45.5	99.5
Fossil Hill	13B	3.43	0.18	0.17	21.80	28.70	0.00	0.03	0.00	0.01	0.01	44.9	45.6	99.9
Fossil Hill	13A	6.62	1.31	0.37	20.70	26.00	0.00	0.83	0.06	0.02	0.02	42.9	43.0	98.9
Fossil Hill	31G	4.24	0.22	0.27	21.60	28.20	0.00	0.09	0.00	0.02	0.01	43.6	45.0	99.6
Fossil Hill	31F	1.43	0.38	0.67	21.70	29.10	0.00	0.13	0.01	0.02	0.01	43.4	45.2	98.7
Fossil Hill	31E	3.10	0.11	0.18	21.80	28.80	0.00	0.02	0.00	0.01	0.01	44.3	45.2	99.3
St.Edmund	31D	0.80	0.15	0.19	22.00	29.80	0.00	0.06	0.00	0.02	0.01	45.5	46.6	99.6
St.Edmund	31C	8.18	1.70	0.46	20.30	24.80	0.00	1.07	0.08	0.03	0.01	42.2	41.6	98.2
St.Edmund	31B	5.80	1.21	0.38	21.00	26.50	0.00	0.74	0.05	0.02	0.01	43.3	43.5	99.2
St.Edmund	31A	2.93	0.65	0.26	21.45	28.20	0.00	0.37	0.03	0.02	0.01	44.0	45.3	99.2
St.Edmund	21	0.84	0.21	0.14	22.10	29.80	0.00	0.05	0.00	0.01	0.01	44.8	47.0	100.1
St.Edmund	22	5.97	1.29	0.36	20.90	26.20	0.00	0.77	0.05	0.02	0.01	43.8	43.4	99.0
St.Edmund	23B	1.23	0.28	0.22	22.10	29.60	0.00	0.13	0.01	0.02	0.01	45.6	46.3	99.9
St.Edmund	23A	1.24	0.26	0.22	21.90	29.60	0.00	0.10	0.01	0.01	0.01	44.1	46.6	99.9
St.Edmund	60	1.20	0.30	0.20	21.30	30.00	0.00	0.08	0.00	0.02	0.02	44.8	46.8	99.9
St.Edmund	57B	2.08	0.24	0.21	22.00	29.20	0.10	0.01	0.01	0.02	0.01	45.3	46.0	99.8
St.Edmund	57A	7.56	0.13	0.19	21.20	27.00	0.00	0.02	0.00	0.04	0.01	41.3	43.3	99.4
St.Edmund	53B	0.48	0.10	0.14	22.10	29.90	0.00	0.01	0.00	0.02	0.01	44.5	47.1	99.8
St.Edmund	58	1.50	0.16	0.30	21.70	29.70	0.00	0.06	0.01	0.01	0.02	44.9	46.2	99.6
St.Edmund	34	1.11	0.20	0.21	4.85	50.60	0.06	0.07	0.00	0.02	0.01	43.1	43.1	100.2
St.Edmund	59C	1.02	0.14	0.12	1.15	54.10	0.08	0.04	0.00	0.02	0.01	42.8	43.2	99.9
St.Edmund	59A	0.75	0.11	0.12	0.93	54.50	0.10	0.03	0.00	0.02	0.01	39.9	42.9	99.5
Dyer Bay	32	0.71	0.16	0.31	21.60	30.00	0.00	0.04	0.00	0.01	0.02	44.2	46.9	99.7
Precambrian*	101	48.10	5.96	35.80	3.67	0.81	0.04	1.07	0.22	0.00	0.11	7.2	4.0	99.8
Precambrian*	102	46.27	0.35	34.10	3.86	2.99	0.03	1.86	0.36	0.07	1.02	2.6	1.7	99.5

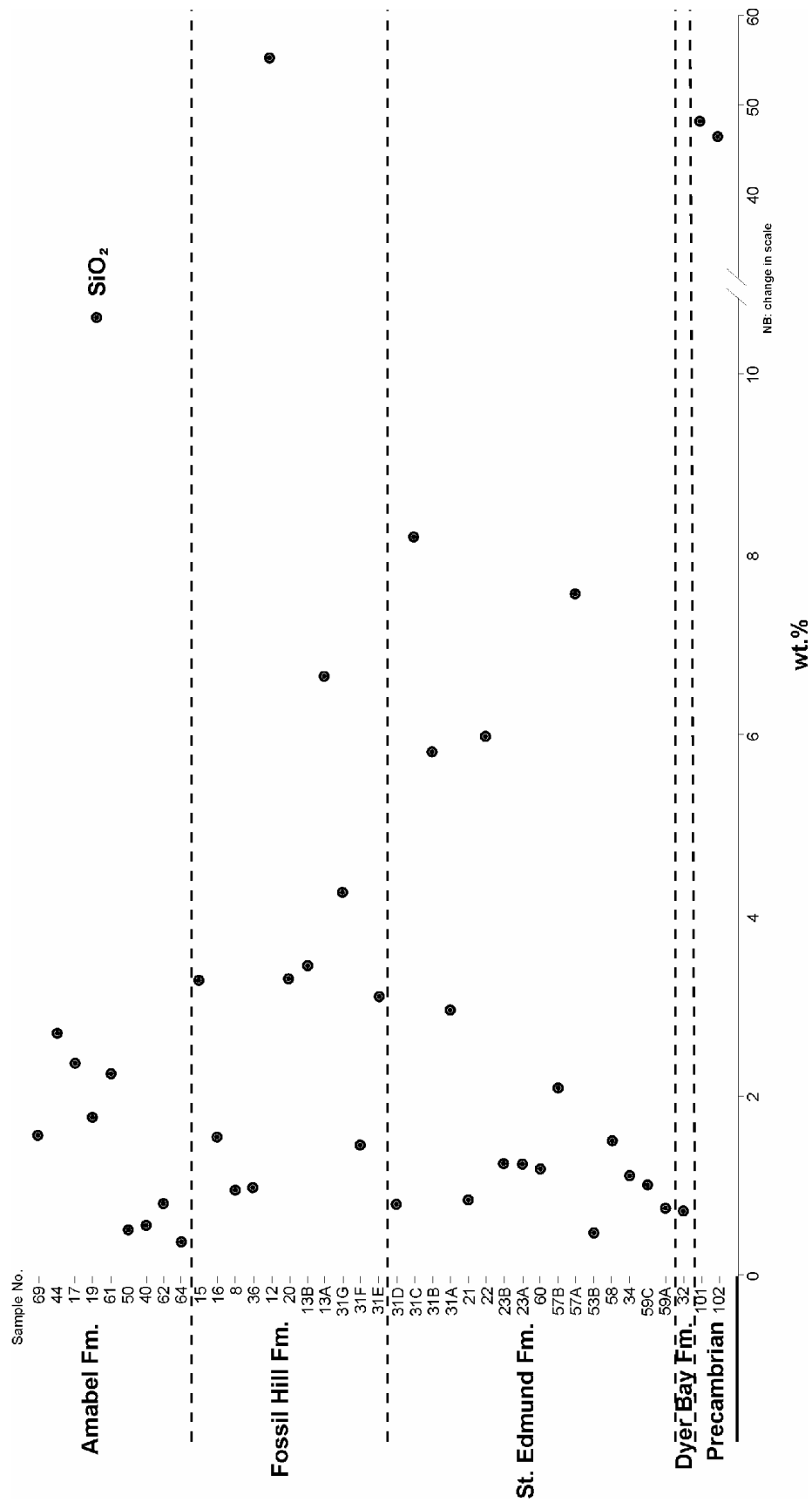


Figure 8. Vertical variations in SiO₂ content in the Precambrian rocks and formations exposed at surface on Cockburn Island.

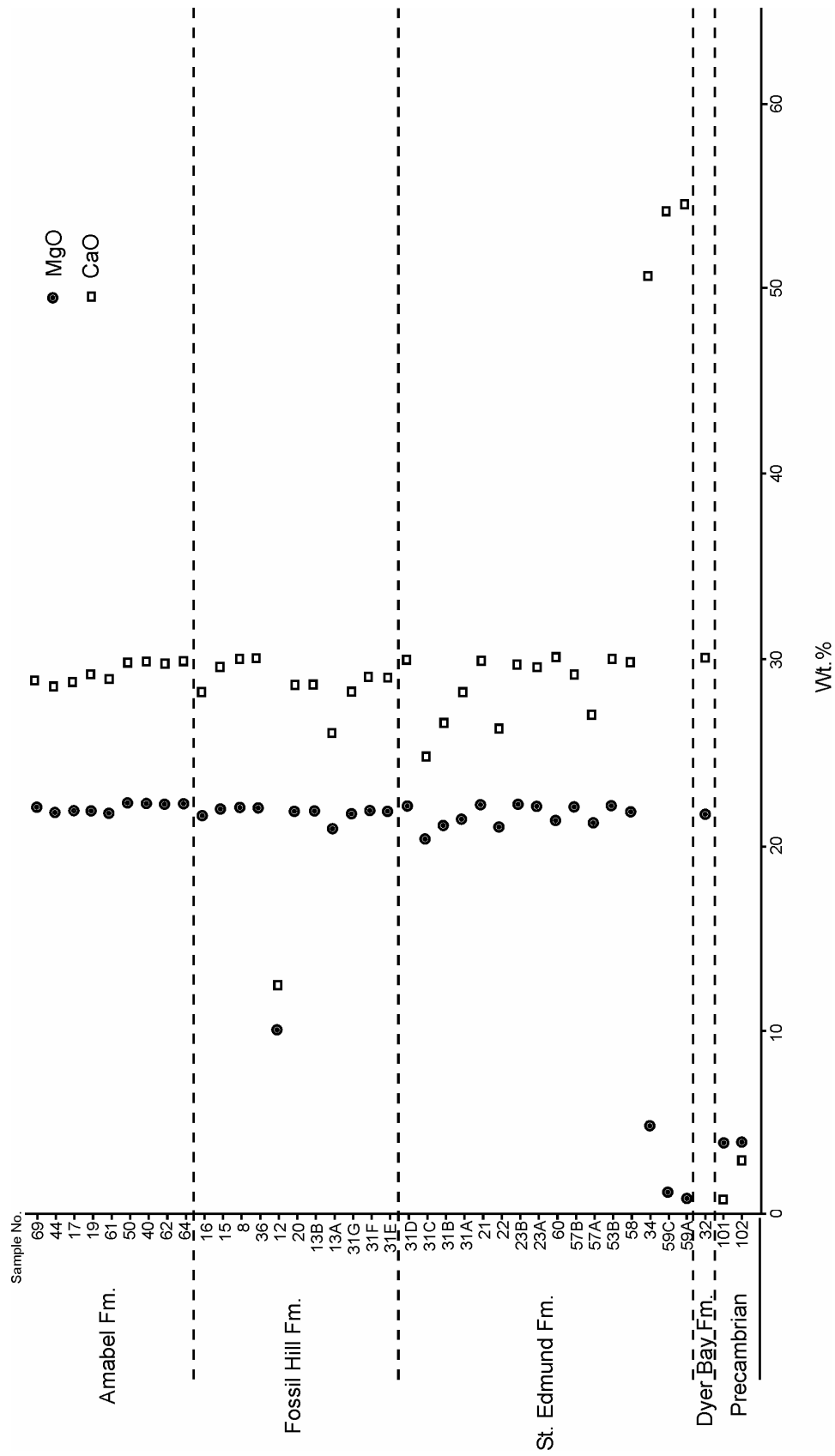


Figure 9. Vertical variations of MgO and CaO contents in the Precambrian rocks and formations exposed at surface on Cockburn Island.

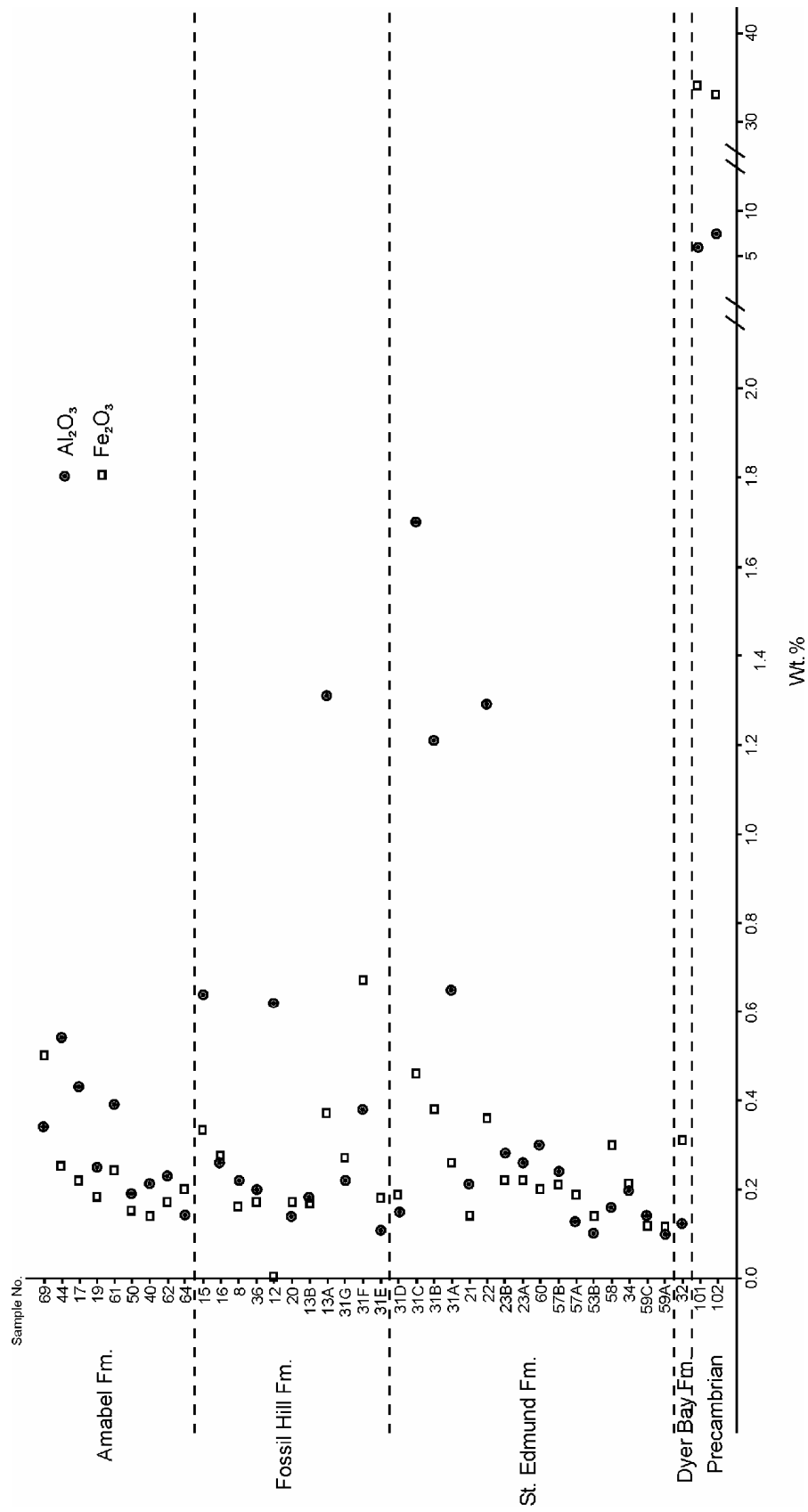


Figure 10. Vertical variations of Al_2O_3 and Fe_2O_3 contents in the Precambrian rocks and formations exposed at surface on Cockburn Island.

This page left blank intentionally.

Appendix 2

Geological Log of Drill Hole OGS-85-7 Cockburn Island

DRILLHOLE NAME: OGS-85-7 Cockburn Island
LOCATION: Lot 16, Concession II, Township of Cockburn Island, District of Manitoulin
ELEVATION: 192 m above sea level

QUATERNARY DEPOSITS

0.0-29.0 m

0.0-19.0 m

Interstratified Sand and Cobble-rich Gravels:

Sand: moderately well sorted, quartz-rich, fine- to medium-grained, with scattered thin gravel-rich beds.

Cobble-rich gravels: well-rounded clasts from pebble to boulder size, with Huronian quartzites most common, in addition to granite, diabase, and dolostone clasts; matrix is a poorly sorted quartz-rich sand.

19.0-29.0 m

Boulder-rich Gravels:

Matrix: poorly sorted, quartz-rich sand and gravel; gravel also quartz-rich, subrounded to well rounded.

Clasts: boulders appear to be well rounded, consisting of quartzite, granite, and dolostone; increase in abundance with depth.

AMABEL FORMATION

29.0-74.5 m

Dolostone:

Blue-grey with white and light grey intervals; medium crystalline with a uniform texture, rare coarse crystalline intervals; sparsely fossiliferous, with rare corals (e.g., *Syringopora* sp.); scattered soft, white, chalk-like chert nodules occur between 46.0-58.0 m; stylolites common, in scattered intervals, stylolites closely spaced producing thin-bedded dolostone; small, open vugs common throughout, rarely larger vugs which are filled with calcite, dolomite, or quartz crystals.

Lower contact of formation sharp and irregular, marked by a distinct change in texture and colour.

FOSSIL HILL FORMATION

74.5-107.7 m

Chert-rich Dolostone:

Light grey-brown, with patches of light to dark grey; fine to coarse crystalline, with a non-uniform texture; very fossiliferous, with most fossils replaced by silica, include stromatoporoids, tabulate and rugose corals, (no pentamerid brachiopods were observed); abundant soft, white, chalk-like chert nodules throughout; hard, black, flint-like chert nodules present between 94.0-97.0 m; stylolites common, some with up to 2 cm relief; small vugs common, larger vugs less abundant, usually filled with drusy quartz crystals.

Lower contact of formation sharp.

98.4-102.3 "FALSE MINDEMOYA BED"

Dolostone:

Light grey; very fine crystalline; structureless, except for rare, thin intervals of thin laminae; scattered small, white patches, may be re-crystallized crinoidal debris.

Upper and lower contacts of unit sharp.

ST. EDMUND FORMATION

107.7-147.3 m

Dolostone and Limestone:

Dolostone: light grey, very fine to fine crystalline (porcellaneous texture), thinly laminated, partially burrowed dolostone interbedded with light to medium brown, medium- to coarse-crystalline (sucrosic texture) dolostone; very thin, dark grey to black shale partings common throughout; black shale bed 2 cm thick between 139.1-139.2 m; small vugs common, especially in coarser crystalline intervals.

Limestone: present between 135.5-138 m and 142.5-145 m; light grey to medium brown; fine to medium crystalline; sparsely fossiliferous, with scattered tabulate corals.
Lower contact of formation sharp.

WINGFIELD FORMATION

147.3-160.4 m

Shale, Shaly Dolostone, Dolostone and Gypsum:

Shale: light green to grey-green; usually burrowed.

Shaly dolostone and dolostone: light grey to grey-brown; fine crystalline; intensely burrowed.

Gypsum: between 150.5-157.0 m scattered, small mottled patches of white and light grey gypsum (or anhydrite), and a white, fibrous gypsum bed, 2 cm thick.

Lower contact of formation sharp.

DYER BAY FORMATION

160.4-164.8 m

Dolostone:

Medium brown; medium crystalline; fossiliferous, with abundant pentamerid brachiopods (*Virgiana* sp.) between 161.0-163.0 m; rare, large vugs, filled with calcite crystals.

Lower contact of formation sharp.

CABOT HEAD FORMATION

164.8-185.0 m

Shale, Gypsum and Anhydrite, and Shaly Dolostone:

Shale: light to dark green, medium to dark red; noncalcareous; thinly laminated in some intervals.

Gypsum and Anhydrite: occur as a) horizontal beds up to 2 cm thick of white, fibrous gypsum; b) mottled white to light grey, rarely translucent patches of gypsum and anhydrite replacing shaly dolostone and shale; c) as thin fracture-filling white gypsum which cuts bedding at high angles.

Shaly Dolostone: (minor constituent) light grey to light brown; fine crystalline.

Lower contact of formation sharp

MANITOULIN FORMATION

185.0-200.9 m

Dolostone and Shale:

Dolostone: light to medium grey to light brown; fine to medium crystalline; scattered crinoid and stromatoporoid fossil fragments.

Shale: present between 199.0-200.9 m; medium to dark grey; thinly laminated, commonly mudcracked; noncalcareous; interbedded with very thin beds of fine-crystalline dolostone.

Lower contact of formation lost as a result of grinding of core (less than 2 cm of core is estimated to be missing).

GEORGIAN BAY FORMATION

200.9-259.7 m

Dolostone:

Medium grey; fine to medium crystalline; fossiliferous in places, with abundant brachiopods, bryozoans, gastropods and rugose corals; some intervals also very intensely burrowed, producing a faint nodular texture in places; scattered, thin interbeds of dark grey to black shale, some of which contain rip-up clasts of small, light brown dolostone fragments; small vugs common in lower part of formation, some of which are filled with dolomite crystals.

Lower contact of formation sharp, at base of lowest dolostone bed.

BLUE MOUNTAIN FORMATION

259.7-326.65 m

Shale (noncalcareous):

Medium to dark grey; very fissile; in uppermost 2 m and between 302.0-303.0 m rare, thin (less than 1 cm thick) intervals of fine-crystalline, shaly dolostone; in lowermost 0.65 m is a very dark grey, slightly petroliferous, nonfissile, noncalcareous shale with thin fossil-rich layers; scattered

throughout formation there are very thin layers of pyrite and pyritized fossil fragments, also very thin laminae of dark grey, silty shale which contain a mud-flake conglomerate; sparsely fossiliferous with rare, scattered lingulid brachiopods and graptolites (indeterminate graptolites between 304.3-306.5 m, *Climacograptus* sp. at 315.4 m, and small, orthid brachiopods between 315.0-317.0 m); at 325.5 is a very thin, phosphate-rich (?) layer.

Lower contact of formation very sharp.

LINDSAY FORMATION, COLLINGWOOD MEMBER

326.65-331.7 m

Shale (Calcareous):

Black; nonfissile; strong petroliferous odour from freshly broken surface; fossiliferous, includes: lingulid brachiopods (*Lingula* sp.), cephalopods, conularids, trilobites (*Triarthrus* sp.), and graptolites (*Climacograptus* sp.).

Lower contact of member very sharp and irregular.

UNDIFFERENTIATED STRATA

331.7-430.6 m

The strata in this interval cannot be assigned to any published stratigraphic nomenclature, thus, just the lithologic descriptions are presented here.

331.7-350.8 m

Dolostone:

Light to medium grey; coarse to very coarse crystalline; very porous; at 333.7 m and 336.3 m are zones which have been stained black, probably by hydrocarbons; thin shale and shaly dolostone partings present, commonly burrowed.

Limestone and calcareous shale between 342.0-344.5 m, light grey; very fine to fine-crystalline limestone is interbedded with dark grey calcareous shale; shale-limestone contacts are sharp and irregular; shale content in this interval is about 30%.

350.8-361.0 m

Limestone and Shale:

Limestone: light grey; very fine to fine crystalline; intensely burrowed, producing a nodular texture;

Shale: calcareous; dark grey; generally barren of fossils and burrows; shale content about 35% of unit; shale-limestone contacts sharp and horizontal.

Between 351.8-351.9 m is a grey-brown, medium-crystalline, porous dolostone.

361.0-374.1 m

Limestone:

Light grey; medium to coarse crystalline; moderately fossiliferous, with abundant brachiopods, corals, and crinoidal debris; some intervals intensively burrowed, producing a nodular texture in places; small patches of calcite crystals scattered throughout, as are small, open vugs.

Calcareous shale and shaly limestone interbeds scattered throughout unit, thin bedded, dark grey; less than 10% of unit.

374.1-374.8 m

Dolostone:

Medium to dark grey-brown; very coarse crystalline; porous, with abundant small, open vugs; upper and lower contacts of unit sharp and planar.

374.8-386.0 m

Limestone and Shale:

Limestone: light grey; fine to medium crystalline; sparsely fossiliferous with scattered brachiopod fragments.

Shale: dark grey to black; calcareous; sparsely fossiliferous with scattered brachiopod fragments and rare burrows; shale content about 25% of unit.

Limestone-shale contacts sharp and planar.

386.0-389.4 m

Limestone and Shale:

Limestone: light grey; microcrystalline to very fine crystalline; no fossils observed.

Shale: dark grey; calcareous; no fossils or burrows observed; shale content about 25% of unit.

Limestone-shale contacts sharp and planar.

389.4-390.3 m

Dolostone:

Medium grey-brown, with black stains; medium crystalline; porous, with small vugs common; black stains possible as a result of hydrocarbons; upper and lower contacts of unit sharp.

390.3-390.45 m

Limestone:

Light grey; very fine to fine crystalline; stylolites common; burrows abundant; no shale.

390.45-391.05 m

Dolostone:

Medium grey-brown; medium crystalline; porous with abundant small vugs; scattered stylolites.

391.05-415.0 m

Limestone and Shale:

Limestone: light to medium grey; fine to medium crystalline; between 392.0-394.0 m several 20-30 cm thick intervals of coarse-crystalline, bioclastic limestone; between 406.0-409.0 m several intervals of light grey, microcrystalline lithoclasts in mottled, fine-crystalline limestone.

Shale: dark grey; calcareous; commonly burrowed, with burrows filled by fine-crystalline limestone; shale content about 40% of unit.

415.0-418.0 m

Shale and Limestone:

Shale: dark grey to green-grey; calcareous; fossiliferous, with abundant brachiopods and numerous burrows; shale intervals up to 50 cm thick; shale content about 60% of unit.

Limestone: medium grey; fine to medium crystalline.

418.0-429.1 m

Limestone and Shale:

Limestone: light to medium grey; very fine to fine crystalline; sparsely fossiliferous.

Shale: medium to dark grey; calcareous; commonly burrowed, with burrows filled by fine-crystalline limestone; shale content 20% of unit.

Between 421.0-422.0 m there is a dark grey, burrowed, noncalcareous shale, which contains very thin, mottled, medium grey, medium-crystalline limestone interbeds.

429.1-430.6 m

Dolostone:

Medium grey-brown; medium crystalline; porous with abundant, small vugs; thin shale partings scattered throughout unit.

430.6-431.3 m

Shaly Dolostone:

Dark grey; very fine crystalline; intensively burrowed; thin interbeds, up to 5 cm thick, of fine-crystalline dolostone.

431.3-432.0 m

Limestone and Shale:

Limestone: light grey, very fine crystalline; fine-grained fossil debris scattered throughout unit.

Shale: dark grey; calcareous; shale content about 50% of unit.
Lower contact of unit sharp and planar.

GLENWOOD FORMATION

432.0-440.5 m

432.0-432.6 m

Shaly dolostone:

Dark grey; fine crystalline; fossiliferous and burrowed; small vugs in more crystalline intervals; lower 15 cm of unit contains increasing amounts of coarse- to very coarse-grained, well-rounded, quartz sand grains.

Lower contact of unit sharp.

432.6-433.3 m

Dolomitic Sandstone:

Mottled, light brown to grey-brown; medium to coarse-grained quartz sand grains in a dolomitic cement; intensely burrowed with scattered brachiopod fragments; lower contact of unit sharp.

433.3-434.6 m

Shale and Dolostone:

Shale: dark grey; noncalcareous; sparsely fossiliferous with scattered lingulid brachiopods and other pyritized fossil fragments.

Dolostone: medium grey; fine to medium crystalline; sparsely fossiliferous and sporadically burrowed; scattered, thin layers of coarse-grained, well-rounded quartz sand grains in dolostone beds; dolostone up to 50% of unit.

Lower contact of unit sharp.

434.6-435.9 m

Shale:

Dark grey; noncalcareous; sparsely fossiliferous, with some intervals burrowed; in uppermost and lowermost 20 cm of unit there are thin interbeds of medium brown, fine-crystalline, intensely burrowed dolostone which have gradational contacts with the shale.

435.9-436.8 m

Dolostone grading up into shale:

Two cycles of medium grey, fine-crystalline dolostone grading up into shaly dolostone and finally into dark grey, noncalcareous shale; each cycle approximately 50 cm thick; shales intensely burrowed; basal 10 cm of unit contains increasing amount of coarse-grained quartz sand.

Lower contact of unit sharp.

436.8-438.6 m

Sandstone, grading up into shale:

Shale: between 436.8-436.9 m shale is dark grey; noncalcareous; intensely burrowed with fine-crystalline dolostone burrow fills; scattered patches of small pyrite crystals and pyritized fossil fragments; coarse, well-rounded quartz sand grains scattered throughout; lower contact gradational.

Sandy dolostone: between 436.9-437.3 m dolostone is light grey-brown, fine-crystalline, with coarse, well-rounded quartz sand grains; intensely burrowed; lower contact gradational.

Sandstone: between 437.3-438.3 m sandstone is light grey to light brown; coarse grained to very coarse grained at base; well sorted, well rounded; dolomitic cement; scattered patches of small pyrite crystals in upper 30 cm of interval; patches of green, shaly sandstone in lower 60 cm; no sedimentary structures in sandstone; lower contact gradational.

Sandstone: between 438.3-438.6 m sandstone is light brown to light green; very coarse grained; well sorted, well rounded; dolomitic cement; patches of light green, glauconitic shale, possibly rip-up clasts.

Lower contact of unit very sharp and planar.

438.6-439.3 m

Shale:

Dark grey to black; noncalcareous; intensely burrowed (*Planolites* sp.), with burrows filled by dolomitic sandstone or mud; lower 5 cm grades into slightly sandy, burrowed shaly dolostone.

Lower contact very sharp and irregular; marked by irregular surface on underlying dolostone with 0.05 cm thick, dark grey to hematitic clay seam, which follows irregularities.

439.3-440.5 m

Alternating Dolostone and Shale:

Dolostone: between 439.3-439.7 m dolostone is light grey; medium crystalline; rare, large vugs, filled with dolomite crystals; lower 20 cm with increasing amount of dark green-grey shale.

Shale: between 439.7-439.95 m shale is dark green-grey; noncalcareous; upper part sparsely burrowed grading down into nonburrowed shale; very thin, rare, sandy partings scattered throughout.

Lower contact sharp.

Dolostone: between 439.95-440.05 m dolostone is light grey; fine crystalline; burrowed; with thin grey, shale partings every 1 to 2 cm; lower contact gradational.

Shale: between 440.05-440.5 m shale is mottled dark and medium grey; intensely burrowed with burrows filled by fine-crystalline dolostone; scattered coarse, well-rounded, quartz sand grains.

Lower contact of formation very sharp and irregular.

(?) ST. PETER FORMATION

440.5-452.6 m

440.5-441.85 m

Sandstone:

Light grey-brown to light grey; coarse-grained, well-rounded, well-sorted quartz grains; dolomitic cement; in lower 30 cm medium-grained, quartz sandstone with thin grey-green, shaly, sandy dolostone interbeds; sandstone intensely burrowed, no sedimentary structures; between 440.8-441.1 m is a pink to light red, coarse- to very coarse-grained, friable quartz sandstone.

Lower contact of unit sharp.

441.85-443.0 m

Shale:

Medium grey; noncalcareous; contains variable amounts of interbedded dolomitic shale and sandy shale; burrowed with lingulid brachiopods scattered throughout; lower 40 cm grades into shaly, dolomitic sandstone, with fine- to medium-grained quartz grains, and is intensely burrowed.

Lower contact of unit gradational.

443.0-445.9 m

Sandstone:

Light brown to greenish brown; medium-grained, well-rounded, well-sorted, quartz sand grains; dolomitic cement; scattered mottles of finer grained, glauconitic quartz sandstone throughout unit; distinct burrows in lower 30 cm coincident with increasing amounts of dolomitic cement.

Lower contact of unit gradational.

445.9-447.3 m

Sandstone:

Tan to light brown; coarse- to very coarse-grained, well-rounded, well-sorted quartz sand grains; dolomitic cement; some porous intervals present. Between 447.0-447.25 cm are small pebbles of quartz and quartzite, well rounded, well sorted in a coarse-grained quartz sandstone. At 447.1 m there is a black stain, possibly as a result of hydrocarbons.

Lower contact of unit gradational.

447.3-449.0 m

Sandstone:

Light brown to light grey-brown; fine- to medium-grained; well sorted, well rounded; dolomitic cement; grades into sandy dolostone in some intervals; distinct burrows scattered throughout.
Lower contact of unit gradational.

449.0-450.4 m

Quartz Pebble Conglomerate

Matrix: light brown; medium- to coarse-grained; well-rounded, moderately well sorted quartz sand grains; dolomitic cement.
Clasts: well-rounded, well-sorted pebbles of quartz and quartzite; coarsest pebbles found between 449.5-450.0 m.
Lower contact of unit gradational.

450.4-451.35 m

Sandstone:

Light brown to cream; medium- to coarse-grained; well-rounded, fairly well-sorted, quartz sand grains; dolomitic and quartz cement; upper 30 cm with burrows and greater amount of dolomitic cement.
Lower contact lost as a result of grinding of the core.

431.35-451.8 m

Shale:

Dark grey to black; noncalcareous; intensely burrowed; scattered medium-grained, well-rounded quartz sand grains grading into sandy shale in places; thin interbeds of shaly dolostone scattered throughout unit.
Lower contact of unit gradational.

451.8-452.2 m

Quartz Pebble Conglomerate:

Matrix: light brown; medium to coarse grained; well-rounded, fairly well-sorted, quartz sand grains; dolomitic cement.
Clasts: moderately well-rounded, moderately well-sorted pebbles and cobbles of quartz and quartzite; maximum size: 10 cm.
Lower contact of unit gradational.

452.2-452.6 m

Intraformational Conglomerate:

Matrix: light grey-brown; fine to medium grained; well-rounded, fairly well-sorted, quartz sand grains; dolomitic and quartz cement.
Clasts: angular, light brown to cream, very fine-grained, muddy quartz sandstone.
Lower contact of formation very sharp and irregular.

(?) PRAIRIE DU CHIEN FORMATION

452.6-483.55 m

452.6-456.95 m

Shale:

Dark grey, green-grey, and reddish-grey; noncalcareous; laminated; with thin, rare, light grey and grey-brown fine-crystalline dolostone, fine-grained sandy dolostone, and shaly dolostone, increasing in abundance to base of unit; ripple cross-laminae and horizontal laminae common; stylolites present in some dolostone intervals, as are small vugs filled with dolomite crystals.
Lower contact of unit very sharp and planar.

456.95-457.3 m

Shale:

Dark green-grey and reddish-grey; noncalcareous; laminated, with thin layers of shaly dolostone and medium- to coarse-grained, dolomitic quartz sandstone.

457.3-460.0 m

Dolostone:

Light grey to light green; fine crystalline; thin, light green shale partings and thin, coarse-grained, glauconitic quartz sandstone scattered throughout unit; lower 10 cm has a red tinge.

Lower contact of unit gradational.

460.0-460.8 m

Shale:

Reddish brown to green-grey; laminated with thin intervals of shaly dolostone and thin layers of medium- to coarse-grained, dolomitic sandstone.

460.8-462.0 m

Sandy Dolostone:

Light grey, with light green intervals; fine-crystalline dolostone with medium- to coarse-grained, well-rounded, quartz sand grains which "float" in dolostone; thin layers of laminated, glauconitic quartz sandstone.

Lower contact of unit gradational.

462.0-466.0 m

Dolostone:

Light to medium grey; fine crystalline; rare, thin intervals of glauconitic quartz sandstone; one, small white chert nodule at 464.0 m; scattered pyrite crystals rare in unit.

Lower contact of unit sharp.

466.0-468.8 m

Shale and Shaly Dolostone:

Light green, laminated, noncalcareous, glauconitic shale and shaly dolostone, with thin interbeds of light grey, fine-crystalline dolostone and sandy dolostone; shales fractured and mudcracked in places.

Lower contact of unit gradational.

468.8-472.15 m

Shale:

Reddish brown, green, grey-green; thinly laminated, with ripple cross-laminae; noncalcareous shale, with thin intervals of fine-grained, sandy shale and fine-crystalline dolomitic shale; lower 5 cm of unit is very fine-grained, ripple cross-laminated quartz sandstone.

Lower contact of unit sharp and irregular.

472.15-475.7 m

Conglomerate:

Matrix: light green to light brown, medium- to coarse-grained, well-rounded, poorly sorted, glauconitic quartz sand grains in a dolomitic and/or clay-rich cement.

Clasts: well-rounded pebbles and cobbles of quartz and quartzite, and angular clasts of sandy dolostone, quartz sandstone, and dolomitic sandstone; maximum clast size: 10 cm; conglomerate is matrix supported.

Lower contact of unit gradational.

475.7-476.6 m

Sandstone:

Light green-grey; medium grained; well-rounded, well-sorted, quartz sand grains; dolomitic cement; glauconitic with scattered, well-rounded quartz pebbles.

Lower contact of unit gradational.

476.6-478.5 m

Conglomerate:

Matrix: light grey to green, medium- to coarse-grained, well-rounded, poorly sorted, glauconitic, quartz sandstone.

Clasts: subrounded quartz and quartzite pebbles and cobbles, and angular to subrounded sandy dolostone and dolostone cobbles; maximum size: 15 cm; conglomerate is clast supported in some places, otherwise matrix supported.

Lower contact of unit sharp.

478.5-480.8 m

Sandstone:

Light to medium brown to light grey-brown, with green intervals; fine- to medium-grained; laminated to ripple cross-laminated, glauconitic, quartz sandstone; thin intervals of shaly dolostone in lower part of unit.

Lower contact of unit sharp.

480.8-483.55 m

Conglomerate:

Matrix: light green to brown, fine- to very coarse-grained, angular to subrounded, poorly sorted quartz sand grains.

Clasts: increase in size and abundance downward; subangular to subrounded quartz, quartzite, diabase, quartz sandstone, and sandy dolostone; maximum size: 70 cm; lower 1.5 m of unit is clast supported.

Lower contact of formation is very sharp, and irregular; with some reddish colour in lowest 5 cm.

PRECAMBRIAN

483.55-521.0 m

Magnetite-rich Amphibolite:

483.55-497.0 m

Altered: reddish brown, hematite-rich, very fine crystalline (or grained), generally structureless.

497.0-521.0 m

Unaltered: black, fine crystalline, irregularly foliated, at varying angles with depth; magnetite-rich; thin, white, quartz veins common throughout interval.

521.0 m TOTAL DEPTH OF DRILL HOLE

Appendix 3

Geophysical Wire-Line Logs of Drill Hole OGS-85-7 Cockburn Island

Figure 11. Gamma ray and bulk density log (resampled and resized)

In Back Pocket:

Figure 12. Gamma ray, bulk density and caliper log

Figure 13. Gamma ray and focussed electric log

Figure 14. Gamma ray and neutron porosity log

Abbreviations:

API	American Petroleum Institute
GR	gamma ray
RHOB	bulk density

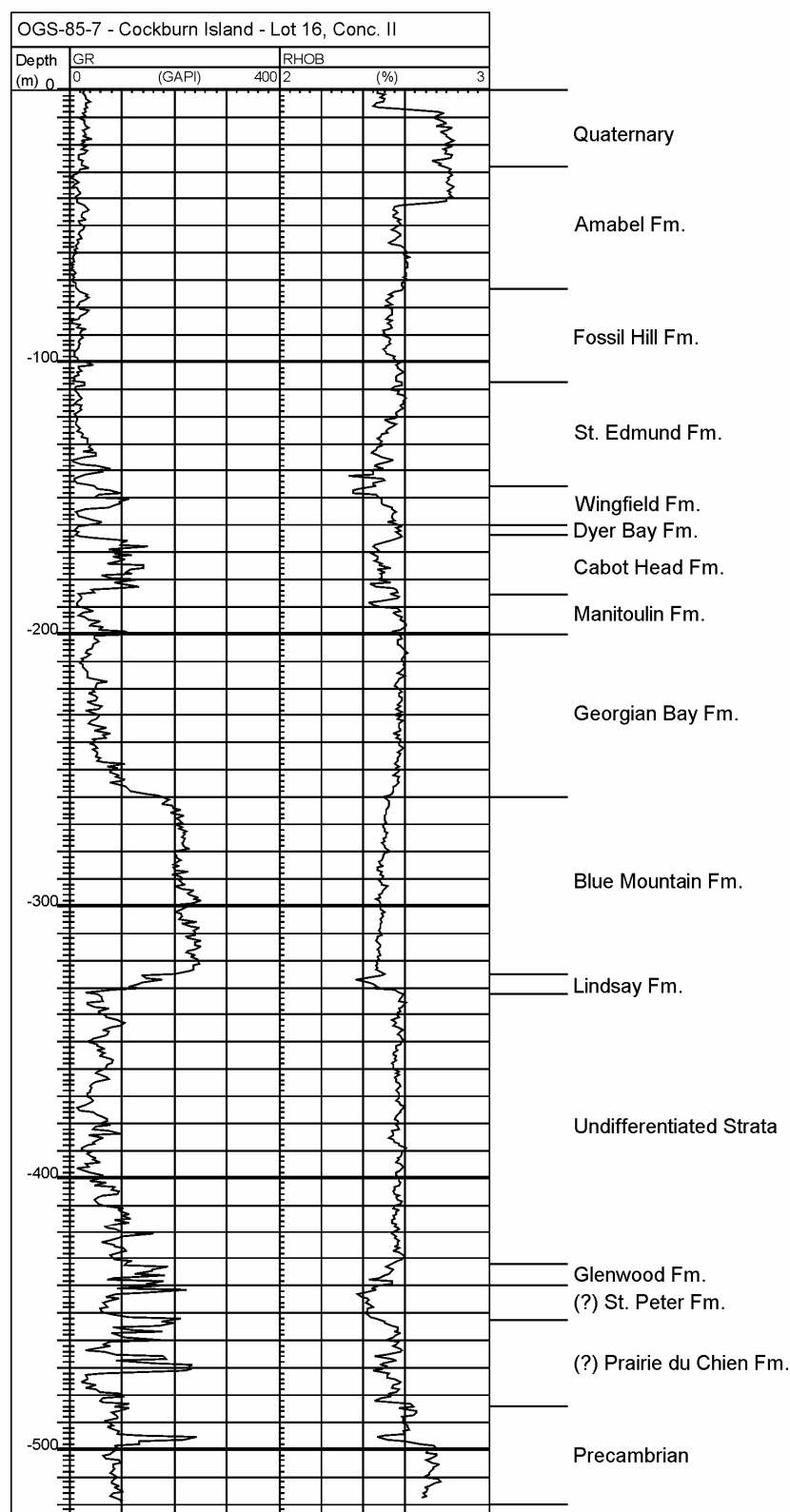


Figure 11. Gamma ray and bulk density geophysical log of drill hole OGS-85-7 Cockburn Island. The geophysical data have been resampled and the log resized to fit the page. Formation contacts shown are based on depths from the geological log (Appendix 2; *see also* Map P.2987, back pocket).

Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
<i>SI Unit</i>	<i>Multiplied by</i>	<i>Gives</i>	<i>Imperial Unit</i>	<i>Multiplied by</i>	<i>Gives</i>
LENGTH					
1 mm	0.039 37	inches	1 inch	25.4	mm
1 cm	0.393 70	inches	1 inch	2.54	cm
1 m	3.280 84	feet	1 foot	0.304 8	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	1.609 344	km
AREA					
1 cm ²	0.155 0	square inches	1 square inch	6.451 6	cm ²
1 m ²	10.763 9	square feet	1 square foot	0.092 903 04	m ²
1 km ²	0.386 10	square miles	1 square mile	2.589 988	km ²
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
VOLUME					
1 cm ³	0.061 023	cubic inches	1 cubic inch	16.387 064	cm ³
1 m ³	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m ³
1 m ³	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m ³
CAPACITY					
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	4.546 090	L
MASS					
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	31.103 476 8	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	0.453 592 37	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	907.184 74	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	0.907 184 74	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	1016.046 908 8	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	1.016 046 90	t
CONCENTRATION					
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	<i>Multiplied by</i>	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

ISSN 0826-9580
ISBN 1-4249-1821-9

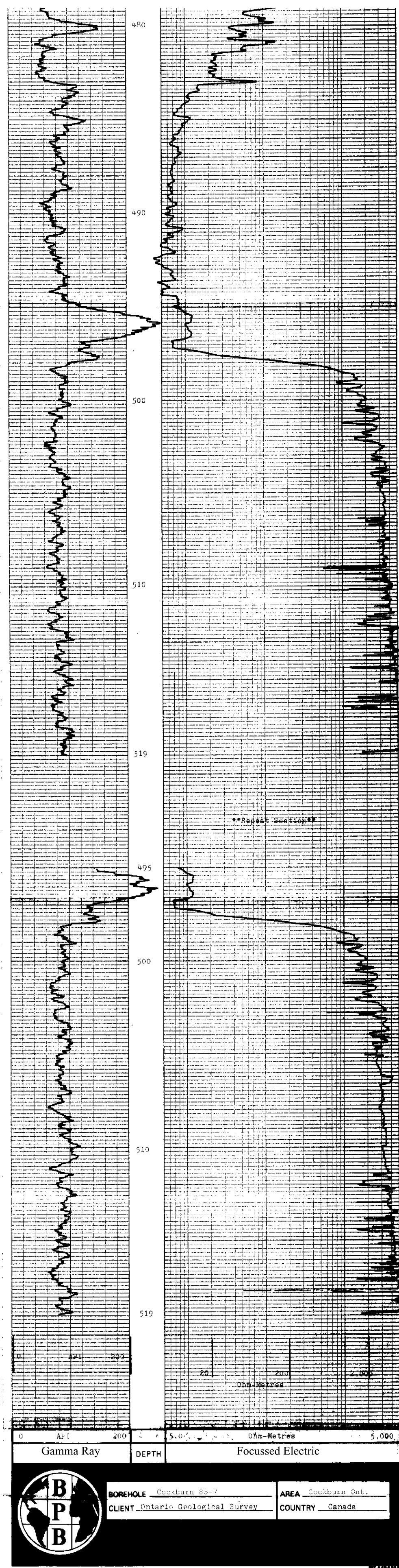
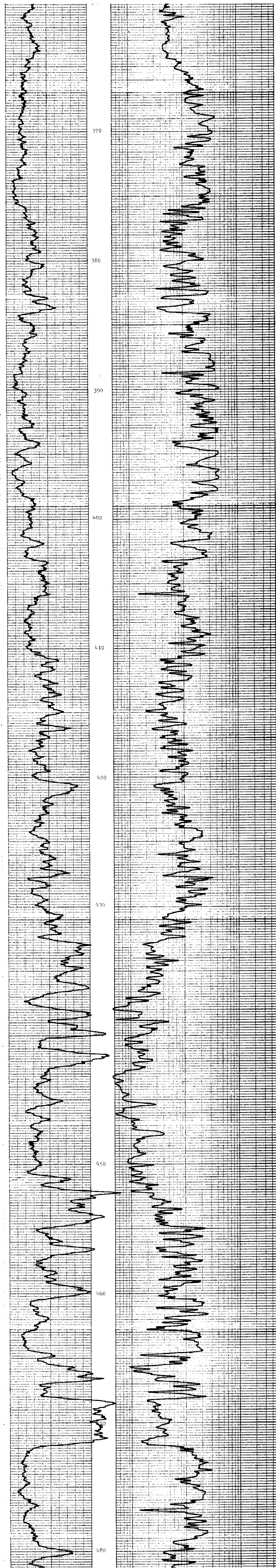
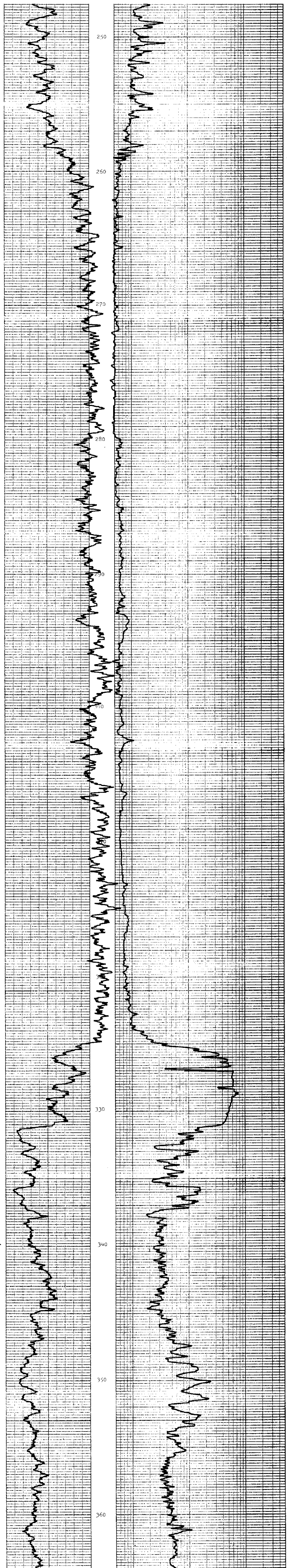
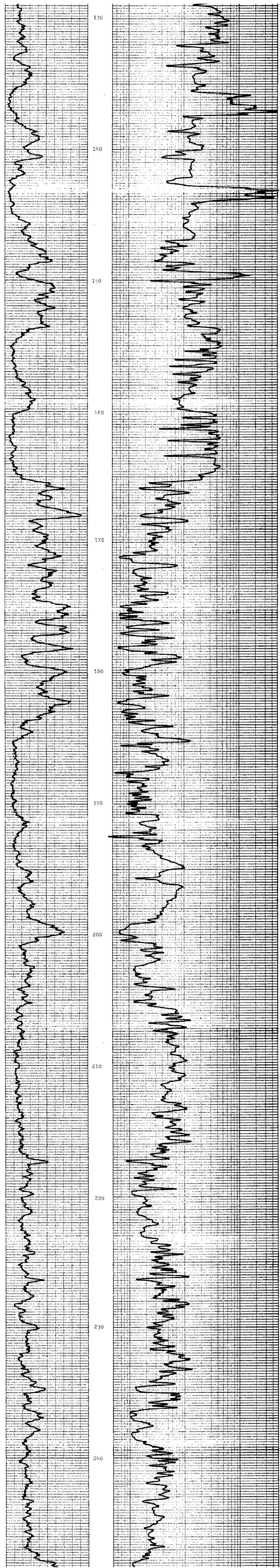
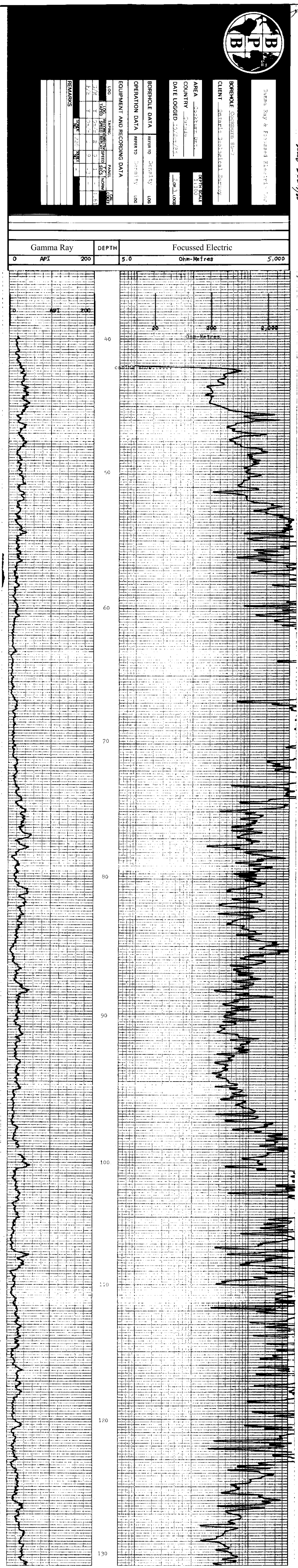


Figure 13.

Gamma Ray and Focussed Electric Log,
Drill Hole OGS-85-7 Cockburn Island

MARGINAL NOTES

INTRODUCTION

Cockburn Island, situated in northern Lake Huron between Manitoulin Island and Drummond Island, Michigan, is accessible only by boat, helicopter, or float plane. Gravel roads, well maintained by the Township of Cockburn Island, provide access to most of the interior of the island.

The first geological description of the island was by Bigsby (1821, 1824) who noted the presence of fossiliferous limestones along the shoreline. Subsequent geological mapping (Murray 1849; Bell 1870; Williams 1919; Kelley 1949) culminated with the study by Liberty between 1954 to 1957 (Liberty 1972). Recent revisions to the geological maps of Manitoulin Island (Johnson and Telford 1985) indicated the need for the re-examination of the Paleozoic rocks on Cockburn Island.

The topography of Cockburn Island is controlled by thick Quaternary deposits. A central hill of moraine till, with surface reworking by glaciolacustrine beach processes, is surrounded by approximately concentric glacial beaches and wave-cut terraces. Bedrock outcrops are confined to the northern part of the island, generally as flat bedding plane exposures. Regional dip of the bedrock is about 6 m per kilometre to the south.

To supplement the outcrop data, a deep stratigraphic test hole (OGS 85-7, Cockburn Island) was drilled. The drillhole was located on lot 16, concession II, Township of Cockburn Island. A continuous section from the Middle Silurian down into the Precambrian, for a total depth of 521 m, was obtained (Table 1). The thickness of the Middle Silurian formations discussed below was measured from this drillhole.

STRATIGRAPHY

Only those Middle Silurian rock units which form part of the bedrock surface on Cockburn Island are described in detail. The thickness and names of older units present only in the subsurface, and intersected in OGS 85-7, are provided in Table 1. Detailed descriptions of these units will be released in a subsequent Ontario Geological Survey Open File Report.

The Cabot Head, Dyer Bay, Wingfield, and St. Edmund rock units (in ascending order) were previously designated as members of the Cabot Head Formation (Liberty and Bolton 1971; Liberty 1972). Due to recent revisions of Middle Silurian stratigraphy on Manitoulin Island (Johnson and Telford 1985), these four units are now accorded formal status, as previously used by Bolton (1957) and earlier workers.

DYER BAY FORMATION

The oldest exposed unit on Cockburn Island is the Dyer Bay Formation. Outcrops are restricted to a small area at the northern extremity of the island. Neither the lower nor the upper contacts are exposed on Cockburn Island, though outcrops on nearby Manitoulin Island and drillhole OGS 85-7 indicate that the Dyer Bay Formation conformably overlies the Cabot Head Formation. The contact is placed at the top of the uppermost green or red shale of the Cabot Head Formation. The exposed thickness of the Dyer Bay Formation is <0.5 m; in drillhole OGS 85-7, 4.4 m of Dyer Bay Formation was measured (Table 1).

The Dyer Bay Formation consists of blue-grey to grey-brown, thinly-bedded, medium crystalline, fossiliferous dolostone which weathers a light brown. Where fossils are absent, a silty to very fine grained sandy dolostone may occur. The fossils consist exclusively of the pentamerid brachiopod *Virginia*.

WINGFIELD FORMATION

No outcrops of the Wingfield Formation were observed on Cockburn Island, though 13.1 m of this formation occurs in drillhole OGS 85-7. The unit is considered to subcrop beneath surficial deposits in a narrow band across the northernmost part of the island. On Manitoulin Island, Johnson and Telford (1985) described this formation as a thin and evenly bedded green shale, interbedded with brown, very finely crystalline dolostone. The lower contact with the underlying Dyer Bay Formation, as seen in the drillhole core, is sharp and conformable.

ST. EDMUND FORMATION

The St. Edmund Formation was redefined by Johnson and Telford (1985) when detailed mapping and subsurface studies on Manitoulin Island (Johnson and Telford 1981a, 1981b) revealed that the St. Edmund Member (Cabot Head Formation) and Mindemoya Formation of Liberty (1968, 1972) actually constitute a single, mappable rock unit.

The base of the St. Edmund Formation is placed at the top of the uppermost green shale of the Wingfield Formation. The lower contact is not exposed on Cockburn Island but in drillhole OGS 85-7 it appears to be fairly sharp and conformable. The formation is 39.6 m thick in drillhole OGS 85-7 (Table 1). Outcrops occurring in a narrow band across the northern part of the island display only about 12.0 m of stratigraphic thickness.

The St. Edmund Formation consists of pale grey, thinly bedded, lithographic to sublithographic, laminated dolostone weathering white to cream, alternating with beds of medium brown, medium bedded, medium to coarsely crystalline dolostone. The pale grey, lithographic dolostone occurs predominantly in the upper part of the formation whereas the brown, medium to coarsely crystalline dolostone is more common in the lower part. Some outcrops of the brown dolostone beds also contain horizons which exhibit a distinctive vuggy texture due to extensive silicification.

A 2 m thick interval of medium grey, medium bedded, lithographic limestone occurs along the northwestern shoreline, south of Burns Bay. This interval may correlate with the Fiborn Limestone Member of the Hendricks Dolomite, Drummond Island, Michigan (Johnson and Sorensen 1978). The Hendricks Dolomite is the equivalent formation in Michigan to the St. Edmund Formation of Ontario. Lithographic limestone was also observed in the St. Edmund Formation during a preliminary examination of the core from drillhole OGS 85-7.

Most of the St. Edmund Formation, especially the lithographic dolostone, is extensively jointed. The dominant trend is 140° and there is a minor trend at 050°; joints are spaced up to 1 m apart.

FOSSIL HILL FORMATION

The Fossil Hill Formation disconformably overlies the St. Edmund Formation, though the contact is not well exposed on Cockburn Island. In exposures and drillholes on Manitoulin Island (Johnson and Telford 1985), and in drillhole OGS 85-7, the contact is sharp and exhibits features suggestive of only a short period of erosion. From surface exposures, the Fossil Hill Formation is estimated to be 30 m thick. In the core of drillhole OGS 85-7, 33.2 m of the Fossil Hill Formation was measured (Table 1). Individual surface exposures do not exceed 2 m in thickness.

The Fossil Hill Formation consists of light brown to grey-brown, irregularly thin to medium bedded, fine to coarsely crystalline, fossiliferous dolostone which weathers buff to cream. Soft, white chert is abundant near the top of the formation and also occurs sporadically throughout. Several horizons within the Fossil Hill Formation are profusely fossiliferous, usually with disarticulated and disoriented, silicified fragments. The most common fossils include pentamerid brachiopods, stromatopores, and a large variety of tabulate and rugose corals. Other less common types include gastropods, cephalopods, and orthid brachiopods. The informally named "False Mindemoya beds", a 3 to 4 m thick horizon of lithographic dolostone (St. Edmund Formation lithology), occurs 5 m above the base of the Fossil Hill Formation; it is also present across much of Manitoulin Island (Johnson and Telford 1985).

AMABEL FORMATION

The Amabel Formation, the youngest Paleozoic formation exposed on Cockburn Island, and most areally extensive, disconformably overlies the Fossil Hill Formation. The lower contact is very sharp and easily identified in drillhole OGS 85-7; it was not found in any surface exposures. Most outcrops of the Amabel Formation are flat bedding plane exposures which usually display deeply weathered and enlarged joints and fractures. The Amabel Formation was the uppermost unit in drillhole OGS 85-7; 45.5 m of the formation was cored (Table 1).

The Amabel Formation on Manitoulin Island was subdivided into four major lithofacies by Johnson and Telford (1985). Only one of these facies, Facies III, has been identified on Cockburn Island. The strata consists of white to blue grey, thick to massive bedded, medium crystalline dolostone, which weathers a light to medium grey. Thin horizons of pentamerid brachiopods were observed in a few outcrops.

ECONOMIC GEOLOGY

A small abandoned quarry southeast of the village of Cockburn Island was worked for a short period during the early part of this century to obtain rock for use in a sulphite-pulp mill (Miller 1904; Goudge 1938). Three petroleum exploration wells were drilled on Cockburn Island during 1936 and 1937. All three penetrated the Precambrian, but were unsuccessful in locating commercial oil or gas deposits (Sanford 1964). Several small gravel pits are used as sources for aggregate on local roads.

Manitoulin Dolomite Limited is currently operating a quarry on nearby Manitoulin Island, approximately 3 km west of Cinder Point. Dolostone from the Amabel Formation is crushed on site, loaded onto lake boats and is shipped to both Canadian and American ports to supply a variety of industries. Outcrops of the Amabel Formation on Cockburn Island, north of Ricketts Harbour, may also be a potential source of similar dolostone.

REFERENCES

- Bell, R.
1870: Report on the Geology of the Grand Manitoulin, Cockburn, Drummond, and St. Joseph Islands; Geological Survey of Canada, Report of Progress for 1866-1869, p.109-116.
- Bigsby, J.J.
1821: Geological and Mineralogical Observations on the Northwest Portion of Lake Huron; American Journal of Science, 1st Series, Volume 3, p.254-272.
1824: Notes on the Geography and Geology of Lake Huron; Transactions of the Geological Society of London, 2nd Series, Volume 1, Part 2, p.175-208.
- Bolton, T.E.
1957: Silurian Stratigraphy and Paleontology of the Niagara Escarpment in Ontario; Geological Survey of Canada, Memoir 289, 145p.
- Goudge, M.F.
1938: Limestones of Canada: Their Occurrence and Characteristics, Part IV, Ontario; Canada Department of Mines and Resources, Mines and Geology Branch, Publication No. 781, 362p.
- Johnson, A., and Sorensen, H.
1978: Drill Core Investigation of the Fiborn Limestone Member in Schoolcraft, Mackinac and Chippewa Counties, Michigan; Michigan Geological Survey Division, Report of Investigation 18, 51p.
- Johnson, M.D., and Telford, P.G.
1981a: Preliminary Results of 1978-1979 Drilling Programme, Manitoulin Island Limestone-Dolostone Assessment Project; Ontario Geological Survey, Open File Report 5360, 81p.
1981b: Preliminary Results of 1980 Drilling Programme, Manitoulin Island Limestone-Dolostone Assessment Project; Ontario Geological Survey, Open File Report 5364, 44p.
- 1985: Paleozoic Geology of the Midland Bay Area, District of Manitoulin, Ontario Geological Survey, Geological Series, Preliminary Map P.2667, scale 1:50 000, Geology 1979 to 1981.
- Kelley, R.W.
1949: Silurian Stratigraphy of Cockburn Island, Ontario; Unpublished M.Sc. Thesis, Wayne University, Detroit, Michigan, 81p.
- Liberty, B.A.
1968: Ordovician and Silurian Stratigraphy of Manitoulin Island, Ontario; p.25-37 in The Geology of Manitoulin Island, Michigan Basin Geological Society, Annual Field Excursion Guidebook, 101p.
1972: Midland Bay Area, Manitoulin District; Ontario Division of Mines, Map 2244, scale 1:63 360.
- Liberty, B.A., and Bolton, T.E.
1971: Paleozoic Geology of the Bruce Peninsula Area, Ontario; Geological Survey of Canada, Memoir 360, 163p.
- Miller, W.G.
1904: The Limestones of Ontario; Ontario Department of Mines, Annual Report for 1904, Volume 13, Part 2, 354p.
- Murray, A.
1849: Report on the Bruce Peninsula and Manitoulin Islands; Geological Survey of Canada, Report of Progress for 1847-1848, p.81-121.
- Sanford, B.V.
1964: Catalogue of Ontario Well Samples at the Geological Survey of Canada, Ottawa; Geological Survey of Canada, Paper 63-46, 415p.
- Williams, M.Y.
1919: The Silurian Geology and Faunas of Ontario Peninsula, and Manitoulin Island and Adjacent Islands; Geological Survey of Canada, Memoir 111, 195p.

TABLE 1

Drillhole:	OGS 85-7 Cockburn Island		
Location:	lot 16, concession II, Cockburn Island Township, District of Manitoulin		
Elevation:	192.437 m		
Total Depth:	521.0 m		
Date of Drilling:	September 9-17, 1985		
AGE	FORMATION	DEPTH TO TOP (m)	THICKNESS (m)
PLEISTOCENE	Sand and gravel	0	29.0
MIDDLE SILURIAN	Amabel	29.0	45.5
	Fossil Hill	74.5	33.2
	St. Edmund	107.7	39.6
	Wingfield	147.3	13.1
	Dyer Bay	160.4	4.4
LOWER SILURIAN	Cabot Head	164.8	20.2
	Manitoulin	185.0	15.9
UPPER ORDOVICIAN	Georgian Bay	200.9	58.8
	Blue Mountain	259.7	66.95
	Lindsay (Collingwood Member)	326.65	5.05
MIDDLE ORDOVICIAN	undifferentiated limestone and shale	331.7	100.3
	"Glenwood"	432.0	8.5
	"St. Peter"	440.5	12.1
LOWER ORDOVICIAN	"Prairie du Chien"	452.6	30.95
PRECAMBRIAN		483.55	37.45
TOTAL DEPTH		521.0	

*These units are tentatively assigned to the listed formations. A more precise determination awaits more detailed lithological, sedimentological, and paleontological study.

DRILLHOLES

1. Flood No. 1
2. McMillan No. 1
3. Bay City Bank No. 1
4. OGS 85-7 Cockburn Island

SYMBOLS

- Bedrock outcrop
- Quarry
- Drillhole site
- Geological boundary, approximate
- Geological boundary, interpreted



PALEOZOIC GEOLOGY COCKBURN ISLAND DISTRICT OF MANITOULIN

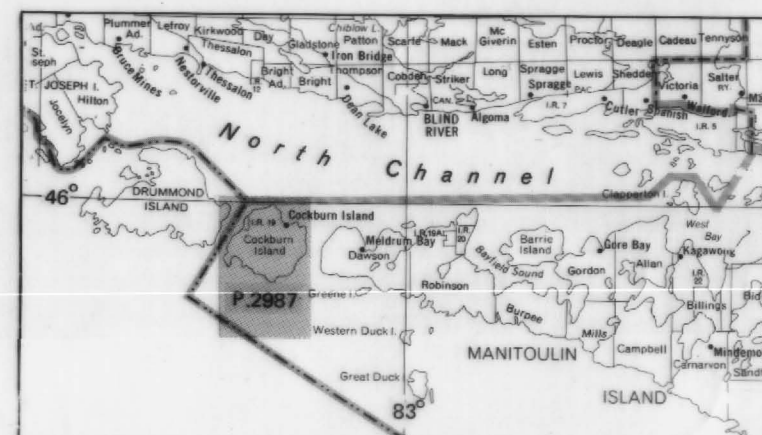
Scale 1:50 000
Metres 1000 0 1 Kilometre
Mile 1 0 1

NTS Reference: 41 G/14W
ODM-GSC Aeromagnetic Map: 2225G
OGS Geological Compilation Map: 2441

© 1986 Government of Ontario
Printed in Ontario, Canada

Parts of this publication may be quoted if credit is given and the material is properly referenced.

This map is published with the permission of V.G. Milne, Director, Ontario Geological Survey.



LOCATION MAP Scale 1:1 548 000 or 1 inch to 25 miles

LEGEND

PALEOZOIC	
MIDDLE SILURIAN	
17*	Amabel Formation (Facies IV): Dolostone, granular, soft, white, massive
16	Amabel Formation (Facies III): Dolostone, medium to coarsely crystalline, blue-grey, massive to thickly bedded
16c*	Facies III, abundant crinoidal debris
16p*	Facies III, abundant pentamerid brachiopods
15*	Amabel Formation (Facies II): Dolostone, fine to medium crystalline, blue-grey to buff, massive; minor, thinly bedded, lenticular debris forming hummocky topography
15c*	Facies II, abundant crinoidal debris
14*	Amabel Formation (Facies I): Dolostone, finely crystalline, brown, thinly bedded
14b*	Facies I, richly fossiliferous
14c-h*	Facies I, abundant nodular chert
13	Fossil Hill Formation: Dolostone, fine to coarsely crystalline, buff-brown, thinly bedded, chert-rich, fossiliferous
12	St. Edmund Formation: Dolostone, lithographic, pale grey and medium crystalline, buff-brown; thin to medium bedding; lithographic, grey limestone near base
11	Wingfield Formation: Interbedded dolostone and green shale
10	Dyer Bay Formation: Dolostone, fine to medium crystalline, buff to grey-brown, thinly bedded, fossiliferous

*Not present in this map area.

Note: Older units underlying the Dyer Bay Formation are listed in the accompanying log of drillhole OGS 85-7 (Table 1). These units have only been recognized in the subsurface and do not outcrop or subcrop beneath surficial deposits on Cockburn Island.

SOURCES OF INFORMATION

Topography from Map 41 G/14 of the National Topographic System.
Metric conversion factor: 1 foot = 0.3048 m

CREDITS

Geology by R.R. Wolf, 1985. Additional geological information from drillhole OGS 85-7 Cockburn Island.

Every possible effort has been made to ensure the accuracy of the information presented on this map; however, the Ontario Ministry of Northern Development and Mines does not assume any liability for errors that may occur. Users may wish to verify critical information; sources include both the references listed here, and information on file at the Resident or Regional Geologist's office and the Mining Recorder's office nearest the map area.

Issued 1986

Information from this publication may be quoted if credit is given. It is recommended that reference to this map be made in the following form:

Wolf, R.R.

1986: Paleozoic Geology of Cockburn Island, District of Manitoulin; Ontario Geological Survey, Map P.2987, Geological Series—Preliminary Map, scale 1:50 000, Geology 1985.

