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DEPARTMENT OF ENERGY, MINES AND RESOURCES

MEMOIR 360

PALEOZOIC GEOLOGY OF THE BRUCE PENINSULA AREA, ONTARIO

B. A. Liberty and T. E. Bolton

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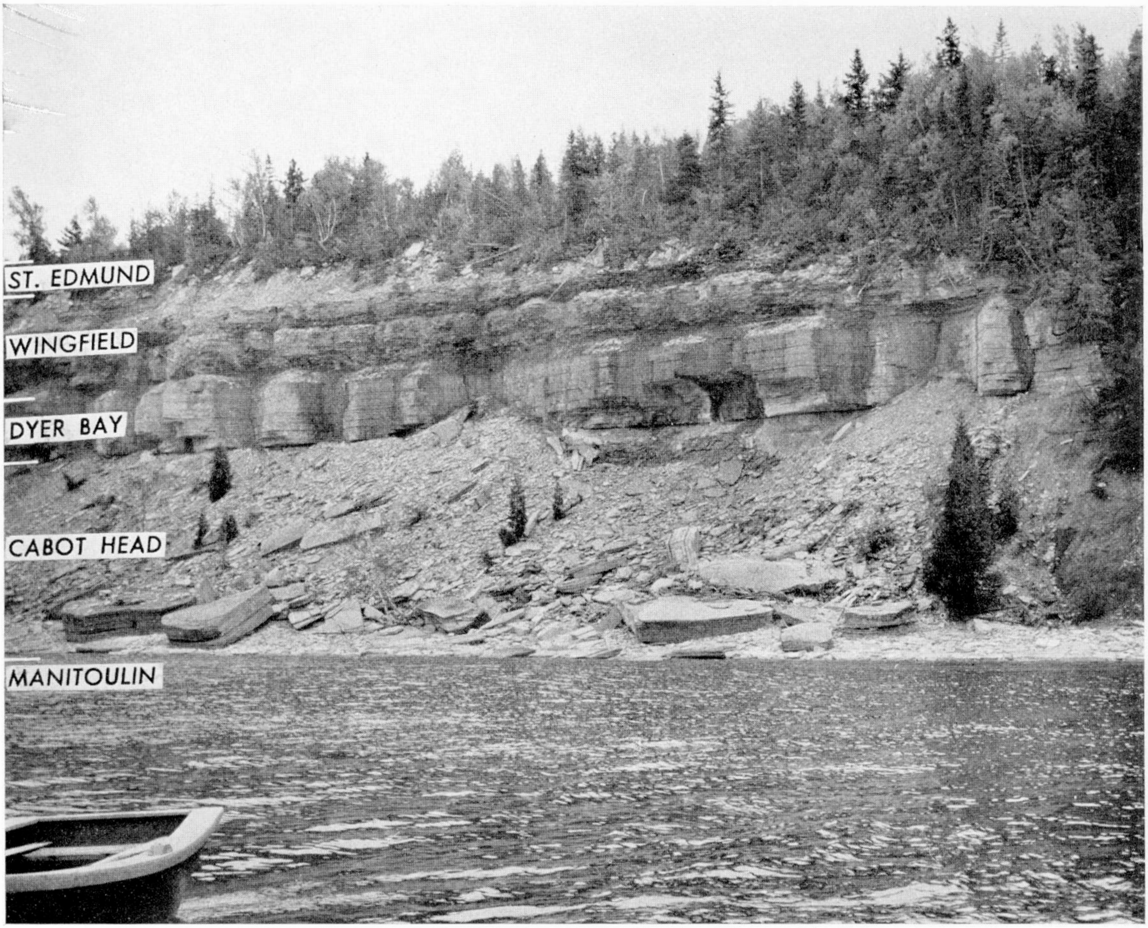

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PLATE I. View of 'Clay Cliffs' at Rocky Bay, 3 miles west of Cabot Head lighthouse, north shore Bruce Peninsula.

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PREFACE

Cambrian, Ordovician, Silurian, and Devonian strata in the Bruce Peninsula extend in subsurface into southwestern Ontario and adjoining states, where they yield valuable petroleum and natural gas. A detailed knowledge of the surface stratigraphy of these predominantly calcareous intracratonic strata should prove invaluable in future subsurface studies.

Stratigraphic units in the Bruce Peninsula continue eastward into the Lake Simcoe area and northward onto Manitoulin Island and, for the first time in many decades, permit the establishment of a uniform stratigraphic nomenclature over this wide area. The lithostratigraphic units so established may resolve several of the existing complex nomenclatural problems. The study has revealed the presence of facies changes, reefal complexes, and important data on the Algonquin (Cincinnati) Arch within the Bruce Peninsula area.

Y. O. FORTIER,
Director, Geological Survey of Canada

OTTAWA, May 13, 1966

MEMOIR 360 — Paläozoische Geologie des Gebietes der Bruce-Halbinsel (Provinz Ontario)

Von B. A. Liberty und T. E. Bolton

Eine Beschreibung der Geologie und Stratigraphie flachliegender kambrischer, ordovizischer und devonischer Karbonatsedimente eines Gebiets an der Ostseite des Michiganbeckens

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МЕМУАР 360 — Геология палеозоя района полуострова Брус, Онтарио.

Б. А. Либерти и Т. Э. Болтон

Описывается геология и стратиграфия горизонтально залегающих кембрийских, ордовикских и девонских карбонатных отложений района на восточном крыле бассейна Мичиган.

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PALEOZOIC GEOLOGY OF THE BRUCE PENINSULA AREA, ONTARIO

Abstract

This report describes flat-lying Paleozoic carbonate strata on the eastern flank of Michigan Basin. Map-units and stratigraphic nomenclature used are consistent with those in adjacent areas to the south and east and can be used on Manitoulin Island to the north.

Subsurface strata comprise the Jacobsville, Mount Simon, and Eau Claire Formations of Cambrian age, and the Shadow Lake Formation, Simcoe Group (Gull River, Bobcaygeon, Verulam, and Lindsay Formations), and the lower and upper members of the Whitby Formation, all of Ordovician age. Oldest surface strata are the Ordovician Whitby and Georgian Bay Formations of the Nottawasaga Group and the Queenston Formation. Overlying these units are the Silurian Whirlpool, Manitoulin, and Cabot Head Formations (of which the last named is further subdivided into Cabot Head (restricted), Dyer Bay, Wingfield, and St. Edmund members) of the Cataract Group, the Lockport (Fossil Hill and Amabel), Guelph, Salina, and Bass Island Formations. The Devonian is subdivided into the Bois Blanc, Detroit River, and Dundee Formations.

The Bois Blanc and Detroit River Formations are considered to comprise the Onondaga Formation of New York State. They are described as lithic units of a reefal complex. A large scale reefal complex is also recognized in Lockport (Amabel) and Guelph strata in the excellent surface exposures north of Owen Sound.

Several southern Ontario stratigraphic problems of long standing have now been resolved through: (1) adoption of the term Dundee in preference to Norfolk and Delaware; (2) definition of the biohermal facies within the Detroit River Formation; (3) establishment of the relationship of the Detroit River Formation to the Bois Blanc and Onondaga Formations; and (4) recognition of the importance of the Rocky Bay section, near Cabot Head, on the Lower and Middle Silurian stratigraphy.

Production of salt and natural gas from the Goderich area and facing stone from the Wiarton area are the sole economic operations within the map-area. The high quality dolomite, sphalerite occurrences, petroleum possibilities, and the proximity of these items to a highly industrialized area, all add to the economic potential of the Bruce Peninsula.

Résumé

Le présent rapport décrit les couches horizontales de carbonates paléozoïques du versant est du bassin du Michigan. Les unités géologiques et la nomenclature stratigraphique utilisées correspondent à celles des régions voisines du sud et de l'est et peuvent être étendues à l'île Manitoulin au nord.

Les couches profondes comprennent les formations de Jacobsville, Mount Simon et Eau Claire, d'âge cambrien, et la formation de Shadow Lake, le groupe

de Simcoe (composé des formations de Gull River, Bobcaygeon, Verulam et Lindsay), ainsi que les niveaux inférieurs et supérieurs de la formation de Whitby, tous d'âge ordovicien. Les couches superficielles les plus anciennes sont les formations de Whitby et Georgian Bay de l'Ordovicien, appartenant au groupe de Nottawasaga, et la formation de Queenston. Recouvrant ces unités, on trouve les formations siluriennes de Whirlpool, Manitoulin et Cabot Head (celle-ci se subdivisant en plusieurs niveaux dont Cabot Head proprement dit, Dyer Bay, Wingfield et St. Edmund) du groupe de Cataract, et les formations de Lockport (Fossil Hill et Amabel), Guelph, Salina et Bass Island. La couche dévonienne comprend les formations de Bois Blanc, Detroit River et Dundee.

Les formations de Bois Blanc et Detroit River sont censées constituer la formation d'Onondaga de l'État de New York. On les décrit comme des unités rocheuses d'un complexe de récifs. On a également identifié un important complexe de récifs dans les couches de Lockport (Amabel) et Guelph, qui présentent d'excellentes surfaces affleurantes au nord d'Owen Sound.

Plusieurs anciens problèmes stratigraphiques du sud de l'Ontario se trouvent actuellement résolus grâce à: 1) l'adoption de l'appellation Dundee de préférence à Norfolk et Delaware; 2) la définition du faciès biothermal à l'intérieur de la formation de Detroit River; 3) l'établissement de la relation entre la formation de Detroit River et les formations de Bois Blanc et Onondaga; et 4) la reconnaissance de l'importance de la section de Rocky Bay, près de Cabot Head, dans l'interprétation des couches du Silurien inférieur et moyen.

La production de sel et de gaz naturel dans la région de Goderich et de pierre de revêtement dans la région de Wiarton demeure la seule activité économique de la région. La dolomie de haute qualité, les venues de sphalérite, les ressources éventuelles en pétrole et leur proximité d'une région hautement industrialisée contribuent toutes au potentiel économique de la péninsule Bruce.

Chapter I

INTRODUCTION

The Bruce Peninsula comprises that part of Ontario between 43°30′ and 45°20′N latitude and west from 80°30′W longitude to Lake Huron, which includes most of Grey and Bruce counties and parts of Wellington and Huron. It is bounded on the east by the Lake Simcoe district and on the south by the London area.

The district is one of the oldest settled areas in Ontario and includes Owen Sound, Wiarton, Tobermory, Southampton, Meaford, Kincardine, Chatsworth, Chesley, Walkerton, Hanover, Durham, Neustadt, Goderich, Clinton, and Seaforth. These localities are linked by a network of paved and gravel roads. Owen Sound, the only city in the area, is a prosperous community of more than 17,000 in an idyllic setting at the head of Owen Sound Harbour. Manufacturing is its chief industry.

Agriculture is the most important industry in the area; the main crops are grains. Cattle raising is primarily for the production of milk. Of increasing importance is the lucrative tourist industry; many thousands of people travel annually into and through the 'Bruce'.

To the writers' knowledge, the only quarries in operation in the area are those of Cook, Ebel, and Bruce Peninsula Stone and Owen Sound Ledgerock, which extract building stone for sills and other purposes on a limited scale. The Sifto Salt, Division of Domtar Chemicals Ltd., at Goderich and the Bayfield gas field are the only other economic geological operations in the map-area.

Previous and Present Work

M. Y. Williams published (1919) a comprehensive report and geological map that included the Silurian strata of the Bruce Peninsula area. J. F. Caley commenced systematic stratigraphic studies in the district in 1940, continuing his mapping and investigations northward from the Toronto-Hamilton (1940), Brantford (1941), and London (1943) areas; he published a preliminary map of the Owen Sound area in 1945. B. A. Liberty continued the field program in 1948, and between then and 1954 worked eastward to the Lake Simcoe district (Liberty, 1969) and northward to Manitoulin Island (Liberty, 1957). In 1950, T. E. Bolton extended his studies of the Niagara Escarpment northward into the Bruce Peninsula, and in 1951 and 1953 worked both there and on Manitoulin Island (Bolton, 1953, 1957). The present report includes all work undertaken by Caley, Liberty, and Bolton up to 1959.

Physical Features and Drainage

The most prominent physical feature of the Bruce (also known as Interlake, Saugeen and Indian) Peninsula is the Niagara Escarpment, which extends northward to Manitoulin

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Island and southward to the Niagara Peninsula. The greatest relief of this escarpment (or cuesta) is about 200 feet, but it averages between 120 and 140.

West of the escarpment, the topographic relief is low and rolling and the surface gradually slopes towards Lake Huron. Although drift thicknesses increase westward, the topography is essentially bedrock-controlled for a considerable distance from the face of the cuesta. The bedrock beneath this area is chiefly Silurian, but south and west from a line joining Kincardine and Walkerton Devonian strata are present. Below the Niagara Escarpment, on its east face, is a narrow band of bedrock consisting mainly of Ordovician shales. Into these soft Ordovician sediments and their covering boulders, gravel beaches, and clays are cut notches and terraces of the Nipissing Great Lakes. These features were produced during the evolution of the Great Lakes (Hough, 1958; Chapman and Putnam, 1951).

There is little overburden on the Bruce Peninsula. Sand dunes and gravel bars are exceptionally well developed in Eastnor township. The long flats between the resistant rock knobs (reefal bioherms) on highway 6 north of Wiarton are underlain by silt beds and lacustrine clay deposits. The rock knobs appear to increase northward towards Tobermory, where the Guelph reefal complex becomes continuous and forms the northern headland from there to Cabot Head.

South and westward from Wiarton, moraines, kames, drumlins, eskers, and clay plains may be found. The Saugeen clay plain (lacustrine clays) lies between Singhampton, Walkerton, Gibraltar, and Chesley. Morainal deposits are typified by the Chesley moraine. Fringing the Lake Huron side of the area is a thin belt (the Huron Fringe of Chapman and Putnam, 1951) that comprises wave-cut terraces, gravel bars, and sand dunes. On the Bruce Peninsula it is typified by a scoured belt of the Guelph dolomites.

Because of the Niagara cuesta, with its monoclinal structure, drainage is prevailingly westward towards Lake Huron. Creeks flowing eastward are small and of little significance; East Meaford Creek is perhaps one of the more important. Few exposures of bedrock are found in any of the streams. Westward-flowing streams, such as Maitland, Teeswater, Penetangore, Saugeen, Bayfield, and Ausable Rivers are in many places excavating pre-Pleistocene drainage channels that are now filled with sands and gravels. These rivers greatly influenced the opening-up of this country by the early settlers in the middle of the 19th century.

Acknowledgments

Over the years since the date of initiation of field work, many parties of the Geological Survey of Canada have worked in the Bruce Peninsula district. During the field seasons of 1940 to 1947, J. F. Caley was assisted by A. K. Watt, R. J. W. Douglas, R. M. Watt, W. Hubachuk, W. Dickson, and B. A. Liberty. From 1948 to 1950, B. A. Liberty was assisted by C. W. Stearn, A. M. Turner, and E. W. Best. From 1950 to 1953, T. E. Bolton was assisted by B. Sivak, G. E. Bourns, and W. M. McNeely.

Courtesies were extended by owners of the many quarries visited, and continued cooperation was given by the late C. S. Evans, Union Gas Co. of Canada, Chatham, and by W. A. Roliff of Imperial Oil Ltd., Toronto.

The authors are especially indebted to J. F. Caley of the Geological Survey of Canada for permitting the unrestricted use of his unpublished manuscript on the map-area, and for his interest and constructive criticism during the preparation of this report; and also to Madeline A. Fritz of the Department of Geological Sciences, University of Toronto, for making available the faunal collections, including type specimens, of the Royal Ontario Museum.

Chapter II

STRATIGRAPHY

(*B. A. Liberty and T. E. Bolton*)

The Bruce Peninsula district is underlain by strata that range in age from Cambrian to Devonian. The beds are generally flat lying with a southwesterly regional dip averaging about 23 feet to the mile, but local structures are present in a few places. For the most part the area lies above the Niagara Escarpment with but a thin belt following the base of the cuesta. The entire area has been glaciated, and thickness of drift varies from a few feet on

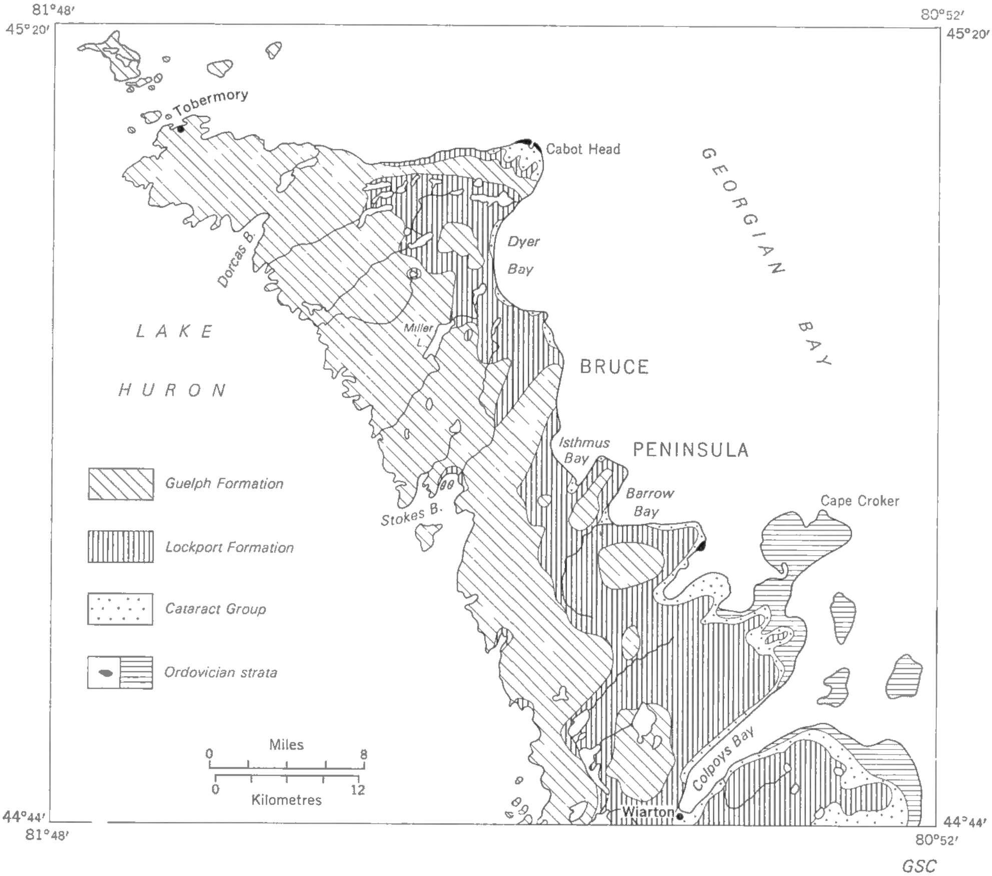


FIGURE 1. Regional geological map of Wiarton north area.

Table of Formations

		GROUP	FORMATION/MEMBER	
DEVONIAN	MIDDLE		Dundee	
			Detroit River	
			Bois Blanc	
SILURIAN	UPPER		Bass Island	
			Salina	
	MIDDLE	ALBEMARLE	Guelph	
			Lockport	
	LOWER	CATARACT	Cabot Head	St. Edmund Wingfield Dyer Bay Cabot Head
			Manitoulin	
			Whirlpool	
ORDOVICIAN	UPPER		Queenston	
		NOTTAWASAGA	Georgian Bay	Upper Lower
			Whitby	Upper Lower
	MIDDLE	SIMCOE	Lindsay	
			Verulam	
			Bobcaygeon	
			Gull River	
		BASAL	Shadow Lake	
CAMBRIAN	UPPER		Eau Claire	
			Mount Simon	
			Jacobsville	

the main peninsula to more than a hundred feet south of Wiarton and Owen Sound. South of these localities outcrop is much less numerous and occurs mostly in bedrock valleys that are now being re-excavated. Quarries are relatively few. Additional stratigraphic information was obtained from wells that have been drilled in search of petroleum.

The four formations in the basal group and the four in the Simcoe Group occur only in the subsurface in the Bruce Peninsula district. All formations from the Whitby upward are known to outcrop within the district (Fig. 1).

Cambrian and Ordovician

Basal Group

The term 'basal beds' has been used by most workers for the clastic beds below the main carbonate development of the Simcoe Group (Black River-Trenton age). As so defined, this basal group in central Ontario embraces strata of Cambrian and Ordovician age, which accumulated on the Precambrian surface and attained their greatest thicknesses in the 'basins' on the site of the present Great Lakes. The group comprises four formations within the map-area, the Jacobsville, Mount Simon, Eau Claire, and Shadow Lake, which are known solely from subsurface studies. Reference wells are the Flesherton well (600 feet from the intersection of highway 10 and the Ceylon Road, behind the Co-op store on the north side of the Ceylon Road) in Artemesia township, and the E. Hind No. 1 well in lot 28, concession III, Sarawak township, Grey county. The Shadow Lake Formation is of Middle Ordovician age, in contrast to the Late Cambrian age of the other formations. It is included in the group because of its closer affinity to the 'basal beds'.

As the Bruce Peninsula district is approached from the centre of the Michigan Basin, progressively younger formations lie on the Precambrian surface, because of truncation, erosion, and progressive overlap. The Cambrian and Ordovician seas may well have transgressed a higher Precambrian surface.

Jacobsville Formation

Definition

The name Jacobsville was first proposed by A. C. Lane and A. E. Seaman in 1907, from Jacobsville, Houghton county, in northern Michigan. As used here, the term applies to strata at the base of the Paleozoic, which constitute the oldest Paleozoic strata in southwestern Ontario.

Distribution

This formation is considered to underlie only a small part of the Bruce Peninsula district (*see* Roliff, 1954, Fig. 1), being identified in the E. Hind No. 1 well and the Flesherton well. Its presence at a given locality would be dependent on the configuration of the Precambrian surface at the time of deposition and the subsequent erosional history. The youngest strata would tend to overlap farther and would have been more susceptible to erosion during the hiatus between Late Cambrian and Middle Ordovician times.

Thickness and Lithology

Well data indicate a thickness of a few feet to 27 feet. The formation is red, brown, and purplish, fine-grained sandstone, and arenaceous shales. At the type locality, the unit is red and reddish brown, fine-grained sandstone with minor shale, conglomerate, and breccias.

Contacts

As with all thin units, contacts can be difficult to delimit, for example, the 27-foot unit in the E. Hind No. 1 well in Sarawak township. The lower contact with the Precambrian basement rocks is readily delimited by the contrasting rock types below, which include granite and granite-gneiss; the upper contact is arbitrarily defined so as to retain the clastic nature of the unit. Thus the formation must include any arkosic units that underlie typical Jacobsville sediments and overlie the Precambrian surface.

Stratigraphic Relations

Cohee (1945a) used the term Jacobsville in southern Michigan; Roliff (1954) traced this defined unit into central Ontario. More recently, Hamblin (1958) restricted the term to the Lake Superior area, north of a structural and source barrier, thus casting serious doubt on the identity of the named Jacobsville sediments in southern Michigan and Ontario.

The writers consider the Jacobsville Formation of Hamblin to embrace the Paleozoic sandstone at Sault Ste. Marie, Ontario (the Sault Ste. Marie sandstone of Logan, 1863, and the St. Mary sandstone of Collins, 1925). These sandstones are traceable southeastward to Sugar Island and Cockburn Island. The writers concur with Logan (1863) as to the similarity of the unit on La Cloche Island in the Manitoulin Island map-area. At an equal distance but southward from La Cloche Island is the Sarawak well near Owen Sound. There, similar sediments occur (Roliff, 1954).

Age

The Jacobsville appears to underlie conformably the Middle Ordovician rocks south of Sault Ste. Marie (Logan, 1863). The formation is more closely related to Upper Cambrian rocks west of Sault Ste. Marie, where in the type section in northern Michigan it is of Dresbachian age. In the Bruce Peninsula map-area the unfossiliferous strata referred to as Jacobsville are accordingly considered as Late Cambrian.

Sedimentary Environment

The sediments of the Jacobsville Formation show a curious consistency of character wherever they occur, i.e., Lake Simcoe map-area, Bruce Peninsula, La Cloche Island, Sault Ste. Marie, or northern Michigan. This suggests them to be basinal rather than of restricted origin, which would imply a local provenance for each deposit.

Mount Simon Formation

Definition

The name Mount Simon was proposed by C. D. Walcott (1914) for rocks exposed near Eau Claire, in southwestern Wisconsin. The formation there consists of a well-sorted grey sandstone that lies between Precambrian rocks and the Eau Claire Formation.

Distribution

Within the Bruce Peninsula district, Roliff (1954) and Sanford and Quillian (1959) have shown a narrow belt of Mount Simon. The latter have shown the formation only in the Goderich, Kincardine, and Southampton area, and extending inland for about 20 miles. The formation probably rims the west shore of the Bruce Peninsula.

Thickness and Lithology

Maximum thickness is about 100 feet, but the formation thins inland from Lake Huron. A thickness of 43 feet is known in a well in lot 60, concession A, Kincardine township, Bruce county.

At the type locality the formation is reported to be a medium- and coarse-grained sandstone with subangular to rounded grains, and to lie on the Precambrian wherever the Jacobsville is absent (Cohee, 1945a). In the map-area, the Mount Simon consists of light grey, medium- to coarse-grained, friable, quartz sandstone. Generally the grains are rounded, clear, and frosted, but finer and more angular grains occur in the lower part of the section. Glauconite may occur in greater than 'minor' or 'trace' amounts. Light to dark brown, fine-crystalline dolomite, may be present, least in the lower beds. Minor shaly intervals and arkose have been reported.

Contacts

Within the map-area, the formation generally lies directly on Precambrian strata. Thus the lower contact is a precise one, the underlying igneous and metamorphic terrain commonly comprising granite or granite-gneiss or quartzite. The Mount Simon Formation is generally overlain by the Shadow Lake Formation (Middle Ordovician), which consists of red and green shales. Stratigraphically, however, the Mount Simon is overlain by the Eau Claire Formation from which it can be distinguished by its lighter colour, a greater quantity of glauconite, and particularly by the interbedding of grey sandstone and dolomite.

Stratigraphic Relations

Cohee (1945a, 1948) traced the Mount Simon Formation into the Michigan Basin from the type area in Wisconsin. This unit was then traced by Roliff (1954) into Ontario where Sanford and Quillian (1959) have presented the most recent interpretation of its areal extent. The Mount Simon is known to lie above the Jacobsville Formation and below the Eau Claire. These two bounding formations are not everywhere present with the Mount Simon. Its occurrence depends almost wholly upon the pre-Mount Simon surface topography. It is probable that the Mount Simon was deposited only along the western flank of the northeasterly trending Algonquin Arch. The arch was a positive feature across the map-area in Cambrian time, but was irregularly eroded during the Late Cambrian–Middle Ordovician hiatus.

Correlation

The Mount Simon Formation is dated as Croixan (late Cambrian) in the type area. There, it is regarded as a basal member of the Dresbach by Bell, Berg, and Nelson (1956). No fossils have been found in this formation within the map-area.

Sedimentary Environment

Glauconite within the sandstone of the formation indicates that the sediments were deposited in a marine environment. The cleanness and purity of the quartz sand grains, together with the degree of roundness, indicate that the sands were extensively reworked, sorted, and transported far from the source area. The local dolomite and shale indicate variations in depositional conditions.

Eau Claire Formation

Definition

The name Eau Claire was proposed by L. C. Wooster (1878) for rocks exposed near Eau Claire, in southwestern Wisconsin. As used in Ontario, the Eau Claire is a distinct unit that overlies the quartz sandstone of the Mount Simon Formation.

Distribution, Thickness, and Lithology

The formation is believed to form a thin wedge beneath the Bruce Peninsula between Goderich and Southampton (Roliff, 1954). Within the map-area, the formation is 41 feet thick in the McRae Point well (lot 60, con. A, Kincardine tp., Bruce co.). In Michigan and adjacent states, it consists of sandstone, shale, and shaly and sandy dolomite. The dolomite beds vary from grey to dark grey, dark purple, red to brown; the shale is similarly coloured. Glauconite is locally abundant (Cohee, 1945a).

In the map-area the Eau Claire consists of (1) buff to grey-buff, fine- to medium-crystalline dolomite and coarse quartz sandstone composed of frosted, well-rounded grains; (2) white to grey, fine- to medium-grained sandstone containing angular and subangular quartz grains and interbeds of grey, fine-crystalline dolomite; and (3) light to dark grey dolomite with light to dark zones that are red, pink, and buff, fine- to medium-crystalline, arenaceous and argillaceous, and contain some glauconite. Arkose is present in the basal few feet of the formation. The Eau Claire sediments are distinguished from the subjacent Mount Simon by their darker colour, pink colorations, arenaceous dolomite, and glauconite.

Contacts

The Eau Claire Formation lies stratigraphically above the Mount Simon. Its lower contact is delimited on the basis of gross lithology where grey interbedded sandstone and dolomite rest upon the quartz sandstone of the Mount Simon Formation. Where the Eau Claire overlaps the Precambrian surface, the contact with the granite–granite-gneiss terrain is generally sharp. In Michigan, the Trempealeau overlies the Eau Claire Formation; within the map-area the Trempealeau is absent and the Shadow Lake overlies the Eau Claire.

Stratigraphic Relations

Cohee (1945a, 1948) traced the Eau Claire Formation from the type area in Wisconsin across the Michigan Basin; Roliff (1954) traced it into Ontario, believing it to be overlain by the Dresbach Formation. Sanford and Quillian (1959) considered Roliff's Eau Claire to be divisible into two units, the lower one being the true Eau Claire, the upper one being the Trempealeau Formation, which they considered to embrace all the post-Mount Simon strata in the McRae Point well. The writers of this report follow Roliff in assigning the shale in the McRae Point well to the Eau Claire Formation. As Roliff (1954, p. 108) has pointed out, it is a logical inference that the formations of Late Cambrian age originally encroached more of the Algonquin Arch than their present distribution indicates. This distribution is the result of erosion during the Late Cambrian–Middle Ordovician hiatus.

Correlation and Sedimentary Environment

In the Bruce Peninsula district the formation is tentatively assigned a Late Cambrian (Croixan) age on the basis of fossil data from Wisconsin. No fossils have been recognized from the McRae Point well.

Pelletoid glauconite indicates a marine origin. The glauconite content may be as high as 10 per cent.

Shadow Lake Formation

Definition

The term Shadow Lake Formation was proposed by Okulitch in 1939. Liberty (1955) redefined the term to apply strictly to the 'basal beds' of Johnston (1911) in the same area. As such, the definition differs from that of Okulitch in that the unit contains only clastic sediments. The reference section is 4 miles north of Coboconk in the Lake Simcoe district (Liberty, 1969).

Distribution

The formation underlies most of the Bruce Peninsula district, but has been recognized only in well-cuttings. Its presence at any given locality, however, depends upon the topographic relief of the underlying Precambrian surface.

Thickness and Lithology

Well records show rapid variations in thickness of the Shadow Lake strata from 3 to more than 65 feet, owing to irregularities in the Precambrian floor. Over some Precambrian 'highs' the formation is entirely absent.

The formation consists chiefly of red and green shale with embedded angular and subrounded quartz and feldspar grains. Arkosic sandstone and arkose commonly occur as thin bands directly above the Precambrian surface. Where underlying Cambrian sediments are or were present the formation may include reworked material. In well-cuttings the formation appears to be more arkosic and sandy, with green and red shale fragments, the softer shales having been 'washed out' during the course of drilling.

Contacts

Where the formation overlies the Precambrian gneiss, the lower contact can be readily defined. Where it lies on the Jacobsville Formation both units are thin (one 5-foot sample contains both formations) and the contact is delimited at the boundary between red and green shale and arkose of the Shadow Lake Formation and the purplish sandstone and shale of the Jacobsville Formation. The upper contact is drawn where the clastic sediments of the Shadow Lake Formation change to the carbonate sequence initiated by the Gull River Formation.

Age and Sedimentary Environment

No fossils have yet been found, but the formation is dated as Middle Ordovician because it is overlain with apparent conformity by limestones enclosing a Pamelia fauna of Black River age.

As the Shadow Lake was deposited in the map-area and over the Algonquin Arch, the Ordovician sea advanced and overlapped any Cambrian strata that may have been deposited. Such a surface would present an eroded and truncated pattern as suggested by Roliff (1954, Fig. 1). Thus, the underlying formations were probably limited in their extent by erosional processes between Upper Cambrian and Middle Ordovician time. The Middle Ordovician sea reworked parts of the Cambrian sandstones and 'tapped' the great mass of weathered detritus that must have been produced by weathering of the Precambrian Shield.

Ordovician

Simcoe Group

The term Simcoe Group was proposed by Liberty (1955) for the limestone sequence between the basal clastic group and the 'Collingwood' black shales. This group is divided into the Gull River, Bobcaygeon, Verulam, and Lindsay Formations.

No formations outcrop within the map-area; all information has been gathered from subsurface investigations. The group's thickness is about 515 feet near Owen Sound, 506 feet at the north end of the Bruce Peninsula, and about 550 feet near the eastern limit of the map-area. Each of the four formations within the group is a rock unit readily traceable into a surface formation of the same name in adjacent map-areas. The formations are also traceable eastward into the Ottawa Valley and New York State and northwestward into Mani-

TABLE I | *Ordovician nomenclature and correlation chart (compiled from published literature).*

TIME-STRATIGRAPHIC TERMS	TIME-ROCK, ONTARIO STANDARD (?) SECTION	ONTARIO FORMATIONS (this report)			NORTHERN MICHIGAN BIOSTRATIGRAPHIC UNITS (modified from Stumm and Kauffman, 1958)	
RICHMONDIAN	WHITEWATER - SALUDA - ELKHORN		QUEENSTON			BIG HILL / KAGAWONG
RICHMONDIAN	MEAFORD	NOTTAWASAGA GROUP	GEORGIAN BAY	upper member		STONINGTON: OGONTZ
RICHMONDIAN	MEAFORD	NOTTAWASAGA GROUP	GEORGIAN BAY	lower member		STONINGTON: BAY DE NOC
MAYSVILLIAN	DUNDAS	NOTTAWASAGA GROUP	GEORGIAN BAY	lower member		STONINGTON: BAY DE NOC
EDENIAN	BLUE MOUNTAIN	NOTTAWASAGA GROUP	WHITBY	upper member		BILLS CREEK
EDENIAN	GLOUCESTER	NOTTAWASAGA GROUP	WHITBY	upper member / middle member		BILLS CREEK / HAYMEADOW CREEK
EDENIAN	COLLINGWOOD	NOTTAWASAGA GROUP	WHITBY	lower member	TRENTON	HAYMEADOW CREEK
TRENTONIAN	COBOURG	SIMCOE GROUP	LINDSAY		TRENTON	GROOS QUARRY
TRENTONIAN	SHERMAN FALL	SIMCOE GROUP	VERULAM		TRENTON	CHANDLER FALLS
TRENTONIAN	HULL - KIRKFIELD	SIMCOE GROUP	BOBCAYGEON		TRENTON	
TRENTONIAN	ROCKLAND	SIMCOE GROUP	BOBCAYGEON		BLACK RIVER	BONY FALLS
BLACKRIVERAN	LERAY	SIMCOE GROUP	BOBCAYGEON / GULL RIVER		BLACK RIVER	BONY FALLS
BLACKRIVERAN	LOWVILLE	SIMCOE GROUP	GULL RIVER		BLACK RIVER	
BLACKRIVERAN	PAMELIA	BASAL GROUP	SHADOW LAKE		BLACK RIVER	
UNDERLYING ROCKS	UNDERLYING ROCKS	BASAL GROUP	UPPER CAMBRIAN			UPPER CAMBRIAN

GSC

toulin Island and northern Michigan. The Simcoe Group itself is the correlative of the Ottawa Formation in the Ottawa Valley as well as its lithic equivalent for the most part.

The contacts of the group are fairly precise. As the underlying Shadow Lake Formation consists of clastic rocks, the clastic rock–limestone contact can be recognized fairly easily, though there are several feet of transitional beds containing an alternation of both facies. These transition strata are arbitrarily placed in the Simcoe Group. Similarly, at the upper contact, there are several feet of interbedded limestone and black shale below the main black shale section of the lower member of the Whitby Formation. The boundary between the Simcoe Group and the Whitby Formation is arbitrarily drawn at the base of the black shale, and the alternating limestone–shale transition beds are therefore included in the Whitby Formation.

The Simcoe Group appears to be the product of continuous sedimentation. The Bobcaygeon calcarenitic sediments are interpreted as the product of shallow-water conditions related to a biostrome development, in contrast to the quieter, lagoonal lithographic limestones of the Gull River. The Verulam and Lindsay Formations indicate fairly shallow deposition with oscillatory conditions producing the alternations of shale, limestone, and argillaceous limestone. The denser, sublithographic strata in the uppermost part of the Lindsay Formation may indicate quiet, deeper water conditions for these calcareous claystones. It appears to be a consistent unit occurring over a wide area.

The terms Black River and Trenton have only recently (Kay, 1960) evolved formally into time terms. In older reports 'Trenton' was used casually (as jargon) by oil company personnel, etc., for the strata included in the Simcoe Group of this report. Too few workers have realized that the Black River–Trenton boundary is delimited by recourse to the enclosed faunas (and thus it must be a time boundary). In this report this boundary is placed within the lower member of the Bobcaygeon Formation.

Gull River Formation

Definition

The name Gull River was proposed by Okulitch in 1939. Liberty (1955) subsequently modified the original definition so that it would apply to the natural rock unit for which Johnston (1910, 1911) used the term 'Lowville'. As such, the formation essentially consists of the lithographic and sublithographic limestone section that lies above the red and green shales and arkoses of the Shadow Lake Formation and below the fine- and medium-grained bioclastic and calcarenitic limestones of the Bobcaygeon Formation.

As so defined, the formation comprises and/or embraces (1) the '*Beatricea* beds', which are the same rocks as Liberty's lower member of the Gull River Formation; (2) Okulitch's Moore Hill beds, which Liberty (1963, Geol. Surv. Can., Paper 63-14, p. 6; 1969) called the upper member of the Gull River Formation in the Lake Simcoe district; and (3) the 'Birdseye limestone' (Johnston, 1911), which effectively embraces the Moore Hill beds and corresponds to Liberty's middle and upper members of the Gull River.

In the subsurface the formation is not formally subdivided. A two-fold subdivision is believed possible, however, with the lower containing variable amounts of dolomitic limestone.

Distribution, Thickness, and Lithology

The Gull River Formation does not outcrop within the map-area, but well records indicate that it is consistently present beneath younger strata. In the adjacent Lake Simcoe district, where it outcrops, the formation is about 85 feet thick (Liberty, 1969). In the Bruce

Peninsula district, according to wells for which the drilling samples are available, it thickens to 100 feet in Nottawasaga and Collingwood townships, 135 feet in Sarawak, 187 feet in Keppel, 200 feet in Amabel, 198 feet in Albemarle, 174 feet in Eastnor, and 210 feet in St. Edmunds townships.

The formation can be divided into two members in the Bruce Peninsula district. The lower is the same rock unit as the lower member recognized by Liberty (1969) in the Lake Simcoe area to the east; the upper in the Bruce Peninsula district is a combination of the middle and upper members recognized by Liberty in surface exposures in the Lake Simcoe area. This combination in the Bruce Peninsula district is necessitated by the absence of distinguishing characteristics for the two members in drillhole samples.

The lower member of the Gull River Formation is chiefly grey to dark grey to brown sublithographic to lithographic limestone. Important amounts of dolomitic limestone and dolomite are present, increasing in abundance down section; their presence distinguishes the lower from the upper member. Thus the lower member is a more impure unit than the upper member, which comprises the high calcium limestone section. The dolomite varies from fine to medium crystalline and is brown. Some samples show these dolomitic strata to be fossiliferous, ostracods, bryozoans, and brachiopods having been observed. Insoluble residue studies indicate a fine quartz sand in some samples only. Minor amounts of clay-like glauconite, and traces of pyrite, shale, calcarenites, and oölites have been reported in well-cuttings from the lower member.

A persistent clay seam (bentonite-metabentonite[1]), in the upper part of the lower member can be traced for many miles. It forms the MX seam at the top of the lower member in the Lake Simcoe district (Liberty, 1969). The top of the lower member cannot be defined by this clay seam, however, as it may transgress rock units and not always occur at the same stratigraphic level. The seam is laminated, generally not more than half an inch thick, is light green to pale blue, and samples from it will swell slightly with the application of a moderate amount of water. In well-cuttings and core it makes a distinctive, easily recognizable horizon.

Another locally important constituent of the lower member is a digitately mottled dolomite (fine crystalline) or limestone (lithographic) in which the digits are lithographic limestone and finely crystalline dolomite respectively. Where present this is a very distinctive unit and can be easily recognized.

The upper member is essentially a lithographic to sublithographic limestone, varying from brown to light brown, tan, grey, and chalky grey. It also includes minor to trace amounts of dolomitic limestone and dolomite, which are in general finely crystalline. Oölites and clastic pellets of lithographic limestone are often observed. Fossils are relatively rare and consist mainly of ostracods. Pyrite, shale, and mineral moulds are found in trace quantities. The moulds are small to large gashes in the rock, and in places are filled with crystals of calcite or celestite.

Usually present within the uppermost strata of this upper member are traces of the MH clay seam (Liberty, 1969). This seam is amazingly persistent over long distances, having been traced from well to well from the Lake Simcoe district into southwestern Ontario. Like the MX seam, it may be used as an 'indicator', but should not be used to define the upper contact of the formation, for it may not everywhere occur at the same stratigraphic position. Traces of this seam may occur 'down hole' for several samples owing to 'cavings' so that the footage of the highest occurrence should be noted for the level of the seam.

[1]As the clay mineral in this seam is illite, Forman and Lake (1954) concluded that the strata should no longer be called bentonite (in which the clay mineral is montmorillonite) or metabentonite (in which the clay mineral is beidellite), but rather "persistent clay seam". However the terms bentonite and metabentonite have been used for many years and carry a time-line connotation not expressed in the term "persistent clay seam", which may justify retention of the term bentonite.

The origin of the persistent clay seams (bentonite) in the Gull River Formation deserves further investigation. Whether or not these are the result of volcanic ash falls has never been satisfactorily explained. The MH seam is known to extend for more than 200 miles without any apparent change of thickness, whereas the MX seam extends for more than 50 miles and according to the drillers, locally thickens from its normal $\frac{1}{2}$ to 1 inch to 5 feet or more in the Skeele well in Adjala township. Whether or not these seams were originally volcanic ash, they seem to have the same practical value as if they were, in that they serve as excellent stratigraphic horizon markers.

Contacts

The lower contact of the Gull River Formation is drawn where the basal carbonate unit is in contact with the red and green 'basal' clastic strata of the Shadow Lake Formation. It is of necessity an arbitrary contact; minor carbonate beds may be assigned to the Shadow Lake and minor traces of shale to the Gull River.

The contact between the lower and upper members of the formation in the Bruce Peninsula district is drawn at the base of the cryptocrystalline limestone of the upper member. Glauconite and digitate mottling in the upper part of the lower member greatly assist the assignment of this contact, for these features have not been observed in samples of the upper member. The MX clay seam is an additional guide, for it generally occurs in the uppermost few feet of the lower member; however, caution must be exercised in using it as a horizon marker for it may conceivably occur above the contact.

The upper contact is drawn at the top of the highest lithographic or sublithographic limestone; this is overlain by the Bobcaygeon's fine-grained argillaceous limestone or calcarenitic limestone. The contact is generally sharp. Where transitional strata are present, the concept of assignment on the basis of gross lithology is used and any transitional strata are arbitrarily placed in the Gull River Formation. The use of chert to recognize the Bobcaygeon–Gull River contact must be done with considerable caution and attention to the lithology. For example, black chert nodules have been found in uppermost Gull River Formation in the eastern part of the Lake Simcoe district near Oak Lake. In addition, the uppermost beds of the lower member of the Bobcaygeon Formation consistently include chert, both in the surface and subsurface.

Stratigraphic Relations

The lower member of the Gull River Formation (Simcoe Group Unit A of Liberty, 1969) is essentially the same as the '*Beatricea* beds' of Johnston (1910, 1911, 1912) and the Pamelia of Young (1943). The upper member in the Bruce Peninsula area comprises the middle and upper members in the Lake Simcoe area (Simcoe Group Unit B) and is the same as the 'Birdseye limestone' or Lowville unit of Johnston (1910, 1911, 1912) and the Lowville and Chaumont of Young (1943).

Correlation

On the basis of fauna in the Gull River Formation in the Lake Simcoe area (Liberty, 1969), the lowest member is correlative with the Pamelia and the middle and upper members with the Lowville and Chaumont of New York State. In the Bruce Peninsula, the lower member is the lithic equivalent of the Pamelia; the upper member (comprising middle and upper members) is the lithic equivalent of both the Lowville and Chaumont.

Sedimentary Environment

The Gull River sediments indicate deposition under quiet lagoonal conditions. The alternating lithologies may be indicative of an influx of more coarse material (the clastic grains) during continuous sedimentation. To a greater or lesser degree also there may be developed, in the lower member, the digitate facies to which reference has already been made. Such digitate material does not differ markedly from the digitate carbonate observed on the outcrop (Liberty, 1969). Much of the reported dolomite may be of secondary origin for in the Proton well, lot 10, concession XIX, Proton township, the entire Gull River interval has been dolomitized into brown, buff, and grey dolomite, with but minor amounts of limestone remaining. The sharp relations of the upper contact are indicative of corrosion surface phenomena (Weiss, 1954, 1958). Whatever their explanation may be, their presence supports the idea of local diastems. For the most part the Gull River presents a fairly uniform lithic unit that is certainly the extension of the Lowville lithographic units from northern United States. Generally then, quiescent, shallow, lagoonal conditions are envisaged for the deposition of this formation.

Bobcaygeon Formation

Definition

The term Bobcaygeon was proposed by Liberty (1969, 1963) for the granular calcarenitic sequence of rocks that lies immediately above the lithographic limestone sequence of the Gull River Formation and below the distinctively interbedded limestone and shale of the Verulam Formation. In outcrop in the Lake Simcoe district Liberty divided the formation into three members. This division is of practical value in geological mapping and in interpreting geological history, but only one unit is recognized in the subsurface in the Bruce Peninsula district and elsewhere in southwestern Ontario.

Distribution, Thickness, and Lithology

The Bobcaygeon Formation is not known to outcrop in the map-area, but well records indicate that it is present beneath younger strata throughout the area.

In the Lake Simcoe area to the east the formation is 79 feet thick. In the Bruce Peninsula area, however, thickness ranges between 190 and 230 feet.

The Bobcaygeon Formation consists of grey to brownish grey, argillaceous to calcarenitic, fine- to medium-grained, and bioclastic limestone. Except for the lowest few feet, it is fairly fossiliferous. In the uppermost strata very thin black shale partings become prominent. Chert nodules consistently occur about 20 feet above the base of the formation, where they probably represent the same horizon as the black chert nodules seen in the outcrop in the uppermost few feet of the lower member of the formation in the Lake Simcoe area (Liberty, 1969). No chert has been reported from higher in the formation. A persistent clay seam (bentonite[1]) generally occurs above the chert at about the same stratigraphic level from well to well. This seam was assigned the code letters MR in the Lake Simcoe area, where both the chert and the MR seam occur within the Trenton part of the lower member of the Bobcaygeon Formation. It seems reasonable therefore to assign the chert and MR seam in the subsurface of the Bruce Peninsula area to the Trenton strata of the Bobcaygeon Formation.

In the Lake Simcoe district the following members were recognized:

upper member —fine-grained, argillaceous limestone and fine- to medium-grained calcarenite, with minor dark grey to black shale partings, minor sublithographic limestone (34 feet).

middle member —sublithographic limestone (20 feet).

lower member —fine-grained, argillaceous limestone with fine- to medium-grained calcarenite (25 feet).

[1]This clay seam is not properly a bentonite, by definition, for reasons stated, but there is some value in thinking of it as a bentonite for correlation purposes.

Contacts

The lower contact of the formation is drawn arbitrarily where the lithographic limestone sequence of the Gull River is overlain by fine-grained argillaceous and calcarenitic limestones. One good marker in well samples is the usual occurrence of the MH clay seam (bentonite) about 10 feet below the top of the Gull River Formation. Useful markers for the Bobcaygeon are the MR clay seam and the chert near the base of the formation.

The upper contact is drawn at the 'shale break', which is so prominent throughout the Great Lakes area. This break, which in reality represents a slight increase in argillaceous content and a darkening of the colour of the limestone, is described more fully under the Verulam Formation. The contrast is sharp between the grey bioclastic and calcarenitic Bobcaygeon strata and the darker more argillaceous Verulam strata.

Stratigraphic Relations and Correlation

The term Bobcaygeon rather than the terms Coboconk and Kirkfield was used by Liberty in the Lake Simcoe area as it seemed better to introduce a new term than to redefine existing terms, which themselves had been redefined or whose definitions had caused misinterpretation. Generally, but not precisely, the lower member of the Bobcaygeon as defined in the Lake Simcoe district corresponded to the Coboconk, the middle member had never previously been recognized or described, and the upper member corresponded to the +4- to +36-foot interval of the Kirkfield quarry and therefore is the Kirkfield of Kay (1937). The lowest member was correlated with the Chaumont–Leray–Rockland, the middle and upper members with the Rockland. The writers do not use the term Hull in central Ontario; the context in which this stratigraphic term may be used has been discussed elsewhere (Liberty, 1969).

Thus strata of the Bobcaygeon Formation straddle the Black River–Trenton time-line, which from outcrop studies in the Lake Simcoe district would be drawn within the lowest member. With the terms Black River and Trenton having faunal connotation—indeed, these are biostratigraphic terms (Kay, 1960; Wilson, 1945)—it is no longer proper to refer a formation to either Black River group or Trenton group in Ontario.

Strata of the Bobcaygeon Formation are correlated with the (Chaumont)–Leray–Rockland of the Ottawa Formation in the Ottawa Valley, with the Cloche Island beds on Manitoulin Island, and with the Bony Falls strata on Escanaba River in northern Michigan. The formation is also the lithologic equivalent of the units exposed at the last two localities.

Sedimentary Environment

Liberty considers the Bobcaygeon sediments to fit into a biostromal pattern. Thus thinning and thickening on both local and regional scale may occur and one member may not be present in all sections.

Much of the Bobcaygeon sediment is considered to be the product of erosional processes in adjacent areas, or to be from stratigraphic levels as yet not suspected to represent diastems. Such material would have been transported and deposited in the course of continuous sedimentation. Normal marine conditions existed, the sediment, depth, and turbulence appearing to have been more conducive to life and preservation of organic remains than the conditions existing during the deposition of the Gull River Formation. In contrast to the more quiescent sediments as typified by the middle member, small scale cross-lamination (microcrossbedding) and small diameter 'eddies' in the clastic, bioclastic, and fragmental material indicate moderately shallow depths of deposition, about 20 to 40 feet.

For a discussion of the chert at this stratigraphic position, *see* Liberty, 1969.

It is interesting to note that most of the above rock units and stratigraphic markers are traceable throughout Ontario and into adjacent states. The persistency of these features over such a widespread area is a most impressive phenomenon.

Verulam Formation

Definition

The term Verulam was proposed by Liberty (1955) for the distinctively interbedded limestone and shale that lie above the fine-grained to calcarenitic limestone of the Bobcaygeon Formation, and below the grey limestone of the Lindsay Formation. The formation consists essentially of a fine-textured and bioclastic limestone, which alternates with distinct shale beds that typify the "Trenton (restricted)" (Raymond, 1914) to which this unit, approximately, conforms lithologically.

Distribution

The formation is not known to outcrop within the map-area. Well records, however, indicate that it is present beneath younger strata throughout this area, becoming perhaps thinner in the north.

Thickness and Lithology

Near Collingwood, at the eastern edge of the map-area, the formation is about 200 feet thick (Liberty, 1969). Northward, it thins to 90 feet at Owen Sound and to about 50 feet at the top of the Bruce Peninsula.

Essentially, the Verulam is a grey, fine-grained limestone. Shale partings and beds are a prominent feature in cuttings and core. These shale partings show in minor proportions in the well-cuttings, however, as most probably the shale washes out. The member is fairly fossiliferous, and in places has some dark grey inclusions.

In the outcrop area the limestone of this unit varies somewhat from the above description. Lower strata are typified by a 'purer' limestone approaching a sublithographic texture, whereas higher strata tend to be fine to medium crystalline. Further, the shale may occur in beds 2 to 3 feet thick rather than in partings, or in thin 1- to 2-inch beds that have been observed in the core. Higher in the formation minor amounts of sugary, fine-, medium-, and coarse-crystalline limestone occur. Minor sublithographic limestone is also present.

Contacts

The lower contact of the formation is defined where the interbedded section of the Verulam lies on the granular-calcarenitic Bobcaygeon Formation. The lowest few feet is generally argillaceous limestone with a profusion of fossils. Liberty believes the 'shale break' (that is so persistent throughout the Great Lakes area) to be located at and in the base of the Verulam Formation. Cohee (1947) referred this 'break' to the Black River–Trenton contact, but noted, however, that Kay (in a footnote in Cohee, 1947) observed that the actual Black River–Trenton contact should be drawn much lower in the section. Liberty agrees with Kay and draws that 'time-line' within the lowest member of the Bobcaygeon. Furthermore, the 'shale break' is not actually a shale break, but rather a change of colour only with but a slight increase in argillaceous content.

The upper contact of the Verulam Formation is drawn at the top of the predominantly medium- to coarse-crystalline unit, between the grey to brownish grey argillaceous limestone of the Lindsay and the Verulam ribbon limestones. A transitional unit of argillaceous or bioclastic limestone with shale partings, which is present in some sections, is arbitrarily assigned to the Verulam.

Stratigraphic Relations, Correlation, and Sedimentary Environment

The lithology of the upper beds is included in the Verulam Formation primarily because it is the upward extension of one of the Verulam's typical lithologies and is dissimilar to typical Lindsay sediments. This stratigraphic interpretation is not in agreement with those of many other workers. Kay (pers. com.), for example, assigned strata corresponding to Liberty's upper member in the Lake Simcoe district to the Hallowell member of the Cobourg biostratigraphic unit.

The Verulam Formation is correlated with lowest Cobourg as defined by Kay (1937), but represents no part of the Cobourg as that term was used by Sproule (1936), Caley (1936), and most subsurface workers. It is also correlated with the "Trenton (restricted)" (Raymond, 1914) of New York State, with the Sherman Fall beds of the Ottawa Formation in the Ottawa Valley, with the upper strata of the 'unnamed beds' of Manitoulin Island (Liberty, 1954), and with the Chandler Falls strata on Escanaba River in northern Michigan.

Perhaps the formation's most characteristic feature is the alternation of irregular thicknesses and unevenly bedded limestone and shale, which indicates alternating conditions between the deposition of shale and limestone. It is believed that the entire formation was deposited in moderately shallow seas, i.e., perhaps 35 to 50 feet of water. Sediments of the formation were very conducive to life and to the preservation of that life, and may be termed very fossiliferous. The degree of the fossiliferous content could almost be termed an integral part of the lithology.

Lindsay Formation

Definition

The Lindsay Formation (Liberty, 1969; 1963, p. 10) constitutes the uppermost formation of the Simcoe Group. The formation overlies the alternating limestone and shale of the Verulam Formation and is in turn overlain by the black shale lower member of the Whitby Formation. The Lindsay occurs at the stratigraphic level of the Cobourg (Raymond, 1921) biostratigraphic unit, but comprises only a part of Kay's Cobourg. As the term Cobourg has faunal connotations, it is unusable for a rock unit. Accordingly the natural rock unit in about the same stratigraphic position but comprising less strata was defined as Lindsay. This unit Lindsay is the Cobourg of Sproule (1936) and Caley (1936). It encloses and conforms to Johnston's (1910, 1911) '*Rafinesquina deltoidea* beds' and the '*Hormotoma* and *Fusispira* beds.'

Distribution

The Lindsay Formation is known, from drilling records, to underlie the map-area. It does not outcrop west of the Lake Simcoe district.

Thickness and Lithology

Within the map-area the formation is about 35 feet, northward it thickens to about 50 feet at the end of Bruce Peninsula. Farther east, in the Meaford–Collingwood area it is about 200 feet.

In contrast to the light colour in surface exposures east of the map-area, the well-cuttings of Lindsay strata are brownish grey to grey. Textures noted are mainly sublithographic, but some fine-crystalline and clastic limestones are known. Shale partings are interspersed through this limestone, varying from paper-thin partings to thin shale beds. In well-cuttings, however, this shale generally washes out. The formation is moderately fossiliferous.

In outcrop the strata are exceptionally fossiliferous. Occasional bands of crinoidal and crystalline limestone from 2 inches to more than a foot thick are interbedded with the typical limestone. Calcareous shale partings exist along most bedding planes. 'Bentonites' have been reported within the section.

In the Collingwood area and eastward, the Lindsay Formation can be divided into five units (Liberty, 1969). The lowest, a blue, very fine grained limestone with thin intervals of shale, has not been recognized in well-cuttings in the Bruce Peninsula district. The overlying unit is present, however; it comprises thin-bedded, grey, fine-grained argillaceous limestone, which reduces to rubble on weathered exposures and locally includes conglomerates and calcarenites. Thin shale partings are also present in some sections. An alternating limestone and shale unit that overlies the thin-bedded limestone in the Lake Simcoe district has not been recognized. The fourth unit consists of grey, bluish grey, and brown, very fine grained to sublithographic limestone (calcareous claystone) with wispy shale partings. In parts of the map-area it forms the uppermost strata of the formation, but in a few places it is overlain by an easily delimited porous buff dolomite in which occurrences of petroleum have been noted.

Contacts

The lower contact of the Lindsay Formation is drawn where the calcareous claystone or interbedded limestone and shale rest on the medium- to coarse-crystalline bioclastic limestone of the uppermost part of the Verulam Formation. The upper contact is drawn where the brownish grey limestone of the Lindsay, which may vary from calcareous claystone to granular and crystalline dolomite, is overlain by black calcareous petroliferous shale, which forms the lower member of the Whitby Formation. Interbeds of limestone have been seen in the black shale in outcrops in the Lake Simcoe district, but these comprise at most less than 15 per cent of the section and occur well up in the shale.

In the map-area the contact between Lindsay and Whitby Formations is sharp. Conglomeratic fragments in the black shale, pyrite, marcasite, and fragmental fossil remains, which mark the disconformity at this contact in outcrops in the Lake Simcoe district, have not been found, as yet, in the subsurface in the Bruce Peninsula district.

Stratigraphic Relations, Correlation, and Sedimentary Environment

Originally the strata now comprising the Lindsay Formation were included in the upper part of the Picton formation by Raymond (1914). Subsequently when it was noted that Picton had been preoccupied Raymond changed the name to Cobourg (1921), for these upper Trenton rocks are exposed at Cobourg on Lake Ontario. The original Picton at the type locality comprised the limestone beds with the gastropod fauna and the underlying limestone with *Rafinesquina deltoidea*, the whole resting on the '*Prasopora* beds,' which was termed Sherman Fall by Kay (1937). Owing to duplication and overlap of units Liberty attempted clarification of the stratigraphy by the introduction of the terms Verulam (1955) and Lindsay (1963). Neither of these terms conforms to Sherman Fall and Cobourg specifically, but both were needed for lithic mapping and subsurface purposes. It is now known that on the basis of Kay's definition of Cobourg in the reference area the Sherman Fall cannot be 200 feet thick but rather about 60 feet. In detail, the Verulam is the 'Sherman Fall' and Lindsay is the 'Cobourg' of Caley and Liberty in their preliminary publications. Liberty (1969) has now defined the Verulam to include Kay's Sherman Fall and part of the Hallowell member of the Cobourg, the Lindsay to conform to Kay's Hillier and an upper part of the Hallowell. This relationship, so seemingly straightforward, resolves a major problem in determining the facts and interpreting the literature. The literature was very complicated and the sequence of rock units presented by Liberty (1963; 1969; this report) seems to be the easiest and best way to handle the stratigraphic and nomenclatural problems. This sequence covers four formations, namely, the Bobcaygeon, Verulam, Lindsay, and Whitby. The upper member of the Bobcaygeon includes the 'crinoid beds;' the Verulam includes the '*Prasopora* beds' and the lower part of the Hallowell (Cobourg); the Lindsay includes the upper part of the Hallowell, and the Hillier; and the lower member of the Whitby is the black shale, the middle member the brown shale, and the upper member the blue shale.

Although Sproule's (1936) Cobourg does not include the lowest unit within the Lindsay, his general observations on faunal zonation can be applied. He wrote (p. 102): "The fluctuating conditions of Middle Ordovician time were such that many forms of life were migratory; sometimes, but not always, recurring in the same region. In different localities they occur at different horizons, depending, of course, on how far laterally uniform conditions persisted. Hence the zones erected may often be shown to be non-existent over any great distance." He found the common zonal fossils *Rafinesquina deltoidea*, *Cyclospira bisulcata*, *Hormotoma trentonensis*, and *Mesotrypa prolifica* to range throughout the formation and that one or more of them might be found in any outcrop of Cobourg limestone.

Liberty has traced the Lindsay laterally into Manitoulin Island (where it is still called Cobourg by other workers) and into northern Michigan to Escanaba (the Groos Quarry beds). In an easterly direction he has traced it into the Hillier and upper Hallowell (Kay) and the upper Picton (Raymond, 1914). The Lindsay is the lithic equivalent of the Cobourg beds of the Ottawa Formation in the Ottawa Valley, and is correlated with the Cobourg beds of the Ottawa Formation, the Groos Quarry beds, with the 'Cobourg' as described biostratigraphically in eastern Ontario and New York State, and with the Utica shales in New York State.

The nature of the Lindsay sediments indicates that conditions were stable and consistent during their deposition. The increase of limestone over that in the Verulam Formation suggests that conditions were more stable than earlier. Fluctuating conditions noted in adjacent map-areas do not seem to have been present. The physical data related to the upper contact strongly suggest unconformable relations in the eastern part of the map-area at least. A cessation in sedimentation is indicated for a limited period and this may be related to the location on the north flank of the Algonquin Arch. Erosion is envisioned only in the proximity of this arch, and, further, the origin of the very porous dolomite at the top of the formation may be related to proximity to the arch.

Nottawasaga Group

The Nottawasaga Group (Liberty, 1955) was redefined by Liberty (1964, p. 43; 1969) to embrace the Whitby and Georgian Bay Formations lying between the Lindsay (Cobourg beds) and the Queenston red shales. Within this group the Whitby Formation comprises three members, black shales, brown shales, and blue shales. The blue shales enclose a Blue Mountain fauna for the most part. The Georgian Bay Formation consists of alternating limestone and shales of the Dundas and Meaford biostratigraphic unit essentially, its upper member embracing the carbonate unit at the top. The latter then is wholly in Meaford strata; the lower member is in Dundas and Meaford strata.

At no locality within the map-area can the group be seen in its entirety. It is about 700 feet thick at the eastern side of the area. Well data suggest that the group thickens southward from 320 to 620 feet within the map-area. Reference sections are on East Meaford Creek, 2 miles east of Meaford and along the creek that crosses highway 26 at Camperdown. The reference well (Front Street Well, between 658 and 1,135 feet) is in the town of Flesherton, behind the Co-op store, 600 feet west of highway 10, and on the north side of the Ceylon Road.

Except for the middle member of the Whitby Formation, which occurs only in the area south of Nottawasaga Bay, the group's succession is considered to be the product of continuous sedimentation. After the recession of the seas in central Ontario, at least, the Appalachian source area was rejuvenated and the basin and shelf areas underwent changes that permitted the widespread incursion of the resultant muddy facies (lower member of the Whitby Formation) that is everywhere younger than the Lindsay. The middle member, which occurs chiefly in the Lake Simcoe area to the east (Liberty, 1969), represents the transition from the black shales of the lower member to the blue shales of the upper member. The lower member of the Georgian Bay Formation initiated the transition limestone again in the form of interbeds with the shale. The carbonate beds increase upwards in frequency until the uppermost strata of this formation are predominantly carbonate.

These items are suggestive of a shift from the shale lithosome to transitional conditions to the carbonate lithosome, which became dominant in highest Meaford strata throughout this northern area. Thus the incursion of the carbonate lithosome was accomplished and also embraces the Kagawong beds (the facies equivalent of the Queenston) on Manitoulin Island.

On faunal evidence the lower and middle members of the Whitby Formation correlate with the Collingwood and Gloucester faunas, and the upper member with the Blue Mountain fauna. The Georgian Bay's lower member contains a fauna that is of Maysvillian–Richmondian age; the upper member is Richmondian.

Whitby Formation

Definition

The term Whitby was proposed by Liberty (1955) as a group term to comprise and to delimit 'Collingwood–Gloucester' strata into rock units essentially. The term was subsequently reduced to formational status (Liberty, 1964, p. 43; 1969) and placed in the base of the Nottawasaga Group. As so defined it comprises the shale strata between the top of the Lindsay (Cobourg beds) and the base of the lowest limestone hard band in the Georgian Bay Formation (Dundas–Meaford strata). The formation is a rock unit embracing black, brown, and blue shales.

The formation is divided into a lower, middle, and upper member corresponding to each of the above noted shale types. These members in turn correspond roughly to the strata making up the Craigleith Formation (Liberty, 1955), Rouge River Formation (Liberty, 1955), and Blue Mountain Formation in ascending order, or 'Collingwood' (in reality lowest Gloucester), Gloucester, and Blue Mountain in so far as general faunal progression is concerned. The reference section for the upper member is near the map-area at the base of East Meaford Creek, 2 miles east of Meaford. Reference sections for the other two members are east and southeast of the map-area (Liberty, 1969).

Distribution

The outcrop belt of the Whitby Formation forms a narrow northwest-trending band paralleling the base of the Niagara Escarpment. It extends from the eastern boundary of the map-area to disappear beneath the waters of Georgian Bay a short distance east of Meaford. In addition to the reference section, the upper member can be seen on a small creek that enters Georgian Bay at Boucher Point and in small streams at the foot of the Blue Mountain near Camperdown.

Well-cuttings indicate that the Whitby Formation underlies the entire map-area.

Thickness and Lithology

With the formation nowhere exposed in its entirety, thickness data must be obtained from well-cuttings. Careful investigation reveals about 30 feet for the lower member and 140 feet for the upper member. The formation appears to retain a fairly consistent thickness throughout the map-area, with a tendency to thicken slightly northward to perhaps 200 feet.

The *lower member* is a dark grey to black fossiliferous shale with a few interbedded grey limestone beds. The shale is thinly laminated and weathers fissile and to almost a paper shale. Some of the shale contains a considerable amount of carbonate; most of it contains some carbonate. In core examination much of the unit is commonly logged as black limestone when it shows no lamination or fissility. For the most part the shale is petroliferous, but not bituminous as often described. The shale produces a brown streak and a brown ring when heated in a closed cold test tube. Thickness of the even limestone interbeds range from 5 to 12 inches. They may be grey, bluish grey, and brownish grey, and are for the most part of hard, brittle, and sublithographic texture. They comprise at most only 15 per cent of the member, leaving the gross lithology as black shale. In well-cuttings the black shale is easily recognized, but thickness appears to be less than in adjacent areas. The limestone interbeds are rarely noted.

The *middle member* is not known to be present in the reference sections at the eastern limit of the map-area; it may however occur to the west and north where the formation thickens slightly. Absence of this unit is interpreted as being indicative of an erosional disconformity. It comprises the soft brown shales, which are the transition beds between the lower member's black shales and the upper member's blue shales in the Toronto area. These brown shales have previously been called Gloucester by most workers, but the term Gloucester is biostratigraphic. Thickness in the Toronto area is as much as 100 feet.

The *upper member* consists of soft grey, greenish grey, and bluish grey shale, which weathers grey and bluish grey. Commonly this member weathers into thin even beds. It may be a clay shale and in many places is more nearly a mudstone, breaking with a conchoidal fracture. It includes no limestone beds or hard bands, so is a shale unit. Fossils seem to be confined to narrow zones separated by thick barren intervals. In well-cuttings the unit presents a lithologically uniform succession of soft grey shale. Some 'traces' of limestone have been reported in the well logs, but these are considered to be 'cavings' from the overlying Georgian Bay Formation. In a few wells minor petroliferous content and carbonaceous material have been reported.

Contacts

The Whitby Formation is separated from the underlying Lindsay (Cobourg) Formation by a sharp lithological change. The rubbly weathering sublithographic limestone or buff, fine- to medium-crystalline dolomite of the Lindsay is succeeded abruptly upwards by black shale of the Whitby.

The base of the middle member (where present) is delimited in such a manner that any transitional strata are arbitrarily included in the middle member. Thus the typical brown shales will embrace a lower transitional unit from the typical black shale. Similarly the upper contact of this member will be drawn so that it encloses, arbitrarily, transitional strata between typical brown shale and typical blue and greyish blue shale of the upper member. Absence of this middle member and a corresponding sharp contact between the lower and upper members in the Meaford–Collingwood area led Parks (1928) to the interpretation that a disconformity is present at this stratigraphic position in that part of the map-area at least.

The upper contact of the Whitby Formation is drawn at the base of the lowest of the carbonate 'hard bands' in the lower member of the Georgian Bay Formation. Should transitional relations develop this contact must still be defined at the lowest carbonate bed in order to retain the upper member of the Whitby as a shale unit.

Stratigraphic Relations

It would appear that the original name for the strata now referred to the lower member of the Whitby Formation was Collingwood (Raymond, 1912). It was introduced for the alternating layers of limestone and thick beds of shale containing '*Ogygites*' *canadensis, Dalmanella emacerata, Triarthrus becki,* and *Oxoplecia calhouni* that overlies the Trenton limestone in the Ottawa Valley. "This Atlantic fauna is well developed at the same stratigraphic horizon at Collingwood, Ontario, and that name is suggested for the formation"

(Raymond, 1912, p. 355). Subsequently certain confusion arose in the literature and it now appears that the term Collingwood is used for a biostratigraphic unit (Wilson, 1946; Kay, 1937, 1960). The strata enclosing the Collingwood fauna are in both the Eastview and Billings Formations of the Ottawa Valley. The Whitby Formation's lower member contains a Collingwood fauna on Georgian Bay. The Eastview's lithologic characteristics are found in the top of the Lindsay Formation (Cobourg beds).

The term Blue Mountain was proposed by Parks (1928) for the soft grey and bluish grey shales overlying the black shales of the 'Collingwood' on Georgian Bay. By description and definition, however, the Blue Mountain was used as a biostratigraphic term, being defined by the upward limit of the trilobite genus *Triarthrus*. An attempt (Liberty, 1969) to redefine the upper contact of the Blue Mountain at the first carbonate bed occurrence defeated the original purpose of Parks, since it assumed that the lowest carbonate bed occurred everywhere at about the same stratigraphic horizon and lacked corroborative faunal evidence. Liberty (1955; 1964, p. 43) introduced the name 'Whitby Formation—upper member' for the rock unit rather than redefine the biostratigraphic term Blue Mountain.

Although the upper member of the Whitby Formation and the overlying formations represent continuous sedimentation, there is probably a disconformity at the base of the upper member, at least in the eastern part of the map-area. The present interpretation is that the middle member does not extend into the Nottawasaga Bay area from Toronto, but that it extends southward from Manitoulin Island into the northern part of the map-area. The limitation is considered to be truncation on the flanks of the Algonquin Arch. Alternative interpretations are either (1) the unit was deposited over the arch area and later removed by erosion or (2) it was never deposited. Either leads to the interpretation of a positive arch area with the essential point being the *time* of such positiveness.

Parks (1928) was first to note this disconformity and the distinct variation in thickness of the black shale (here called the lower member, Whitby Formation) in the well samples of the Collingwood area. Similar relations are observable on Manitoulin Island, for at Sheguiandah, basement features are known to exist that affect the black shale thickness. Again, in the Collingwood area there is truncation against Precambrian highs, and similar conditions are believed to be present.

Correlation

The strata of the lower member are of 'Collingwood' age and are correlated with part of the Eastview and the Billings Formations of the Ottawa Valley, with the Deer River of New York State, and 'Collingwood' of Manitoulin Island and northern Michigan. The lower member is the lithological equivalent of lowest Billings Formation. In the upper member, the enclosed Blue Mountain fauna does not continue as high as the base of the Georgian Bay Formation and thus the uppermost strata of the member must belong to the Dundas biostratigraphic unit. It is interesting to note that of the thirty-five species of the Blue Mountain fauna, eighteen start in the upper member (Whitby) and range upward, whereas only six within the lower member and eight in the middle member range upward into the upper member. The upper member is correlated with the Sheguiandah beds of Manitoulin Island, the Carlsbad of the Ottawa Valley, and the lower part of the Whetstone Gulf (Lorraine) of New York. Lithologically this unit can be traced southward into the Toronto area, and northward into the Sheguiandah beds on Manitoulin Island, and the Bills Creek beds in northern Michigan.

Sedimentary Environment

Within the map-area it is suggested that erosional processes were effective at the end of Lindsay sedimentation. Shallowing conditions on the northern flank of the Algonquin

Arch are indicated, but not to as intense a degree as on Manitoulin Island. Some conglomerates were formed in the eastern part of the map-area, but their areal extent is not known. Oscillatory conditions led to the deposition within the black shale of limestone beds, which were deposited under stagnant non-aerated reducing conditions. Slow quiet sedimentation is postulated in part as there are many examples of trilobite pleurae lying beside the thoraxes. Where fragmental remains have been accumulated, more turbulent and shallower conditions are considered to have been effective. Ripple-marks and mudcracks are absent in the Whitby strata, but suncracks are known in the middle member. In consideration of this and the fissile nature of the deposits, shallow quiet waters are envisioned as the type of sedimentary environment.

Georgian Bay Formation

Definition

The name Georgian Bay was proposed by Liberty (1964, p. 45; 1969) for the rock unit of alternating grey carbonate beds and grey to bluish grey shale that lies between the Whitby Formation shales and the red shales of the Queenston Formation. The reference section for the formation is in East Meaford Creek, about 2 miles east of the town of Meaford.

As so defined, the Georgian Bay is a rock unit and embraces, for the most part, the biostratigraphic unit Dundas and Meaford. The lower contact of the formation lies within and above the base of the Dundas, and the upper contact lies within the Meaford.

Distribution

The outcrop area of the Georgian Bay Formation forms a northwest-trending belt, from less than a mile to several miles wide, extending along the lower part of the Niagara Escarpment from near the southeastern corner of the map-area to Owen Sound. Although small isolated exposures occur on creeks throughout the entire outcrop area, only at a few localities can the formation be seen to advantage. These include East Meaford Creek (Workman's Creek), 2 miles east of Meaford; along the shore of Georgian Bay between Boucher Point and Meaford; and at Claybanks north of Mountain Lake. From well-cutting data, the Georgian Bay Formation is known to underlie younger strata throughout the remainder of the area.

Thickness and Lithology

Only on East Meaford Creek is the thickness obtainable by direct measurement. The section there is exposed over a distance of about 2 miles and contains numerous small crumples and minor faults. These conditions, coupled with the difficulty in determining the attitude of the strata owing to lack of key beds, makes accurate measurement of the stratigraphic thickness very difficult. Fritz (1926) recorded a thickness of about 359 feet for Dundas (251 feet) and Meaford (108 feet) strata. Caley's plane-table measurement of the section yielded a thickness of 418 feet, which is the figure used in this report. Subsurface data indicate a thinning of the formation northwestward across the area to somewhat over 300 feet at the north end of the Bruce Peninsula.

The formation consists primarily of shale with thin interbeds of limestone and dolomite. These interbeds become thicker and the dominant lithology, with very thin beds to partings of shale in the uppermost 30 to 50 feet. Thus a twofold subdivision of member rank is believed possible.

The *lower member* consists essentially of shale with thin interbeds of impure siltstone (subgreywacke), and calcarenite, whose composition is more often limestone than dolomite. The 'hard bands' are reputedly lensitic, but the edge of a lens has yet to be seen or recorded. Thickness is generally a few inches, rarely more than a foot. The shale is commonly grey, bluish grey, and greenish grey. In the unbroken succession on East Meaford Creek the number and thickness of carbonate beds increase towards the top of the unit. In general, this member would include all biostratigraphic 'members' except the Vincent (Fritz, 1926) and Streetsville–Meadowvale (Dyer, 1925b).

In well-cuttings the lower member appears as a thick section of grey shale, the carbonate beds being indicated solely by 'traces' of limestone and dolomite. Higher strata appear as grey, bluish, and greenish shale with greater carbonate content. Medium grey prevails throughout.

The *upper member* consists essentially of grey carbonate with limestone as the dominant lithology. The lithology varies from calcarenites to medium-crystalline limestone. Thickness of bedding ranges from several inches to a foot. Uppermost strata may weather rusty. The shale occurs in 2½- to 3-inch partings, but 1- to 2-foot sections do exist; the lower contact is arbitrarily defined. This member consists of the Vincent (Fritz, 1926) and Streetsville–Meadowvale (Dyer, 1925b) beds and comprises 30 to 50 feet of strata. In subsurface samples, it appears as grey, fine-crystalline limestone. Shale is present in small amounts or as a 'trace', as it washes out readily in the course of drilling.

Contacts

The lower contact of the Georgian Bay Formation is defined to include the lowest occurrence of carbonate 'hard bands' within the unit, where they overlie the bluish grey shale of the upper member of the Whitby Formation. The upper contact with the Queenston red shale is transitional, the typical carbonate with shale partings grading upward into red arenaceous shale, red mottled green shale, and reddish limestone at one or two localities (Appendix A, section 8). At two localities only is grey limestone overlain directly by red shale (Appendix A, sections 1, 7). Arbitrarily the red mottled shale and red carbonates are included in the Queenston.

The contact between the lower and upper members is arbitrarily defined to retain the gross lithology of both units. The shale from 2½- to 3-inch beds will be mostly washed out in the course of drilling, and thicker beds will be reported as 'traces' of shale. Thus in well-cuttings when the shale beds are less than 6 inches thick, the consistent carbonate nature of the upper member will be more prominent. At only one or two localities are difficulties encountered in this respect; generally the contact is readily delimited.

Stratigraphic Relations

As the contacts of the Dundas and Meaford are delimited solely on faunal evidence, they are biostratigraphic units. As the highest observed occurrence of the trilobite genus *Triarthrus* did not conform to a change in sedimentation and the initiation of transitional carbonate sedimentation did not conform with a faunal change, lithological mapping in the Bruce Peninsula district required the establishment of newly defined rock units, namely, the Whitby Formation upper member and Georgian Bay Formation lower member.

It should be noted that the upper member thickens north of the map-area, where it embraces the carbonate facies equivalent of the Queenston Formation. With an arbitrary cut-off being used north of the Bruce Peninsula proper to delimit the Queenston from the carbonate Kagawong beds on Manitoulin Island, these latter beds are designated Georgian Bay upper member. This cut-off is quite in order, for there is no known occurrence of Queenston red shale on Manitoulin Island (Liberty, *in preparation*). 'Kagawong' biostromes are known to be interbedded in the Queenston red and red-mottled green shales in the Bruce Peninsula; these are referred to as Queenston Formation biostromes. The carbonate Kagawong beds, of biostratigraphic status, together with the underlying 'Meaford' (on Manitoulin Island) constitute the Georgian Bay's upper member, whose thickness increases to almost 200 feet. As this 'thickening' is concerned with facies change from the Queenston, whose lower interface may transgress time across this map-area, and as the sediments on Manitoulin Island are assigned to this upper member, these data are reported here. The Tobermory 'wedge', which may contain upper member strata, is discussed under the Queenston Formation.

Correlation

The lower member is traceable into the Wekwemikongsing beds (for the most part) on Manitoulin Island, and into the Bay de Noc member of the Stonington Formation in northern Michigan. Eastward this lower member appears to be the Carlsbad of the Ottawa Valley. As Dundas and Meaford are included within its limits, it is dated as Maysvillian–Richmondian. The upper member is directly traceable into the 'Meaford' of Manitoulin Island and the Ogontz member of the Stonington Formation in northern Michigan. Eastward it may conceivably be part of the Russell in the Ottawa Valley. Its strata lie wholly within the Meaford time-rock unit and is accordingly dated as wholly Richmond. Fossils collected from Georgian Bay sections within the map-area are listed in Appendix B. For details of the Dundas and Meaford biostratigraphic units *see* Liberty, 1969.

Sedimentary Environment

Deposition in moderately shallow waters is indicated by ripple-marks. For the lower member, rather than local shallow areas conducive to the accumulation of lime, fluctuating conditions are suggested for the resultant alternation of the carbonate and shale. As the lensitic form of the beds has never been proven, nor has a wedge edge been seen, the latter concept is equally valid. Higher in the member the carbonate becomes more pronounced, the transition zone of the shale and carbonate lithosomal interface tracing southward, culminating in the dominant carbonates in the Meaford–Kagawong strata. This effect is much more pronounced on Manitoulin Island to the northwest than within the map-area.

Queenston Formation

Definition

The term Queenston, proposed by Grabau in 1908 and defined as a formation by Foerste (1924), applies to the red shales that overlie the shale–carbonate sequence of the Georgian Bay Formation, and which are in turn overlain by the Manitoulin dolomite formation within the map-area. The Queenston Formation is not included in the Nottawasaga Group, but is, however, considered to be the facies equivalent of the uppermost strata of that group in the Bruce Peninsula–Manitoulin Island area.

The reference section is at Queenston, Ontario, where a part of the formation is exposed.

Distribution

The outcrop area follows closely that of the underlying Georgian Bay Formation. It forms the higher steep slopes of the Niagara Escarpment, extending generally northwestward from the southeastern corner of the area to disappear beneath the waters of Georgian Bay, a short distance north of Cape Croker. Small outcrops are numerous, but exposures of any appreciable thickness are few. The formation may be seen to advantage at East Meaford Creek, $\frac{1}{2}$ mile above highway 28; on a small creek $1\frac{1}{2}$ miles west of Mansfield; on Sucker Creek 3 miles above its mouth (Appendix A, section 1); at Owen Sound (Appendix A, section 2); at North Keppel; and at Cape Croker (Appendix A, sections 3, 4). It is visible only at low water level at Cabot Head lighthouse where it underlies the Manitoulin Formation (Williams, 1919). Queenston strata beneath the younger beds throughout the map-area are indicated by well samples.

Thickness and Lithology

The thickness of the formation is difficult to obtain from outcrops. Composite sections prepared in the Cape Croker–Colpoys Bay area, however, indicate a minimum of at least 235 feet, but this figure would be increased if the presence of red shale could be determined below the Montressor Point biostrome arbitrarily located at the lower contact in that area. Possible errors in calculating the thickness stem from the difficulty in determining dips occurring on these almost flat-lying strata. That it varies rapidly is indicated by the following well data: 291 feet in lot 28, concession I, Sarawak township (F. McNeill well); 248 feet in lot 28, concession III, Sarawak township (E. Hind well), 1.1. miles down dip; and 200 feet in the Mulberry Creek well in lot 17, concession IVW, Eastnor township, which is 25 miles obliquely across strike from the E. Hind well.

The Queenston Formation consists typically of brick red, thinly bedded, micaceous and arenaceous shales and clay shales. There is little variation in character laterally or vertically. Part of the formation presents a mottled appearance owing to patches that may be either red or green in a matrix of the alternate colour. At Keppel, the lowest few feet contains greenish grey and reddish ripple-marked limestone and silty shale layers, which enclose Richmond fossils. Most of the shales are unfossiliferous. The shales are commonly seamed by narrow greenish bands disposed at right angles, oblique and parallel to the bedding planes. The Queenston shale readily breaks down on exposure to the atmosphere, forming a fine red clay soil, which is plastic when wet.

In contrast with the typical red shale development, northwards the strata within this unit change slightly. Two biostromes of grey fossiliferous limestone consistently occur interbedded in the section near Cape Croker. These are believed traceable northward into the Kagawong biostromes on Manitoulin Island and southward into the Meaford area. Northwards, there is an increase in limestone to the top of the Bruce Peninsula, but the red shale is persistently present to Cabot Head. By arbitrary cut-off these strata are retained in the Queenston Formation, as no red shale (of the Queenston) is known in the Manitoulin Island area. There is, however, an undefined area south of Tobermory—the Tobermory 'wedge'—west of Cabot Head and north of the Mulberry Creek well in Eastnor township, in which the section is comprised of 103 feet of grey carbonate and 109 feet of grey shale, whose uppermost part shows minor red and green colorations (W. Watson No. 1 well, lot 44, con. IE, St. Edmunds tp.). Liberty suggests that the strata in this area be arbitrarily assigned to the Queenston rather than to the Meaford–Kagawong argillaceous limestone strata of the Georgian Bay Formation for the following reasons: (1) the small area and the necessity to make an arbitrary cut-off between Manitoulin Island and the Bruce Peninsula; (2) some red colorations with the grey shale, even though they are minor in amount; (3) the dominance of shale (just over the 50 per cent) in the section. Arbitrarily, then, these strata of the Tobermory 'wedge' are retained in the Queenston Formation.

In well-cuttings the formation appears as a uniformly red shale with many sections of red and green mottled shale and green shale. In the Meaford–Owen Sound area traces of greenish grey and grey shale and grey, fine-crystalline, fossiliferous limestone indicate the lithosomal interface zone and the probability of a biostrome. These changes increase northward to the grey shale and carbonate of the Tobermory 'wedge'. The subsurface data thus emphasize how the units change, the limit to which arbitrary contacts can be carried, and the nature of the increasing carbonate content as the area of the Meaford–Kagawong carbonate beds is approached.

Contacts

In the Meaford area where the Queenston is almost wholly red shale, its separation from the underlying Georgian Bay Formation is based on colour change. Transition units of red mottling are arbitrarily included in the Queenston. On Bruce Peninsula proper, however, where greenish grey shale and grey limestone are interbedded with typical red shale, identification of each outcrop is not always possible. Similarly, in the Cape Croker area, the lowest biostrome (Montressor Point biostrome = *Columnaria* reef) has never been seen to overlie red shale. A 10-foot covered interval has been delimited between this biostrome and highest Georgian Bay strata, however, and for this reason this biostrome has been arbitrarily used to delimit the base of the formation. It thus belongs in the lowest 20 feet or so of the Queenston Formation.

The upper contact is a sharp one between Queenston red shales and the grey and brown, fine-crystalline dolomite of the Silurian Manitoulin Formation. Geographically, the Manitoulin overlaps the Whirlpool sandstone a few miles south of Duntroon, east of the map-area, and there the contact is between red shale below and grey sandstone above. At each of the two contact localities: (1) lots 26-27, concession XI, Nottawasaga township, 2¼ miles northwest of Duntroon (Queenston–Whirlpool), and (2) in a small stream at Duncan in concession XII, Collingwood township (Queenston–Manitoulin), the uppermost 6 to 24 inches of Queenston consist of bluish grey, soft shale. The undulatory character of the contact, the abrupt change in lithology, and the Silurian age of the Whirlpool and Manitoulin rock units suggest a stratigraphic break at the top of the Queenston. The upper contact is believed to coincide with the boundary between the Ordovician and the Silurian Systems.

Stratigraphic Relations

Where the Queenston Formation rests visibly upon the underlying formation with which it forms a continuous series, Meaford fossils range upwards from the Georgian Bay strata into the basal Queenston for at least 20 feet. In this lower part of the Queenston, near Meaford, Foerste (1916) found a biostromal reef development whose fauna included: *Bythopora delicatula*, *Zygospira meafordensis*, *Byssonychia radiata*, *Pterinea demissa*, *Drepanella richardsoni canadensis*, *Eurychilina* (?) *striatomarginata*, *Leperditia caecigena*, *Primitia lativia*, and *Leperditella* (?) cf. *glabra*. This may well be the Montressor Point biostrome (20 feet), which occurs in the lowest 30 feet of the formation on Cape Croker (Appendix A, section 3), and which was used arbitrarily by Caley and Liberty as the base of the Queenston for mapping purposes in the Bruce Peninsula. There, this unit includes the following fauna: *Streptelasma rusticum*, *Columnaria alveolata*, *Calapoecia canadensis*, *Tetradium huronense*, *Constellaria polystomella*, *Rhombotrypa quadrata*, *Platystrophia clarkesvillensis*, *Herbertella occidentalis*, *Strophomena planumbona*, *Zygospira kentuckiensis*, *Z. meafordensis*, *Z.* cf. *modesta*, *Byssonychia praecursa* var., *Pterinea* sp., *Salpingostoma* sp., *Bellerophon parksi*, *Cyclonema bilix conicum*, *Lophospira* cf. *beatrice*, *L. bowdeni*, *Eotomaria* sp., *Liospira micula*, *Ormoceras* sp., *Leperditia* cf. *manitoulinensis*, and *Primitia* sp.

A higher 'reef' is the Prairie Point biostrome (20 feet), which lies about 110 feet above the base of the Queenston Formation (Appendix A, section 4). Included in its fauna are: *Tetradium huronense*, *Columnaria alveolata rigida*, *Zygospira kentuckiensis*, *Z. meafordensis*, *Byssonychia radiata*, *B. grandis*, *Ischyrodonta* (?) *manitoulinensis*, *Lophospira* sp., cf. *Actinoceras crebriseptum*, and *Leperditia manitoulinensis*.

These biostromes, the Montressor Point and Prairie Point, are easily traced throughout the outcrop belt in the map-area. They, with the biostromes in the underlying upper member of the Georgian Bay Formation, are believed traceable into the Gore Bay, Mudge Bay, and Maple Point (in ascending order) biostromes on Manitoulin Island. Furthermore, there is a close correlation between the Gore Bay biostrome and the *Columnaria* reef of Dyer (1925b) in the upper member of the Georgian Bay Formation near Toronto.

Liberty suggests that optimum ecological conditions conducive to the existence of biostromal reefs would increase shelfwards, away from the clastic, arenaceous sediments towards the more marine Upper Ordovician (Meaford–Kagawong) carbonates. Thus the thin biostromes in the south would thicken and become more fossiliferous nearer the main area of the carbonates.

The Queenston is considered to be the facies equivalent of the Georgian Bay's upper member (for the most part), which embraces the Meaford–Kagawong beds of Manitoulin Island. This is quite the reverse interpretation of many workers; some American stratigraphers consider the Queenston to have been deposited after and above the Kagawong strata and to have been eroded away during the hiatus at the end of the Ordovician. Detailed studies in no way corroborate this latter interpretation.

Caley and Liberty consider that the red shales are anything but consistent. They thicken and thin rapidly, even feathering out fairly abruptly into the Tobermory 'wedge'. In a southerly direction the lower contact seems to keep pace with faunal units, but may comprise slightly younger strata in the Toronto area. The red coloration seems always to start above the base of the Meaford, but Foerste (1916, p. 171) suggested it might be initiated at a lower level at possible anomalous localities.

Correlation

The 'deltaic' estuarine shales of the Queenston Formation are considered equivalent to the Juniata sandstone of the Central Appalachians, and the marine deeper water limestones and dolomites of the Kagawong beds farther out on the shelf to the north with which it interfingers. The formation is correlated with the Juniata, the Queenston of the Ottawa Valley and St. Lawrence Lowlands, New York State, and Michigan, and with the Kagawong strata of Manitoulin Island.

Sedimentary Environment

Field evidence suggests that this formation was deposited as shallow-water sediments—generally as unfossiliferous green and grey, arenaceous marine muds. These green muds were most probably oxidized to varying levels depending entirely on cyclic oxidizing phenomena from place to place as the sediments were deposited, or shortly thereafter. Although the Queenston is generally considered to be unfossiliferous it should be noted that both A. E. Wilson and B. A. Liberty have found fossils in the red shales of the Ottawa Valley (Liberty, 1964, p. 47).

Only a minor break in sedimentation at the top of the formation is known. This is illustrated by the abrupt change in lithology from shales to sandstone and dolomites and by the corresponding lithosomal shift from which basinal reshaping is inferred. Also important is the evidence of an unconformity in the basal few feet of the Manitoulin Formation (Foerste, 1916, p. 166), the undulatory character of the upper contact, and the Silurian age of the overlying Whirlpool and Manitoulin Formations.

Silurian

Cataract Group[1]

Silurian strata in the map-area comprise the Cataract Group (three formations) overlain by the Lockport, Guelph, Salina, and Bass Island Formations. The relationships of these units to those in adjoining regions and to the series in which they belong are shown on Table II.

[1]This is the Medina Formation of Caley (1945)

TABLE II | *Silurian nomenclature and correlation chart.*

TIME-STRATIGRAPHIC TERMS	LITHOSTRATIGRAPHY (FORMATIONS) (sections show comparative stratigraphy only)						
SERIES	WESTERN NEW YORK – NIAGARA PENINSULA, ONTARIO (Bolton 1957, Caley 1940)		BRUCE PENINSULA (this report)			NORTHERN MICHIGAN (Ehlers and Kesling 1957)	
CAYUGAN	BASS ISLAND	AKRON		BASS ISLAND		SALINA GROUP	ST. IGNACE
		BERTIE					
	SALINA			SALINA			POINTE AUX CHÊNES
NIAGARAN	GUELPH			GUELPH			*Megalomus canadensis*
	LOCKPORT			LOCKPORT FORMATION	member 3 = 'Amabel' (Bolton)		ENGADINE
	CLINTON GROUP	DECEW			member 2 = 'Fossil Hill' (Bolton)	MANISTIQUE GROUP	CORDELL
		ROCHESTER					
		IRONDEQUOIT					SCHOOLCRAFT
		REYNALES			member 1 (see text)	BURNT BLUFF GROUP	BYRON – HENDRICKS
		NEAHGA	CATARACT GROUP	CABOT HEAD FORMATION	St. Edmund member		LIME ISLAND
		THOROLD			Wingfield member		
					Dyer Bay member		
ALEXANDRIAN	CATARACT GROUP (= Medina, Caley 1945)	GRIMSBY			Cabot Head member (restricted)	CATARACT GROUP	MOSS LAKE
							CABOT HEAD
		POWER GLEN		MANITOULIN			
		WHIRLPOOL		WHIRLPOOL			MANITOULIN

GSC

The term Cataract Group is used for the Lower Silurian strata in the Bruce Peninsula district in preference to the term Medina, which in New York State includes only red sandstones and shales. In the Niagara Peninsula both Medina and Cataract have been used for the rocks now comprising the Whirlpool, Manitoulin, Cabot Head, Power Glen, and Grimsby Formations. In the Bruce Peninsula district Caley and Liberty considered the Whirlpool, Manitoulin, and Cabot Head Formations, and the Dyer Bay, Wingfield, and St. Edmund members as a natural group of lithic units, and mapped them as such (Fig. 1). This unit they called the Cataract Group, following essentially the formation definition of Williams (1919). The Dyer Bay, Wingfield, and St. Edmund members, however, contain a fauna more characteristic of Clinton strata in eastern North America than of typical Cataract. A more detailed discussion of the Lower Silurian terminology in southwestern Ontario appears in Bolton (1957, pp. 7–9).

The strata described here occupy a position at the base of the Silurian System, resting on the Queenston shales (Ordovician) and succeeded by the Lockport dolomite. The Cataract Group is divided into the Whirlpool, Manitoulin, and Cabot Head Formations, the last named being divisible into four members: Cabot Head (restricted), Dyer Bay, Wingfield, and St. Edmund.

Correlation

The Cataract Group is correlated with the Medina of New York State, the Tuscarora sandstone of Pennsylvania and its equivalent, the Clinch sandstone of Tennessee. Savage (1917, 1919a) from extensive studies of the Lower Silurian rocks in Illinois, Missouri, and in the Hudson Bay region, found a striking similarity in the faunas of the *Virgiana* zone and of the higher strata containing *Stegerhynchus winiskensis*, *Dihogmochilina latimarginata*, and *Leperditia fabulina*. He concluded, therefore, that during the time these strata were being laid down the regions were part of the same basin of deposition that was broadly connected northward with the Arctic Ocean. The presence of *Virgiana decussata* in the Dyer Bay dolomite established its equivalence with the *Virgiana* zones described by Savage. Williams (1919, p. 44) further assigned an upper Edgewood age to this dolomite and a lower Edgewood age to the underlying Cabot Head shales and Manitoulin dolomite.

In the Lake Timiskaming region, Hume (1925, p. 28) reported part of the Wabi Formation as equivalent to the Cataract of Schuchert. The presence of *S. winiskensis*, *L. fabulina*, and *Zygobolba williamsi* indicated a connection between this area and the Hudson Bay region where the same assemblage had been observed by Savage. *V. decussata* in the Dyer Bay dolomite also indicated that Arctic waters were connected for a time with the sea that deposited this phase in Ontario. According to Hume (1925, p. 33) only one fossil is common to the Dyer Bay dolomite and the Wabi Formation; such limited correspondence led him to suggest a separation of these two basins in late Alexandrian time, with much thicker deposits being formed in the Timiskaming area than are found above the Dyer Bay dolomite of Lake Huron.

An examination of the contained faunas from the Lake Timiskaming and Lake Huron regions indicates rather that such a marked withdrawal as postulated by Hume probably did not occur. According to Bolton (1953, 1957), a very close relationship exists between the Wabi and Dyer Bay as well as between the overlying Thornloe limestone of Lake Timiskaming and the Fossil Hill dolomite of Lake Huron. The major inundation of this wide area occurred in early Clinton time, during which were deposited the Severn River–Ekwan River–Attawapiskat coral reef of the Hudson Bay area, Wabi–Thornloe of Lake Timiskaming, Dyer Bay–Wingfield–St. Edmund–'Lockport' up to and including Fossil Hill of southern Ontario, Burnt Bluff–Manistique of northern Michigan, upper part of the Mayville of Wisconsin, and Units B-C-D (?) of the Interlake Group of Manitoba.

Whirlpool Formation

Definition

The term Whirlpool was proposed by Grabau in 1909 for the 25 feet of quartzose sandstone that forms the base of the Silurian on Niagara River. This sandstone rests upon the Queenston shale and is overlain by the Manitoulin dolomite.

The Whirlpool cannot be shown separately on the geological map accompanying this report because of the small scale of the map and the thinness of the formation (about 10 feet). It has therefore been mapped with the Manitoulin and Cabot Head Formations.

Distribution

The extent of the Whirlpool Formation within the present area is imperfectly known. The sandstone may be traced by natural outcroppings along the Niagara Escarpment from near the southeastern corner of the area to about 7 miles south of Collingwood (north of Duntroon). It can be seen to advantage at the falls on a small creek in lot 27, concession IIIE, Mono township, Dufferin county; at Hornings Mills on Pine River; on the road between concessions I and IIE, lot 30, Mulmur township, Dufferin county (Appendix A, section 10); on a small creek in lot 6, concession XI, Nottawasaga township, Simcoe county; in the gully just below highway 24, 2 miles east of Singhampton (Appendix A, section 11); and on a small creek just north of the road between lots 26 and 27, concession XI, Nottawasaga township, Simcoe county, 2¼ miles northwest of Duntroon (Appendix A, section 12).

Wells are too widely spaced to indicate, except very generally, the subsurface distribution of the formation. A well at Flesherton has about 6 feet of light grey sandstone mixed with buff dolomite resting on the Queenston red shale. Wells in Sarawak, Amabel, Culross, and Kincardine townships have no sandstone between the Queenston red shale and the overlying Manitoulin dolomite. So far as is known, therefore, the Whirlpool underlies only the southeastern part of the area, extending from the Escarpment to about the longitude of Durham, and north from the southern boundary of the area to within 4 miles of Georgian Bay.

Thickness and Lithology

Complete sections of the formation exposed at three northwesterly trending localities indicate thicknesses of 10 feet, 4¾ feet, and 7 feet for the Whirlpool (Appendix A, sections 10–12).

The Whirlpool consists of medium to light grey, fine- to medium-grained sandstone, commonly weathering buff and into irregular and lensy beds from a few to 18 inches thick. Some beds have a mottled appearance due to staining by iron oxide, and ripple-marks occur at some outcrops. The most northerly outcrop known is at the falls at the village of Duncan, where the lower 6 feet exposed consists of greenish grey, soft, sandy shale, which may represent an off-shore facies of the Whirlpool. The general lithologic character of the sandstone appears similar to that at the type locality on Niagara River.

Only one well in the map-area from which samples are available shows sandstone at the top of the Queenston shale. In it the Whirlpool is light grey to white, fine- to medium-grained sandstone.

Contacts

The Whirlpool is disconformably underlain by the Queenston Formation (Appendix A, sections 9–12). The conformable upper limit is described with the Manitoulin dolomite.

Correlation and Sedimentary Environment

The Whirlpool sandstone is essentially devoid of fossils and none has so far been observed in the present area. Paleontological correlation is therefore not possible.

Petrologic studies of the rock in the Niagara region (Alling, 1936) have indicated that it is a feldspathic sandstone, containing besides the dominant quartz, such accessory minerals as microcline, plagioclase, garnet, magnetite, leucoxene, tourmaline, apatite, and zircon. The quartz grains are commonly secondarily enlarged, the grain sizes placing the sand in the fine and medium classes of the Wentworth scale. Alling suggested that most of the quartz had been derived from a pre-existing sandstone; this agrees with Grabau's (1913) conclusion that the New York Queenston–Medina is reworked Juniata–Tuscarora of Pennsylvania. More recently, Gietz (1952 MS.) showed, on the basis of lateral variation of grain size and sorting, that the Whirlpool sandstone had its source to the south and east of its present location. It thus represents a marginal deposit laid down on the undulating and mudcracked Queenston shelf surface (Bolton, 1953).

Manitoulin Formation

Definition

The term Manitoulin was proposed by Williams (1913b, p. 37) for the lower dolomitic part of the Cataract Formation because of its typical development on Manitoulin Island. The Manitoulin rests upon the Whirlpool sandstone, or where the sandstone is absent, directly upon the Queenston shale. It is overlain, in turn, by the Cabot Head shale. Because of its thinness and the small map scale it has been shown together with the Whirlpool and Cabot Head Formations on the geological map accompanying this report.

Distribution

The outcrop area of the Manitoulin Formation follows the steep face of the Niagara Escarpment from the southeastern corner of the area to Cabot Head at the end of the Bruce Peninsula. Its physiographic expression is characterized by a low secondary cliff separated from the upper Lockport face by a steep slope formed of the Cabot Head shale. Outcrops are numerous and may be seen to advantage at the dam three quarters of a mile north of Primrose (Mulmur township); in lot 6, concession I, Nottawasaga township, Simcoe county; at Hornings Mills, about 1¾ miles west of Duntroon; on the creek entering Beaver River from the west about half a mile north of Vandeleur (Appendix A, section 16); on a small creek 1¼ miles west of Banks; on the creek in lot 18, concession VIII, Collingwood township, Grey county; a mile east of Fairmount, Euphrasia township (Appendix A, section 15); at Jackson Cove; and about 4 miles north of Hope Bay. The extensive quarries in the northeastern part of Owen Sound and the vertical cliff on the east side of the bay are in the Manitoulin dolomite. This same rock forms a low cliff paralleling the west shore of Owen Sound some three quarters of a mile inland and extending from Gravelly Bay to North Keppel (Plate II A). It reappears near the shore on the east side of Colpoys Bay, where it extends from near Cameron Point almost to Oxenden. Well borings indicate that this formation underlies younger strata throughout the area.

Thickness and Lithology

The formation is not wholly exposed anywhere within the map-area and as it contains no recognizable key horizons its thickness cannot be obtained by direct measurement. The thickest exposed section occurs on a small creek in lot 13, concession VIII, Collingwood township about a mile southeast of Ravenna, where about 44 feet of calcareous rock referable to the Manitoulin may be seen. Subsurface data indicate thicknesses of 72 feet in lot 8, concession V, Culross township; 41 (?) feet in lot 60, concession A, Kincardine township; 95 (?) feet in lot 14, range 10, Amabel township; and 50 feet in lot 17, concession IVW, Eastnor township.

As seen at the outcrop, the Manitoulin Formation consists of grey and bluish grey, fine-crystalline, dolomitic limestone with grey to bluish argillaceous partings, commonly weathering grey to buff and into thin irregular beds from 2 to 6 inches thick, but with some beds up to 2 feet. The lower few feet may be argillaceous; white weathering chert in thin nodular layers or isolated nodules occurs at some localities. Fossils are present though not numerous (Appendix B), and seem to occur most commonly along bedding surfaces.

In well samples the Manitoulin Formation appears as grey to buff, medium- to fine-crystalline, dolomitic limestone with minor quantities of greenish or bluish shale. The chert and traces of pyrite are common and fossil fragments have been observed.

Contacts

Where the Whirlpool sandstone is present, the lower contact of the Manitoulin is commonly sharp, the change from sandstone to limestone taking place without gradation (Appendix A, sections 10–12). At some localities, however, up to 16 inches of bluish grey argillaceous 'mud' intervenes. Where the Whirlpool is absent, the Manitoulin rests with sharp contact directly upon the Queenston shale (Appendix A, sections 13–16).

Cabot Head Formation

Definition

The name Cabot Head was proposed by Grabau (1913, p. 460) for the rocks "well exposed at Cabots Head" lying between the 'Manitoulin' dolomite below and the Lockport Formation above. Because this unit occurs mainly in the face of the Niagara Escarpment and also because of the small scale of the geological map accompanying this report, the Cabot Head Formation has been mapped together with the Manitoulin and Whirlpool Formations.

In the northern part of the Bruce Peninsula area, the formation can be divided into four members: Cabot Head [restricted], Dyer Bay, Wingfield, and St. Edmund (*see* Thickness and Lithology).

Distribution

The outcrop area of the Cabot Head conforms closely to that of the other formations of the Cataract Group, following the Niagara Escarpment from the southern boundary of the area to the end of the Bruce Peninsula. Weathering of this dominantly shale succession has resulted in a physiographic expression, which is characterized by steep, and commonly wooded slopes beneath the cliff of resistant Lockport dolomite that caps the formation. Outcrops are few and those showing any appreciable thickness are confined to the area north of Wiarton; elsewhere red colouring and thin loose slabs of greenish grey, impure limestone with the bryozoan *Helopora fragilis* are the sole indicators of the Cabot Head. The formation may be seen at Hornings Mills; on Noisy River 3¼ miles above Dunedin; at the falls at Eugenia; in a road-cut on the west side of Sydenham River below Inglis Falls, Owen Sound; below the Escarpment at Jacksons Cove; on the shore of Barrow Bay; on the shore 2 miles north of Barrow Bay; and at Gun Point. Well-borings indicate Cabot Head strata throughout the remainder of the area.

Thickness and Lithology

Lateral variation in lithology, coupled with the fact that nowhere is the entire formation exposed, prohibits direct measurement of the thickness. About 113 feet of section is known at 'Clay Cliffs' (Rocky Bay) 3 miles west of Cabot Head lighthouse (Pl. I; Appendix A, section 18). At Sydney Bay, the stratigraphic interval between the base of the Lockport Formation and top of the Manitoulin is about 108 feet; three quarters of a mile east of Glen Huron the same interval is approximately 95 feet; a mile south of Dunedin it is 75 feet. Thicknesses indicated by well-cuttings are: Culross township, 37 feet; Kincardine township, 67 feet; Amabel township, 115 feet; Eastnor township, 90 feet; and Lindsay township, 135 feet.

For the purpose of this report the name Cabot Head has a two-fold application. Primarily it is applied to the strata between the Manitoulin and the Lockport Formations, and at Rocky Bay it includes the following subdivisions in ascending order (Appendix A, section 18): a) a shale member, 51 feet thick (Cabot Head *sensu stricto*, hereinafter noted as Cabot Head member [restricted]); b) a dolomite member, 15 feet thick (Dyer Bay member); c) a ribbon dolomite member with shale interbeds and partings, 36 feet thick (Wingfield member); and d) a member comprising 8 feet of dolomite overlain by 3 feet of soft green shale (St. Edmund member). In the area south of Hope Bay the Manitoulin–Lockport stratigraphic interval is wholly shale, and is called the Cabot Head Formation with no member subdivisions. In the area north of Hope Bay, however, the feather edges of the dolomite members (lentilles of Williams, 1919) are introduced into the section and are traceable to the northern limit of the map-area and west to northern Michigan.

Cabot Head member [restricted][1]. As seen at the outcrop the lithology is identical with that lying between the Manitoulin and Lockport Formations south of Hope Bay. It consists of 51 feet (type section, Rocky Bay) of red, green, and bluish grey argillaceous and calcareous shale, which may be soft and plastic or firm and compact, and with interbeds of grey and greenish grey impure limestone from half an inch to a few inches thick. Gypsum is also present in the lower part of the section. The bedding surfaces of some of the thinner hard layers are characterized by a profusion of the bryozoan *Helopora fragilis;* this abundance is characteristic of the lower shale unit, the number decreasing in the overlying Dyer Bay dolomite.

Dyer Bay member[2]. This unit was named by Williams (1919, p. 35) and designated as a lentille with the type locality on the shore of Dyer Bay. Known from Benallen northward, the best exposures occur at Oxenden, Jacksons Cove, Rush Cove, Barrow Bay, Isthmus Bay, Dyer Bay (Pl. II B), and Rocky Bay (Pl. I). The unit consists of hard, dense, bluish grey and brownish grey dolomite and argillaceous dolomite in thin beds from a quarter of an inch to 4 inches thick, with uneven bedding surfaces and green weathering shale partings. It contains many examples of ripple-marks, and is generally well jointed vertically.

Wingfield member[3]. The first formal usage of this term was by Williams (1937). The type locality was designated as Wingfield Basin at Cabot Head, but it would appear that only the name was taken from that locality, the type section being in reality at Rocky Bay (Pl. I). The member can be seen to good advantage in only two places: on Isthmus Bay a third of a mile north of Lions Head (Pl. II A, Bolton, 1957); and at Rocky Bay. The unit consists of 36 feet[4] of ribbon dolomite, rather than entirely shale as originally described. It consists of thin layers of green, plastic shale between dominant beds of green weathering, brownish and greenish grey, crystalline dolomite, in thin even beds from an inch to 5 inches thick. Included may be green argillaceous pellets in the dolomite and many ostracods in the shale interbeds.

[1]Cabot Head Formation of Bolton (1957).
[2]Dyer Bay Formation of Bolton (1957).
[3]Wingfield Formation of Bolton (1957).
[4]Reported as 32 feet by Williams (1937, p. 16).

St. Edmund member[1]. This unit was named by Williams (1919, pp. 34, 37) for the dolomite and apparently the overlying 3 feet of shale that occur at the top of the Cabot Head Formation near Dyer Bay and Cabot Head; Williams called it a lentille, however, rather than a member. The type section is at Rocky Bay (Pl. I). Its presence at Dyer Bay is suggested by loose slabs of dolomite containing the coral *Favosites cristatus.* At the type locality, the St. Edmund consists of 8 feet of massive- to thin-bedded, brownish grey, finely crystalline dolomite, weathering buff. According to Williams, microscopic examination of the rock shows it to consist of "an aggregate of small uniform, rounded grains of dolomite with an average diameter of 0.01 millimeters" (1919, p. 38). Williams (ibid., Fig. 3) apparently included in the top of the St. Edmund the overlying 3 feet of soft green shale seen at the type section. Such strata are also included in the member in this report.

Cuttings from widely spaced wells show considerable lateral variation in the lithology of the Cabot Head Formation. Typically, it consists of red, greenish grey, and green shale with small amounts of grey and buff coloured calcareous rock. Well logs (Appendix C) indicate Dyer Bay strata at the localities specified: At least 25 feet (305 to 330-foot interval) in the Dept. of Lands and Forests No. 1 well in Lindsay township; 10 feet (270 to 280-foot interval) in the Mulberry Creek well in Eastnor township; and 10 feet (225 to 235-foot interval) in the J. Hughes No. 2 well in Amabel township. Dyer Bay strata are not evident in two other wells to the south. Both the Lindsay and Eastnor township wells contain Wingfield strata; the latter is only 7 miles west of Lions Head where the strata outcrop. The St. Edmund member appears to be present in the Lindsay township well.

Contacts

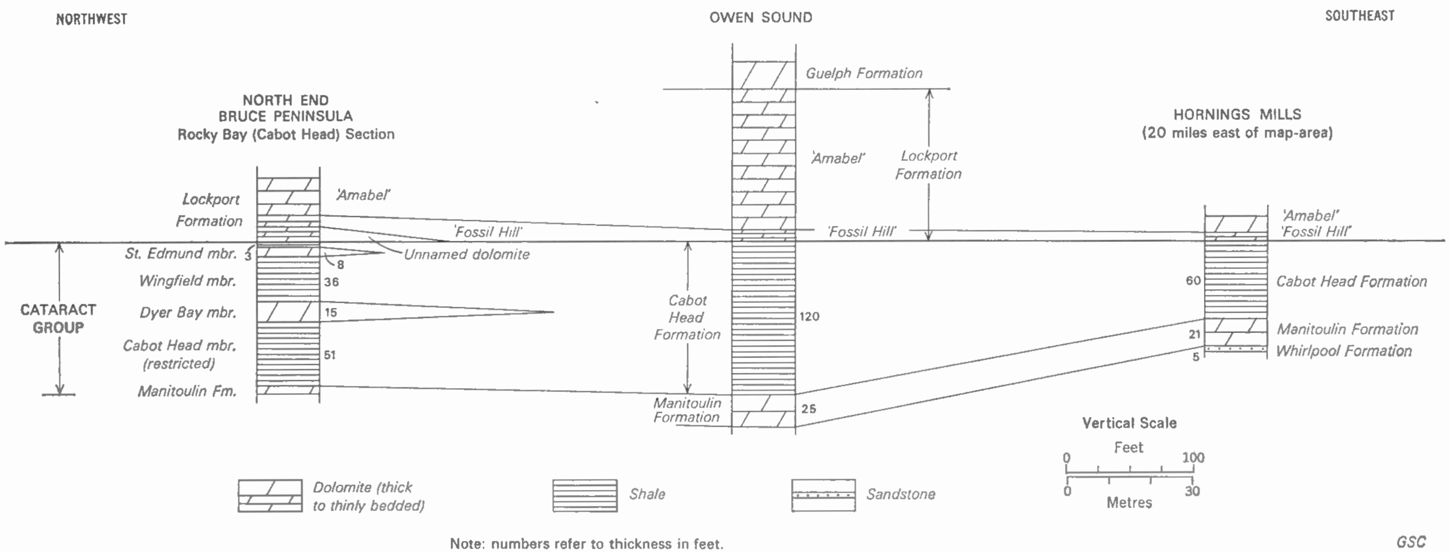
The contact of the Cabot Head Formation with the underlying Manitoulin is nowhere exposed. The change from soft shale to the resistant underlying dolomite is, however, thought to be sharp. This is indicated by the physiographic expression of the two units, the Cabot Head weathering into steep slopes, commonly wooded or covered with vegetation, and the Manitoulin forming the vertical cliffs below. At some localities, as for example at Owen Sound and paralleling the shore to Oxenden, the top of the Manitoulin Formation forms wide, flat areas from which the overlying shale has been largely removed by glaciation. The well logs cited show a change from shale (Cabot Head) to carbonate (Manitoulin) without gradation and thus substantiate the conclusion drawn from the physiographic expression of the two stratigraphic units.

The contacts between the members within the Cabot Head Formation are moderately sharp. With both the Dyer Bay and St. Edmund members being essentially thick bedded dolomite and the Wingfield being predominantly ribbon dolomite, these contacts are readily delimitable. The contact between the Cabot Head Formation and the overlying Lockport Formation is sharp (Appendix A, sections 20, 21), and is marked at the north end of the Bruce Peninsula by 3 feet of shale (Appendix A, section 18). This thin shale unit at the top of the St. Edmund member permits the continued use of the shale to distinguish the Cabot Head Formation from the overlying entirely carbonate Lockport (Fig. 2).

Stratigraphic Relations and Fauna

Various interpretations of the stratigraphic sequence within the Lower Silurian of Ontario, and in particular within the Cabot Head unit itself, have been advanced as a result of varying assignments of thicknesses and lithologies both for the complete unit and for the recognized members, i.e., uncertainty of type sections' geographic location; a thickness for the entire Cabot Head interval ranging from 110 to 133 feet; 32 and 36 feet thickness for the S;. Edmund member; green shale rather than ribbon dolomite defining the Wingfield membert

[1]St. Edmund Formation of Bolton (1957).



Note: numbers refer to thickness in feet.

FIGURE 2. Schematic facies diagram of Silurian strata.

and the apparent assignment of 3 feet of green shale to the top of the St. Edmund dolomite. All these Cabot Head strata comprised the upper unit of Caley's (1945) Medina Formation and, in part only, the Cataract Group of Bolton (1953, 1957). Because of stratigraphic evidence, contained faunas, and the consideration that the red beds of the Cabot Head (the member as herein designated) were the closing facies of Cataract sedimentation in Ontario, Bolton removed the Dyer Bay, Wingfield, and St. Edmund from the Lower Silurian Cataract and correlated them with the Middle Silurian Lower Clinton of the Niagara Peninsula. The stratigraphic grouping adopted in this report was necessitated by the scale of mapping involved and thinness of the respective units.

The following are generalizations on fauna in the Cabot Head Formation (*see* Appendix B): the brachiopod *Virgiana decussata* (Whiteaves) is restricted to the Dyer Bay; the ostracods *Chilobolbina punctata* Ulrich and Bassler and *Zygobolba williamsi* Ulrich and Bassler are common to Dyer Bay bedding planes and lowermost Wingfield; and the coral *Favosites cristatus* Edwards and Haime and brachiopods '*Atrypa*' *parksi* Williams and *Stegerhynchus winiskensis* (Whiteaves) are found in the St. Edmund. The fauna of the Cabot Head [restricted] member includes *Streptelasma* cf. *hoskinsoni*, *Helopora fragilis*, *Dolerorthis flabellites*, *Platystrophia biforata*, *Stegerhynchus neglectum*, *Whitfieldella cataractensis*, *Strophonella striata*, *Leptaena rhomboidalis*, *Parmorthis eugeniensis*, and *Cornulites incurvus* (for illustrations of Silurian faunas of Ontario *see* Bolton, T. E., 1966, *Geol. Surv. Can.*, Paper 66-5).

Niagaran Formations

Strata between the Cabot Head and Salina Formations have proven difficult to subdivide, particularly in subsurface work. It is known that the Lockport dolomites are succeeded by the Guelph dolomites. Their distinction, particularly in outcrop, has been possible because of fairly recent investigations. In the subsurface, however, for several decades the two units have been grouped by most workers and their separation still proves difficult.

TABLE III | *Subdivisions of the Lockport Formation*

	This Report	Bolton (1957), and Liberty (in preparation)		
Lockport Formation	Member 3	c) Eramosa Member b) Colpoy Bay and Wiarton Members a) Lions Head Member	thin-bedded, grey dolomite massive, bluish grey dolomite medium bedded, sublithographic dolomite	Amabel Formation
	Member 2	Fossil Hill Formation	thin, irregularly bedded, cherty dolomite	
	Member 1	An unnamed unit that extends from Manitoulin Island (part of the St. Edmund of Bolton, 1957) southward to Dyer Bay	thinly bedded, lithographic and sublithographic dolomite	

As exposed within the map-area the escarpment-forming Lockport Formation permits a definite lithological subdivision, as shown in Table III. These subdivisions can rarely be delimited in the subsurface. Well-cuttings show the Lockport to possess a fairly uniform lithology, although in some wells brown, dense, bituminous dolomite some distance above the base of the formation may be Bolton's Eramosa Member.

The surface exposures of the Guelph Formation show a lithology similar to that seen elsewhere in Ontario. In well-cuttings the formation appears as a lithologically uniform mass of buff, brown, and brownish grey dolomite. The lack of satisfactory data on which to base the separation of Lockport and Guelph units has led to subsurface workers logging of the combined strata in a single unit under the term Guelph–Lockport.

Correlation

There are few rocks beyond the Great Lakes region that can be correlated with the Guelph–Lockport of Ontario.

In Manitoba the highest Silurian rocks enclose specimens of the typical Guelph coral *Pycnostylus guelphensis*, but Tyrrell (1892, p. 203) did not define the horizon as Guelph on the evidence of a fossil "whose range is so little known." Savage and Van Tuyl (1919a) later showed that these rocks definitely belonged to a lower horizon. Recently, Stearn (1956) correlated units B, C, and D of the Interlake Group (Baillie, 1951) with the Clinton formations of Ontario, leaving only unit E and the upper beds of unit D as equivalent to the Guelph–Lockport (*see* Bolton, 1957; Ehlers and Kesling, 1957).

In the Paleozoic outlier in the Lake Timiskaming region, the Thornloe (Lockport) Formation forms the highest strata except for one exposure that "may represent transition beds from Lockport to the Guelph" (Hume, 1925, p. 34). Bolton (1953, 1957), however, assigned these dolomites principally to the Clinton.

In the Great Slave Lake area Hume (1926) and Foerste and Savage (1927) reported a Guelph fauna from rocks correlated with the Fitzgerald dolomite. They recorded the species *Pycnostylus guelphensis*, *P. elegans*, *Howellella* nearest *coralliensis*, *Phragmoceras cameroni*, *Byronocera* (?) *humei*, and *Crateroceras* (?) *humei*. Although these forms strongly suggest a Guelph age, they are not diagnostic as the two species of *Pycnostylus* are now known to occur low in the Lockport, and the other genera are new local species.

Several authors have referred the latest Silurian rocks in the Hudson Bay and James Bay regions to Guelph time. Savage and Van Tuyl (1919a, p. 368) tentatively correlated the Attawapiskat coral reef with the Eramosa of southern Ontario. Analysis of the Attawapiskat fauna indicates a time within the Racine that could be equivalent to the Eramosa or upper Lockport of southern Ontario. It also shows a close relationship with older Fossil Hill–Manistique faunas.

Correlatives of the Ontario Guelph–Lockport occur in different degrees of development in the states bordering the Great Lakes. In New York State, Clarke and Ruedemann (1903) have described two Guelph faunal zones, the Upper and Lower Shelby dolomites, which are separated by about 32 feet of strata containing a normal Lockport fauna. They also suggested that the two zones can be detected at Niagara Falls, but neither Shaw (1937, p. 348) nor Bolton (1957) was able to verify this occurrence. According to Clarke and Ruedemann, the Lower Shelby encloses a purer Guelph fauna than does the Upper Shelby. This condition would suggest a correlation between the Lower Shelby and part of the Ontario Guelph. Admitting such a relation, the intervening Lockport and Upper Shelby strata must also be equivalent to part of the Guelph, as both lie between the Lower Shelby and the overlying Salina beds. Such a correlation seems justified as at Shelby, New York, 60 feet of Lockport lies below the Lower Shelby and the same thickness underlies the Guelph at Niagara Falls. Shaw (1937) pointed out that neither Upper nor Lower Shelby is characterized by the most typical species of the Ontario Guelph, noting the absence of such forms as *Pycnostylus guelphensis*, *P. elegans*, *Megalomus canadensis*, and *Conchidium occidentale*. The inference may well be that the facies represented by the Ontario Guelph was not present in New York during the time the Guelph strata were deposited. According to Howell and Sanford (1947, p. 34), the Oak Orchard beds (combining the Lower and Upper Shelby) represent a limited and discontinuous dolomite facies within the Lockport Formation in western New York, and are believed to contain a fauna characteristic of the Guelph Formation that invaded the area from the west. (For recent views on correlation of these strata *see* Zenger, D. H., 1965, *New York State Univ. Sci. Service*, Bull. 404).

In Indiana, upper Niagaran strata have been reported on by Cumings and Shrock (1928, p. 97). These authors published a complete list of the Huntington dolomite fauna, and from their own analysis they concluded that the corals, brachiopods, and trilobites showed Lockport affinities; while such forms as *Favosites occidens*, *Pycnostylus elegans*, *P. guelphensis*, *Conchidium*, *Monomerella*, and *Rhinobolus* were of distinct Guelph affinities. Cumings and Shrock further pointed out the lithologic similarity of the Huntington dolomite of Indiana, the Springfield–Cedarville of Ohio, the Racine–Port Byron of Illinois, and the Racine–Guelph of Wisconsin, and stated that hand specimens of the Racine (from Racine, Wisconsin), the Huntington (from Ridgeville, Indiana), and the Cedarville (from Springfield, Ohio), could scarcely be told apart. The Cedarville dolomite of Ohio encloses such fossils as *Trimerella grandis*, *T. acuminata*, *Megalomus canadensis*, *Coelocaulus macrospira*, *Conchidium occidentale*, and *Pycnomphalus solariodes*, and so is correlated with the Guelph Formation in Ontario.

In Wisconsin, Chamberlin (1877) divided the upper Niagaran dolomites into Racine beds below and Guelph beds above. Subsequent workers have expressed the opinion that this division is unwarranted and that neither a stratigraphic nor paleontological break exists from the base of the Racine to the top of the Guelph. Williams (1919, p. 75) made the Guelph strata in Ontario equivalent to the Racine and overlying Guelph beds of Wisconsin. According to Shaw (1937, p. 350) and Bolton (1953, 1957), a Racine fauna is present in the upper Lockport beds (Wiarton Member) of Ontario. It, therefore, becomes more probable that the Racine–Guelph of Wisconsin is the correlative of the combined Lockport–Guelph of Ontario.

In northern Michigan, Ehlers (1948) divided the Niagaran strata into the Burnt Bluff, Manistique, and Engadine Formations. In 1957, however, Ehlers and Kesling designated all strata between the Dyer Bay and Manistique Formations as Clinton (Lime Island, Byron, Hendricks, and Manistique), leaving the Engadine as upper Niagaran and the correlative of Lockport–Guelph. Specifically the Engadine is the lithic equivalent of the Lockport's 3a, b, and c members and Guelph Formation of Ontario.

Lockport Formation

Definition

The term Lockport was proposed by James Hall in 1838 (p. 289) after Lockport, New York. Present usage of the term conforms to Bolton's (1953, 1957) combined Fossil Hill and Amabel Formations and to Williams's (1919) Lockport. The term is here applied to the strata lying above the shale of the Cabot Head Formation (and its St. Edmund member) and below the brown dolomites the Guelph Formation.

Distribution

It outcrops as a vertical face from a few feet to more than 100 feet high, traversing the entire area, and is broken only where crossed by major stream courses. The outcrop area extends back from the escarpment thus forming a northwest-trending belt from 4 to 25 miles wide. The rock is at or near the surface over extensive areas throughout the eastern part of the Bruce Peninsula, but sections of any appreciable thickness are found only along the face of the escarpment.

Thickness and Lithology

At Wiarton the formation is about 147 feet thick, the upper 45 to 50 feet, in part at least, comprising the Eramosa Member. At Cabot Head about 160 feet of Lockport is exposed (according to Williams, 1919, p. 58). Other complete thicknesses are not readily obtained because the upper part of the Lockport and lower part of the Guelph are very similar in colour and texture in well-cuttings, their contact is not always recognizable in outcrop, and well logs generally combine the two formations.

The Lockport locally shows considerable variation in bedding, texture, and colour. It is essentially a thick succession of fossiliferous dolomite, commonly light grey, bluish grey and buff, fine to coarsely crystalline, in places porous, and disposed in beds from 2 to 4 feet thick with both thinner and thicker beds locally developed, the whole weathering characteristically light grey or white. Vertical jointing is common though very irregular, and small solution cavities are numerous at some localities.

Though present only in the northernmost edge of the map-area, the lowest subdivision of the Lockport (member 1 on Table III) is the southern extension of a unit from Manitoulin Island that there lies below the Fossil Hill brown dolomites and above the St. Edmund of Williams (1919). Bolton's (1957) St. Edmund included all strata between the Wingfield and Fossil Hill and thus included member 1 of the Lockport of this report as well as the underlying shales and typical St. Edmund strata. At Rocky Bay 3 miles west of Cabot Head lighthouse, about 3 feet of member 1 (8-to-10-foot thickness reported by Williams, 1919, p. 33) is present in the base of the Lockport, but the member probably does not extend farther south than Dyer Bay. It comprises thin (at the base) to thick beds of white weathering, brown and tan, sublithographic to lithographic dolomite.

Elsewhere in the map-area, member 2 is the lowest unit in the Lockport Formation (Table III), a separable unit of member rank from 6 to 15 feet thick. This unit contains a profusion of the brachiopod '*Pentamerus oblongus*' and corals; Bolton (1953, 1957) named it the Fossil Hill Formation. It may be seen to advantage at Owen Sound (Appendix A, section 20; Pl. II B, Bolton, 1957), Wiarton, Colpoys Bay, Sydney Bay, Hope Bay (Appendix A, section 19), Barrow Bay, Lions Head (Pl. III A), and Cabot Head. At Oxenden and Woodford '*Pentamerus oblongus*' is numerous in the lower few feet of the thin-bedded dolomite. As at Lions Head and Cabot Head, the beds containing the *Pentamerus* are divided into an upper and lower unit by 6 to 8 feet of thin-bedded, brown, dense dolomite (an interbed), which grades laterally into typical fossiliferous dolomite. These strata are normally moderately thin bedded, grey weathering, brown, fine-crystalline dolomite; where fossils are absent, as in the interbed noted above, the rock is closer to a tan colour and sublithographic. Chert nodules have been observed in this unit at Owen Sound.

The overlying unit (member 3a of Table III), is thin bedded (2 to 6 inches) and blocky fractured, consisting of light buff, fine-crystalline to dense dolomite, weathering grey. It has been designated the Lions Head Member of the Amabel Formation (Bolton, 1953, 1957). This unit can be seen to advantage at the base of the upper cliff at Duncan; on highway 26 west of Woodford; and at Owen Sound (Appendix A, section 20), Colpoys Bay, Lions Head (Pl. III A, Bolton, 1957), and Cabot Head.

Next in ascending order is a lithic unit (member 3b of Table III) that embraces the Wiarton and Colpoy Bay Members of Bolton (1953, 1957). This unit constitutes the typical Lockport lithology; white to grey weathering, bluish grey to blue, fine-crystalline dolomite. Minor coarse-crystalline dolomite and porous zones are present. Beds are up to 4 feet thick with thinner beds locally developed. This unit is noted for its well-developed jointing. It can be seen to advantage in the Wiarton north road-cut and on highway 26, near Woodford. Both bioherms and interbiohermal strata have been recognized within this unit locally, where thin beds of interbiohermal strata truncate the reefal cores. A prime example is 2½ miles south-southeast of Owen Sound, on the west side of highways 6 and 10 just south of the radio towers (Pl. IV, Bolton, 1957).

The uppermost subdivision of the Lockport Formation (member 3c of Table III) consists of thin-bedded, grey, dark grey and brown, dense, often cherty, bituminous and non-bituminous dolomite. Typical bituminous dolomites are characteristically exposed along Eramosa River near Guelph and at Wiarton in Cook quarry (Pl. IV A). Bolton (1953, 1957) used the name Eramosa for this member, following Williams' (1915) original definition of the Eramosa; moreover, he included in it thin-bedded, non-bituminous dolomites that occur near or at the top of his Amabel Formation in the Bruce Peninsula. The principal representatives of member 3c are the rocks originally called Eramosa by Williams. They are not exposed along the crest of the Niagara Escarpment, but come to the surface some distance away at Hepworth, 2 miles northwest of Wiarton; at Sky Lake (Appendix A, section 22); on the shore of Stokes Bay; on the east side of highway 6, 3 miles south of Ferndale; and 2½ miles south of Brinkman Corners. Extensive flat areas, as for example along highway 6, 10 miles north of Wiarton and 6 miles north of Lions Head, are considered to be underlain by this member.

According to the writers, the strata of this member (3c) do not form a consistent member at the top of the Lockport. *Their development is directly related to biohermal accumulation at the close of Lockport* (*Wiarton*) *sedimentation.* Wherever seen, this member comprises interreefal strata, consisting of brownish grey to chocolate brown, dense, argillaceous and bituminous dolomite typically in even beds from half an inch to 4 inches thick, which commonly give off a petroliferous odour when struck. Minor lenses of crystalline dolomite, chert nodules, and thin coralline biostromes occur locally, as at Sky Lake road-cut. Chert is also known in this member in the Pike Bay area.

In well-cuttings the Lockport has fairly uniform appearance, and consists of buff, brownish grey, and grey, fine- and coarse-crystalline dolomite. In general the lithological divisions recognized in the outcrops cannot be distinguished in well samples. However, about 10 feet of fine-crystalline, brown dolomite at the base, and about 40 feet of dark brownish grey, fine bituminous dolomite about 175 feet above the base of the Lockport suggest the presence of the members 2 and 3c respectively. Chert nodules in members 2 and 3c at least may also provide a means of recognizing these units in the subsurface. Little is known about occurrences of chert in other parts of the Lockport.

Contacts

The contact of the Lockport dolomite with the underlying Cabot Head shale is generally concealed by talus, but its approximate position is indicated by the physiographic expression of the two formations. On this basis it may be placed below the base of the vertical dolomite cliff along the Niagara Escarpment, below which the Cabot Head shale commonly weathers into a wooded slope. At many localities where the contact zone is cut by a slope, springs issue along the top of the Cabot Head shale, indicating the position of the contact. The actual contact is exposed at a few localities, as for example: at the falls at Eugenia on Beaver River; at Walters Falls; on a small creek 2 miles south of Strathavon; in the road-cut at Inglis Falls, Owen Sound (Pl. II B, Bolton, 1957); and on the shore of Isthmus Bay a third of a mile north of Lions Head dock. At each of these places the Lockport dolomite rests directly on the shale of the Cabot Head Formation without gradation and shows an abrupt change in lithology.

The upper limit of the formation is discussed under the Guelph Formation.

Stratigraphic Relations, Correlation, and Sedimentary Environment

In his 1843 report James Hall (p. 84) referred to the Lockport strata as Niagaran limestone, being the upper division of the Niagara group. The term Lockport was later revived, however, by Clarke and Schuchert (1899, p. 876). More recently, Bolton (1953, 1957) restricted the use of the term Lockport to the Niagara Peninsula facies within his Albemarle Group. The dolomites herein described as a single unit because of the scale of mapping adopted within the Bruce Peninsula and adjoining districts were assigned by Bolton to the Fossil Hill and Amabel Formations. The Fossil Hill includes the *Pentamerus*- and coral-rich dolomites at the base. The Amabel comprises the remaining dolomite sequence underlying the Guelph dolomite and is correlated mainly with the Lockport of the Niagara Peninsula. It was further divided in ascending order into the Lions Head, Colpoy Bay, Wiarton, and Eramosa Members. It should be reiterated, however, that the lowest member herein described, Lockport member 1, is the southern extension of a distinct unit on Manitoulin Island and is considered to wedge out within a short distance of Cabot Head lighthouse, probably in the vicinity of Dyer Bay.

The term Eramosa was first proposed by Williams in 1915, from Eramosa River near Guelph. According to Williams (1919, p. 62) these strata formed a consistent member at the top of the Lockport Formation throughout the western peninsula of Ontario and on the islands to the north as far as Fitzwilliam. More recently, Nowlan (*in* Shaw, 1937, pp. 339, 353) gave the term Eramosa formational rank and divided it into the Ancaster and Speedwell members. The Ancaster included the chert beds exposed near Hamilton, the Speedwell included the original Eramosa of Williams. In 1953, however, Bolton reverted to Williams' original definition of the Eramosa, including in it the thin-bedded, non-bituminous dolomite from near the top of his Amabel Formation in the Bruce Peninsula, as well as thin-bedded, cherty dolomites found around South Baymouth on Manitoulin Island. The authors of this report are in complete agreement that the Lockport 3c member (Eramosa) is not a consistent unit at the top of the Lockport, but rather is interreefal between Lockport bioherms. Its development is directly related to biohermal patch reefs, where it takes the form of interreefal strata, and is absent from as many places as it is present in the stratigraphic sequence.

The abrupt change in lithology between the Lockport dolomite and underlying Cabot Head shale suggests a sedimentary break between the two formations. In the Niagara Peninsula these two units are separated by formations of the Clinton Group (Bolton, 1957). In the Bruce Peninsula map-area, however, it was formerly considered that these rocks either were never deposited or had been entirely removed by erosion before the Lockport was laid down. Either condition would result in disconformable relations. As defined by Bolton (1953, 1957), the Dyer Bay, Wingfield, St. Edmund, and Fossil Hill now represent the lower Clinton formations in this region. Other workers, for example Ehlers and Kesling (1957), concur in this interpretation. The remainder of the Lockport dolomite sequence is regarded as equivalent principally to the Lockport of the Niagara Peninsula. Thus either the upper contact of the Fossil Hill represents a disconformity of considerable magnitude, or equivalents of the missing southern units are as yet unrecognized in the overlying dolomites 3a, 3b (Lions Head or Wiarton–Colpoy Bay) members.

The Lockport does not appear to be very fossiliferous, and the hard crystalline dolomite renders collecting a difficult task. Many forms, as for example, the crinoids, are represented by broken fragments of plates and stems so that specific identification is often impossible. Although practically all the invertebrate phyla are represented, corals are the most numerous with brachiopods a close second (*see* faunal lists in Appendix B).

The Lockport Formation of Ontario is a northwestward extension of the Lockport of New York State. A study of the literature dealing with the upper Niagaran sediments of the Great Lakes area (New York, Michigan, Wisconsin, Illinois, Indiana, Ohio, and Ontario) forces the conclusion that in this region there is no major break, either stratigraphic or faunal, from the base of the Lockport to the top of the Guelph. As this same condition prevails in Bruce Peninsula map-area, discussion of the Lockport in Ontario and the Great Lakes region has been placed in the section on Niagaran formations (Guelph–Lockport).

Guelph Formation

Definition

As now defined, the term Guelph is used as a rock unit and in the same sense as used by Caley in his reports on southwestern Ontario (1940, 1941, 1943, 1946) and on his preliminary map of the Bruce Peninsula (1945).

Logan specified typical localities in the vicinity of Guelph and Galt, Ontario. The writers suggest the following reference sections within the map-area: Wiarton north road-cut; Cook quarry, Wiarton; Sky Lake road-cut; Schoolhouse section on highway 6; Wiarton north bioherm, 2 miles northwest of Wiarton on highway 6.

Distribution

The formation has an areal extent of about 1,000 square miles and forms a northwest-trending belt across the map-area. Width of the belt averages about 18 miles in its south half, but narrows to about 8 miles in the peninsula proper. South of Owen Sound, outcrops are rare except in the valley of Rocky Saugeen River, where at several localities, between Markdale and the confluence with Saugeen River, cliffs expose as much as 60 feet of strata. Guelph strata outcrop almost continuously along the Lake Huron shore from Oliphant to Tobermory and throughout the 'Bruce' as numerous, more or less detached, exposures.

Thickness and Lithology

The formation is nowhere completely exposed. One incomplete section indicates a minimum thickness of 80 feet, another about 130 feet. Subsurface data indicate that the complete section of the Guelph ranges from 100 to 170 feet within the map-area. Rapid changes in thickness are to be expected in a reefal environment.

Typically the Guelph consists of buff and brown, fine- and medium-crystalline dolomite that emits a distinct petroliferous odour when broken. Locally it may be greyish, tan, or dark brown, fine- to medium-granular, lithographic to sublithographic, and fine- to coarse-crystalline. The strata weather brownish, moderately resistant only, and into beds from 2 inches to more than 4 feet thick (Pl. V A). Exposures facing the prevailing elements generally weather into thinner beds. The typically weathered surface appears to be very soft, severely etched, and sculptured. The term scraggy has been applied by many authors to such a surface and typifies most Guelph exposures of the crystalline and granular textures. In finer textures strata appear regularly bedded and more evenly resistant. Also with respect to resistance, the 'bioherms' on highway 6 south of Tobermory strike in the same direction as Pleistocene ice movement; thus the ice did the final sculpturing (Pl. IV B). Small reefs provide the core of ice-produced crags, and interreefal strata may have been left on the flanks in the lee and even low on the stoss side.

Lowest Guelph strata characteristically include dark to black, thin, bituminous partings, and beds are 4 to 8 inches thick. Slightly higher sublithographic and lithographic textures have been observed, locally with preserved algal or stromatolite growths. Higher still in the formation, smaller reef cores show more of a knoll-interknoll development, tan-grey, fine- to very fine crystalline. Argillaceous dolomite is developed there also. Vugs of various sizes represent an integral part of the rock; some are partly filled by subsequent sediments, others are mainly geodes. Fossils are generally rare to sparse. In certain localities such as Hopkins Bay, however, even the elusive *Megalomus canadensis* is abundant. Otherwise the faunal indicators are rare.

The Guelph is in reality a reefal complex, similar in many ways to the Lockport, but reefal to a greater degree. Not only can biohermal units and their interreef strata be distinguished within the Guelph itself but a transition unit between Lockport and Guelph sediments can be delimited both in the apical and flank areas of the Lockport bioherms (*see* Lowenstam, 1950; Cumings and Shrock, 1928). The great mass of detail recognizable in outcrop is completely masked in the thick gross lithology that appears in the well-cuttings. Within this gross lithology would be masked the grey colours within the buffs and browns, the sublithographic and lithographic textures within the fine- and medium-crystalline textures, limestone within the dolomite, and little porosity of the stromatolite strata within the well-developed porosity of the typical Guelph. Detail of the surface of the Bruce Peninsula north of Owen Sound and Wiarton can be examined to such a fine degree that unless the gross lithology concept is retained, mapping of the unit may seem impractical. Features recognized have been: 1) subtle differences and stratigraphic changes within the Lockport's 3c member (Eramosa) and between 3c and 3b strata; 2) the interreefal 3c member (Eramosa) in part contemporaneous with a Guelph bioherm (Sky Lake road-cut); 3) the apical unit transitional between Lockport sediments and Guelph sedimentation (Lions Head south bioherms); 4) biohermal reef cores and their interreefal and subreefal strata high in the Guelph Formation (highway 6, about 8 to 12 miles southeast of Tobermory); 5) bedded deposits flanking the bioherms near Tobermory; and 6) the bioherms themselves (North Wiarton, White Cliffs, Lions Head south, Berford Lake).

Oblique truncation of the formation from west to east across the peninsula exposes the intimate relations, laterally and to an amazing degree vertically, between and within reefal and interreefal areas. Pure interreefal 'Eramosa' beds are exemplified in the Cook quarry exposure where they underlie massive biohermal dolomites. The domal features near the quarry are believed to have been produced by small bioherms now covered by interreefal strata. An example of the Cook quarry type of terrain that has been deeply eroded to expose strata of members 3c and 3b (Lockport Formation) is the schoolhouse section, 3.7 miles south of Edenhurst on highway 6. There an interreefal area shows small reefs with sediment draping off them; the intimate intermixture of the black and grey laminated dolomite between bioherms, on their flanks, and arched over them; and interbedded lenses within the laminated dolomite. At the Sky Lake road-cut the reef is exposed and its lateral outgrowth of structureless dolomite grading into very fine crystalline interreef 'Eramosa' sediments that enclose small lenses of coralline material and chert. Finally, at the north Wiarton bioherm, which Lowenstam (1950) noted, an isolated reefoid mass is about 1½ miles wide by 3 miles long. If this mass were discovered in the subsurface and structurally contoured, its configuration would be very similar to Figure 11 of Lowenstam's 1948 paper. Noticeable within this bioherm is the irregular upper surface; the structureless reefal cores with depressed beds below and truncated flank strata; the drape of the 'cap' beds over the biohermal surface proper; and finally the drape of the strata off the flanks of the bioherm into the extensive interreef flats. That these flats are essentially the interreef facies has been amply shown in excavations and cuts. To the west and higher in the Guelph Formation, the reefal constituents are sufficiently abundant to cover the interreefal flats with a consistent reefal complex, which shows a less extensive but equally persistent interreefal facies. This facies is similar to typical Eramosa (i.e., Lockport 3c) strata in colour and bedding; it is sufficiently unlike the reef 'cap' beds that one may be at a loss as to what to call interreefal. In the upper half of the formation, therefore, typical Guelph lithology and terrain are developed; the biohermal rolls are essentially covered (i.e., Elora River), and the flank strata are of bedded, buff, clastic, and saccharoidal dolomite.

In the subsurface, at least three so-called pinnacle reefs have been found in the Kincardine and Clinton areas. Drawn to natural scale, the implied pinnacle proportions (about 1:40) approach the ratio of exposed reefs in the outcrop area north of Owen Sound. One difference is important: the pinnacle reefs are surrounded and overlain by evaporitic strata of the Salina Formation. As these evaporites are not present in the outcrop belt, this Kincardine–Clinton area must have been located well basinward to permit these reefs to have grown upwards through and above contemporaneous Salina strata. In all probability, a flexure existed between the two areas, which controlled subsidence, reef growth, and sedimentation. Also in the subsurface, the Guelph Formation generally appears as a buff, fine-crystalline dolomite, but its colour varies from light buff and tan to deep brown and grey and its texture varies from fine- to coarse-crystalline and from fine- to medium-granular. Its porosity varies considerably, with some vertical intervals of 40 feet and more being especially porous. Minor amounts of both selenite and pyrite have been reported in well logs.

Analyses of well-cuttings from the Kincardine well indicate a chemical composition different from that reported for outcrop samples and well-cuttings elsewhere in Ontario. The rock in this well, from 860 to 870 feet, is typical of the Guelph Formation (buff, medium-crystalline dolomite). From 878 to 1,425 feet it is unlike that of either the Salina or the Guelph Formation in that it is limestone rather than an almost pure dolomite. From 1,425 to 1,495 feet the rock is again like the typical Guelph–Lockport, but with interbeds of limestone. The limestone interval (878 to 1,425 feet) has previously been logged tentatively with the Guelph–Lockport on the basis of its position relative to the gypsum in the Salina. This gives a greatly increased thickness (635 feet) for the Guelph–Lockport strata, which in two wells about 40 miles to the south and 25 miles southeast respectively are represented by only 100 and 170 feet of dolomite. As a considerable distance intervenes between this Kincardine section and the nearest outcrop or well penetrating the formation, several factors (or combinations of them) could have brought about its uniqueness. 1) Part of the limestone may belong to the Salina and part to the underlying Guelph Formation. For those workers who believe that all the Guelph dolomites are the result of dolomitization processes, perhaps this Kincardine section is evidence from which to infer that the whole 'Guelph' was grey limestone before dolomitization. 2) The apical part of a bioherm is much thicker than the flank-top areas and thus a greater thickness can often be explained. A combination of these factors may approach the truth, in part at least. Surface studies in adjacent map-areas indicate that sharp changes in lithology are the exception rather than the rule in carbonate stratigraphy.

Contacts

Detailed investigations have shown that there is a definite change in lithology from typical Lockport to typical Guelph, but that this change did not occur everywhere at the same time.

In the biohermal phase of the Lockport–Guelph succession there is always a transition unit between these two formations. This unit is closer to tan than to grey, and is more evenly textured than typical Lockport. Moreover, it is not the dense, very hard, brittle, conchoidally fracturing carbonate that so typifies the Lockport and the bedding is generally not so massive. This unit is arbitrarily assigned to the base of the Guelph Formation. It can be recognized readily on the outcrops, where its appearance makes its formational assignment easier. Thickness ranges from inches to 10 feet or more, depending on the position of the section relative to the apex of the bioherm. The whole transition may take place in one massive 3-foot bed. Typical Guelph fossils such as *Trimerella* have been found within a few feet of this transition unit.

In the interreefal phase where the 3c (Eramosa) member of the Lockport Formation is overlain by the Guelph Formation, the contact is fairly easily defined. It has been delimited at the top of the typical, thin-bedded ($\frac{1}{2}$ inch to 2 inches), grey and brown, fine-crystalline, bituminous and non-bituminous dolomites, which may include chert nodules. The colour of these dolomites depends upon dark grey and almost black bituminous partings and bituminous dolomite. Above this unit are thick (3 to 5 feet), massive beds of brown, fine-crystalline dolomite, which may include minor thin bituminous partings. The contact appears to be conformable and is marked only by the physical character of a more or less abrupt change in bedding. As at Cook quarry, near Wiarton, single 2- to 3-foot thick beds of cream coloured, evenly textured, fine-crystalline dolomite may occur interbedded within this Lockport 3c member. These strata are arbitrarily designated as a distinctive rock unit and assigned to the top of the Lockport.

The section at Sky Lake (Appendix A, section 22) shows about 30 feet of thin-bedded, brown, fine-crystalline, bituminous, cherty dolomite directly overlain by, but in part stratigraphically equivalent to (interreef to reef relationship), brown, very fine crystalline, rough weathering dolomite in heavy beds up to 3 feet thick. Cherty dolomite is also known in this unit in the Pike Bay area. At Cook quarry 2 miles northwest of Wiarton, thin-bedded, very fine crystalline, brown bituminous dolomite is overlain by thick-bedded (3 to 4 feet), brown, slightly bituminous dolomite. The coral *Zaphrentis* cf. *racinensis* occurs in the upper beds. About 5 miles northeast of Allenford in lot 7, concession IV, Keppel township, a similar sequence of rocks occurs with about 2 feet of thin-bedded dolomite overlain by 4 feet of massive, brownish grey, scraggy weathering dolomite. No *Zaphrentis* cf. *racinensis* was observed there. On the east-west road near the south end of Mountain Lake in lot 23, concession XVI, Keppel township, about 5 feet of brown to buff, porous, and fine-crystalline dolomite in beds from 1 foot to $1\frac{1}{2}$ feet thick is underlain by 2 feet of brown, very fine crystalline dolomite with black bituminous streaks in beds $1\frac{1}{2}$ inches thick. On the shore at Red Bay, Pike Bay, and Stokes Bay are exposed brown, very fine crystalline, bituminous dolomites in 1-to-4-inch beds, which show low reef-like dome structures. These dolomites are overlain by brownish grey and brown dolomite in beds 1 foot to $1\frac{1}{2}$ feet thick. The biohermal transition unit can be best observed in the road-cuts on the large bioherms on the road from Colpoys Bay to Lions Head. Aside from this type of contact, the more or less abrupt change from thin, brown, dolomite beds below to much thicker, rough weathering, browner and less dense beds above is the most common and prominent physical characteristic of the Lockport–Guelph contact.

As the contact between the Guelph Formation and the overlying Salina Formation is not exposed within the map-area, the only information available is from well-cuttings. One of the wells from which reliable cuttings are available is in Kincardine township, and exhibits a Guelph section unlike any so far seen in Ontario; in it the Guelph–Salina contact has not yet been determined with assurance. In most well-cuttings, it is difficult to draw a sharp boundary between the two formations as there is a transition unit that separates the easily recognizable typical strata of both formations. This transition unit varies in thickness and commonly consists of grey or brownish grey, fine-crystalline dolomite containing varying quantities of anhydrite, and in some wells more or less argillaceous material. Below this unit samples are commonly grey, buff, or brownish, fine-crystalline or fine-granular dolomite with but rare traces of anhydrite. Above it is grey, calcareous shale and brown, fine-crystalline dolomite, commonly with gypsum and anhydrite. The writers prefer to assign this unit arbitrarily to the base of the Salina Formation. The lower limit of the Salina would then be defined to include the lowest occurrence of anhydrite or gypsum associated with grey to brown, fine-crystalline to dense dolomite and grey calcareous shale.

Stratigraphic Relations

The term Guelph was introduced by Logan (1863) for the series of rocks typically developed near Galt and Guelph. As early as 1843 Alexander Murray made special mention of the bituminous rocks in the rapids above Niagara Falls, although he did not note those less typical (Guelph) strata as distinct from the underlying (Lockport) strata. In 1848, however, he recognized the existence of a series of strata that overlay the Niagara Escarpment rocks and which contained a distinctive assemblage of fossils.

With respect to the Lockport 3c (Eramosa–Guelph) contact problem, the type locality of the Eramosa is at Guelph and was described most recently by Caley (1941). According to Williams (1919), the lowest Guelph bed is about 2 feet thick, bituminous, and emits a petroliferous odour when broken. Shaw (1937) stated that about 19 feet up on the quarry wall at the Ontario Reformatory at Guelph, above a 2-foot bed showing curved lines of jointing, the beds are less bituminous and "take on more of a Guelph appearance" (p. 327). *Zaphrentis* cf. *racinensis* was observed above the 2-foot bed. Shaw placed the contact below the first appearance of that fossil, thereby using a biostratigraphic basis for defining his stratigraphic boundary. The rock below that 2-foot bed, in layers from 2 to 8 inches thick, was designated Eramosa. Throughout the Bruce Peninsula area the thin, denser, dolomite beds of the 3c member are similar to the Eramosa of the type locality. Immediately prior to the deposition of the Guelph some areas were dominated by Eramosa sediments, whereas in other areas organic accumulation continued unbroken into the Guelph without deposition of interreefal strata.

Williams (1919) considered the Salina to rest unconformably on the Guelph. This belief that the Guelph strata were eroded prior to deposition of the overlying Salina strata was also held by Evans (1950). On the other hand, Roliff (1949) stated that the Guelph–Salina contact appeared conformable in general, with only local evidence of erosion at the end of Niagaran time. In this, Roliff was concurring with Shaw's conclusions (1937).

It is believed that any reference to an unconformity at the top of the Guelph must be minimized. The term 'minimized' is used guardedly, for with the relief concerned it would be surprising if there were no erosional evidence on the apices or flanks of the large bioherms. In support of this aspect certain relations may be inferred from the subsurface data, for the lowest Salina A_1 unit is sometimes not present on the apex but has wedged out on the flank. There is the possibility that the Salina was not initiated as a suprajacent formation, but as an extension of late Guelph interreefal facies (Bolton and Liberty, 1955). With the Salina's lowest (A_1) strata being cut out, this aspect must be carried farther (*see* Salina Stratigraphic Relations; also Landes, 1945; Evans, 1940). Rather than infer an unconformity at the contact it would be of value to determine whether or not the Guelph interreefal facies 'gives way' laterally as well as vertically into Salina strata. It is believed possible for the Niagaran strata to grade upward into non-evaporites (and at a different time), in the area encircling the evaporite basin. Such an absence of the Salina in a perimeter area would infer not so much that it was never deposited there but rather the possibility that the unit there was a facies equivalent of the Salina.

Investigations in an adjacent area have led to the recognition of a dendritic pattern on the top of a reefal complex of bioherms, biostromes, and interreefal strata at a given time. How to distinguish between this dendritic pattern and the erosional pattern suggested by Evans (1950) is a unique problem. Liberty believes that from the data known, the above superreefal pattern can more easily explain the facts than can an important unconformity. It is considered that all the data so far known are compatible with reefal sedimentation phenomena.

Sedimentary Environment

General conditions of Guelph sedimentation were probably a clear, well-lighted, well-aerated, shallow-water environment 50 to 80 feet deep. Active turbulent water conditions are indicated by the great amount of clastic flank deposits. Whether the bioherms started during deposition of Lockport or Guelph sediments, structural conditions indicate that they commenced on topographically higher areas. As a consequence, contemporaneous interreef-interbiohermal strata could occur at a much lower elevation, in the 'valleys'. Depending on the amount of debris derived from the bioherms themselves, the contemporaneous strata could also occur at about the same levels. This would explain the biohermal hills of Lockport–Guelph and Guelph and the flat areas of the Lockport 3c (Eramosa) member on highway 6 north of Wiarton. Similarly, examples are known in which the Lockport 3c (Eramosa) member is at the same elevation as the Guelph bioherms, which indicates a minor contemporaneity of highest arbitrary Lockport strata and lowest Guelph strata.

The many reefal exposures in the Bruce Peninsula present an excellent opportunity for investigating rock types, permeability, and textures. Even though algal structures are visible only in very fine textured (calcilutite, cryptocrystalline, aphanitic, lithographic) reefal cores, it is believed that algae played an important role in the origin of much of the Guelph strata. Their absence or poor representation in the finely crystalline and coarser Guelph strata could be attributed to recrystallization.

With respect to greater porosity and permeability, dolomitization can be equally important in reefal accumulations. The composition of the circulating (or penetrating) solution will govern the degree of dolomitization. Present studies indicate corroboration of Carozzi's (1960) observation that denser textures are most susceptible to dolomitizing solutions and that reefal–biohermal circulation of these solutions might well be optimum for large scale replacement.

The most striking and important characteristic of the Niagaran (Lockport–Amabel and Guelph) dolomites is their consistency over such a widespread area in the Great Lakes region. So large an area is concerned that it is not tenable to consider these dolomites as of hydrothermal origin. It is more realistic to consider the possibility that circulating solutions (and/or recycling) produced dolomitization so quickly after deposition of the primary sediments that they should be termed penecontemporaneous dolomite. Furthermore, such special chemical conditions probably produced some truly primary dolomites. In this manner, both large scale dolomite areas and small anomalous limestone areas (the Kincardine well area) could be compatible.

Reef Development

A full grasp of the Silurian stratigraphy is obtainable only through a complete examination of the rocks exposed between New York State and northern Michigan—an oblique cross-section across the Michigan Basin. The whole of the Ontario Silurian is best regarded as one giant reefal complex, for almost each unit in turn presents either biostromal and/or biohermal accumulations, or so-called 'independent' strata (i.e., shales) attain interreefal relations—

as the Cabot Head shale on Manitoulin Island. Maximum or optimum reefal conditions appear to have developed in the Manitoulin–northern Michigan area, with biohermal development in the Manitoulin, Lockport member 2 (Fossil Hill–Manistique), Lockport member 3 (Amabel–Engadine), and finally the Guelph (highest Engadine). Biostromal conditions are considered present in the Manitoulin, Dyer Bay–Wingfield–St. Edmund, Hendrick's equivalent in Ontario, Lockport members 1, 2 and 3a, b, and Guelph. Interreefal strata are known in the Cabot Head, Wingfield, and Lockport members 3b and 3c.

At varying locations on the perimeter of the Michigan Basin each formation begins to develop small microreefs and/or biostromes and as the area of optimum development is approached so its bioherms are developed, becoming more numerous, larger, and more complex. Thus a progression from the simple in a more stable surrounding area to the more complex reefal development in the basin proper (a less stable area) is probable. In the latter area, and apparently ringed by perimeter reefs, the evaporite series, comprising the Salina and Bass Island Formations, is limited.

This is the concept and context into which the Silurian formations must ultimately be inserted. The concept of a simple barrier reef surrounding this evaporate basin is unacceptable, especially when simpler more straightforward possibilities are available. The present 'apparent' ring of reefs that surrounds the basin is not merely indicative of a perimeter ring only. Too much is left unexplained by this means, i.e., the restricted faunal migration routes, so inferred, the constant lithology, and mode of occurrence for the Guelph throughout the Great Lakes area. Further, it is incomplete to attempt to plot the bioherms of this ring in Ontario, for the picture is much too complex. Indeed about twenty bioherms are known that have never appeared on any published map. Similarly certain areas in this perimeter ring cannot be easily pin-pointed as access points for rejuvenation waters to the evaporite basin. Far too little is yet known about this aspect, for the present truncated surface either obscures or indicates that too much has been removed for us to determine where the reef barrier was present. One exception exists perhaps, in the deep gorge between the top of the 'Bruce' and Manitoulin Island, as is evident on marine charts.

It is accepted that reefs other than the barrier type can be effective agents in impeding water circulation and in the development of an evaporite basin. Instead of a barrier reef around the rim of the Michigan Basin, Liberty envisions a basinal type 'blanketing' Guelph reef over and across the entire basin. It would be in wholly shallow to moderately deep water. As the central basinal area became depressed, the margins were warped upward (each being relative and complementary to the other). Certain areas of the margin were more stable than others (*see* Ehlers, 1929MS, p. 52); macro-reefal areas (i.e., Bruce Peninsula and Manitoulin Island) define the more unstable parts. Such unstable parts would be the mechanism for maximum development of the reefs, and would be the site for present macro-areas. These marginal areas then could and would impede circulation of basinal waters to greater or lesser degrees. Similarly, temperature and salinity changes would be effected. Thus the thickest Guelph sections would be located in the marginal area, thinning towards the centre of the basin where the evaporite series (Salina and Bass Island Formations) would be initiated contemporaneously with the maximum reefal growth on the mobile marginal area. A band of 'optimum development' extended across the basin striking south-southwesterly from the Manitoulin Island–northern Michigan area towards the Illinoian reefs in the Chicago area. Flanking such a belt on both sides would be the transitional micro-reef conditions observed southward from within the Bruce Peninsula along the Niagara Escarpment to Niagara Falls.

Under such conditions, the evaporite seas would oscillate and present in their sediments the intimate vertical and horizontal relations observed between the reefal and evaporitic facies. Finally, the growth of the reefs would be impeded and 'killed off' by the increasingly predominant evaporite sediment overgrowth. Such a process, on a local scale, could produce very curious results with respect to tabular reefal growths in certain gradients and on certain terraces of the basin.

As part of this pattern, the present Algonquin Arch happens to coincide with the basin's eastern flank. The Bruce Peninsula north of Owen Sound is an area that probably underwent pulsatory movement, i.e., a mobile area. Through the medium of the 'blanket reef' hypothesis, the consistent Guelph lithology, the reefal development, and the open migration of uppermost Niagaran faunas throughout the Great Lakes area, can most easily be explained.

Fauna

The Guelph fauna is known chiefly from localities outside the map-area, although both Williams (1919) and the writers have collected from several localities within the area. The fauna from the typical beds to which the name Guelph was originally applied has been the subject of considerable study [Billings (1861–65), Whiteaves (1884–1906), Parks (1907), and Shaw (1937)]. Shaw not only described new species from Tobermory and Durham, but also published a complete list of the then-known Guelph fauna from Ontario (reproduced in Caley, 1940, pp. 67–70).

Analysis of Guelph fauna shows that approximately half the forms belong to a single taxonomic group, the Gastropoda; half the species are known to occur in rocks older than the Guelph. It is evident that the fauna is characterized not by a failure of earlier forms so much as by the introduction of many new species. For example, two thirds of the gastropod species are not found at lower stratigraphic levels. It is the general assemblage and association of forms rather than the presence of any particular fossils that characterizes the Guelph Formation of Ontario. As Shaw (1937) pointed out, important faunal indicators in the formation include *Megalomus canadensis*, *Trimerella grandis*, *T. acuminata*, *Conchidium occidentale*, *Whitfieldella hyale*, and *Coelocaulus longispira*. Within the map-area these forms are generally sparse to rare, although at one location at Hopkins Bay, south of Tobermory, *Megalomus canadensis* is abundant.

Correlatives of the Guelph and Lockport are particularly well developed in Wisconsin, where the appearance of the typical Guelph is sudden. There, the Racine and Guelph Formations were originally separated on paleontological evidence. Ehlers (1919), however, suggested that there is neither stratigraphic nor paleontologic break in that sequence of strata. The so-called Guelph fauna, therefore, is a gradual derivative of the fauna of the earlier Niagaran strata (Bolton's Wiarton fauna, 1953, 1957), and the apparent sudden influx of new forms in the Guelph in Ontario is due largely to the breaking down of barriers such as coralline reefs that were formed late in Lockport.

Correlation

The Guelph Formation is correlated with the uppermost strata of the Engadine of Michigan, the uppermost Racine–Guelph of Wisconsin, the Cedarville Formation of Ohio, the Huntington of Indiana, and a part at least of the Oak Orchard beds of New York State. It may be also correlated with the uppermost strata of the Interlake Group in Manitoba. Lithologically, the Guelph Formation traces into the Huntington, the Springfield–Cedarville, the Racine–Port Byron in Illinois, and the Racine–Guelph in Wisconsin. In northern Michigan a minor amount of Guelph lithology is present in the top of the Engadine, but from this the Guelph thickens and develops into the reefal complex in the Manitoulin Island area and extends southward into the Bruce Peninsula map-area. It appears more probable, therefore, that the Racine–Guelph of Wisconsin is the correlative and lithologic equivalent of the combined Lockport and Guelph Formations of Ontario.

Salina Formation

Definition

The term Salina was introduced by Dana in 1863 to replace the "Onondaga Salt Group" (Hall, 1839; Vanuxem, 1839), the name Onondaga being preoccupied.

In the map-area the formation comprises an alternation of grey dolomite, green shale, brown dolomite, and red shale. It lies between buff, even textured Guelph dolomite and buff and brown, fine-grained Bass Island dolomite. Lack of outcrops prevents subdivision. A thin reference section is designated at the base of Dunkeld Creek, 2½ miles southeast of Dunkeld, northwest of Walkerton. A reference well for the formation is in lot 5, concession VIII, Culross township.

Distribution

The Salina Formation has an areal extent of about 725 square miles. It forms a northwest-trending belt across the entire region, about 15 miles wide. The southwestern boundary passes just east of the town of Walkerton. Well records show the formation beneath younger strata throughout the remainder of the map-area. Despite glacial drift cover, the formation is exposed in the valley of South Saugeen River between Neustadt and Calderwood (Appendix A, section 23); on Saugeen River at Walkerton and about 2½ miles north of Walkerton; on Teeswater River a mile and 2 miles south of Paisley; and near the mouth of a small stream in lot 3, concession VII, Brant township, Bruce county, 4½ miles north of Walkerton (Appendix A, section 26). A few feet of strata is exhibited at each of these localities.

Thickness and Lithology

The thickness of the Salina can be determined only in wells. In two wells in Culross township, it is 599 and 609 feet thick. In a well in lot 60, concession A, Kincardine township, however, similar strata is only 370 feet thick; these strata are separated from typical Guelph dolomite by 565 feet of grey limestone, which is arbitrarily included in the Salina Formation.

The exposed part of the Salina Formation consists essentially of buff, fine-grained dolomite in even beds alternating from a few inches to 2 feet thick. At several localities small mineral moulds and dark bituminous streaks may be seen. Moreover, drab, greenish grey, and bluish grey shale and calcareous shale appear either in the form of compact mudstone or as laminations. At least two horizons of red shale or red and green mottled shale are present in the formation. The upper few feet comprises both red and green shale, both containing anhydrite. As the red shale is more easily seen, it was used arbitrarily to delimit the upper contact.

In well-cuttings (Appendix C, log 2), the Salina Formation consists essentially of an alternation of brownish grey dolomite and grey and greenish grey argillaceous dolomite and shale. Red shale occurs near the top of the formation and traces of gypsum (gypsum and anhydrite are rarely differentiated in the samples) are found in most samples. Gypsum (?) may also form a bed from 6 to 12 feet thick near the base of the formation. One well in the southwestern part of the map-area contains two salt horizons, about 20 and 165 feet thick.

Contacts

Between typical Guelph and Salina strata there is a transitional unit of variable thickness, composed of grey or brownish grey, fine-crystalline dolomite containing anhydrite. As anhydrite has not heretofore been found in the Guelph Formation, this unit is assigned to the base of the Salina.

The top of the Salina is placed at the highest occurrence of anhydrite, associated with grey or brownish grey argillaceous dolomite. The Salina invariably is overlain by about 100 feet of buff, fine-crystalline to fine-grained dolomite with some oölites and bituminous streaks (Bass Island Formation). In the Culross and Kincardine townships wells, however, 35 feet of grey gypsiferous argillaceous limestone intervenes between typical Salina red shale and typical Bass Island strata.

This gypsiferous unit is absent in Salina exposures $4\frac{1}{2}$ miles north of Walkerton in lot 3, concession VII, Brant township, and (despite the 8-foot thick concealed interval) on the east side of Saugeen River, half a mile south of highway 4 at Walkerton (Appendix A, Section 27).

Stratigraphic Relations, Correlation, and Sedimentary Environment

The "Onondaga Salt Group" of Hall and Vanuxem included four 'deposits', red shale, lower gypsiferous shales, gypsum deposit, and magnesium deposit. This sequence rested upon the Niagara group and was overlain by the Lower Helderberg group. As the term Onondaga was preoccupied for a limestone series, Dana later introduced the term Salina (1863, p. 246). In 1900, Clarke and Schuchert proposed the term "Cayugan period or group" (p. 118) to include the Salina beds, Rondout Waterlime, and Manlius limestone. In 1908, Grabau proposed the usage "Middle Silurian or Salinan", which was represented only by non-marine sediments, and introduced the term Monroe for about 900 feet of fossiliferous strata in Michigan and adjoining regions in Ohio and Ontario. In 1908, also, Schuchert used the term "Cayugan Series" to include the Salina group, thus embracing all formations between the Guelph–Niagara group and the base of the Devonian. Williams (1919) later used the Cayugan group to include all the Silurian in Ontario above the top of the Guelph. Finally, in 1945, Landes subdivided the Michigan Salina lithologic succession into units A to H. Making allowances for lateral variations and salt pinchouts, these units have been traced into Ontario, where unit H is the Bass Island Formation. In 1950, Evans further subdivided unit A into an A_1 and A_2. These Salina subdivisions have also been discussed by Roliff (1949) and Grieve (1955).

No fossils have been found in the Salina. The Camillus beds in New York State and the Salina beds in the Bruce Peninsula map-area occur in the same stratigraphic interval. Despite the Camillus being termed a shale, Alling (1928, p. 214) has noted that at the type locality it is a fine-grained, massive, ashen grey magnesian lime mud-rock. Thus the two formations are lithic equivalents. In Michigan, strata called Salina also are of similar lithology and stratigraphic position. Cook (1914, p. 86) described the Salina in the deepest part of the Michigan Basin as a dolomitic limestone, "grey, buff or brown in colour and at times argillaceous". Thus, these units are lithic equivalents; certain of the A to G units have been traced directly into Ontario from Michigan (not all of the units are present at any particular locality however).

Bass Island Formation

Definition

The term Bass Islands, derived from the group of islands of the same name in western Lake Erie, was proposed by Grabau (1908, 1909). As defined, the Bass Islands occupied a position between the Salina Formation and the overlying Devonian Sylvania Sandstone in that area. 'Bass Island' is herein applied to strata in the post-Salina and pre-Devonian stratigraphic position. Although the name of the islands is 'Bass Islands', the term became Bass Island in Michigan reports in the 1930s. The terms Bertie and Akron (Bertie–Akron), formerly assigned to strata in this same position, are restricted in Ontario to the Niagara River area, as typical lithologies cannot be recognized outside that region.

The formation is not divisible in Ontario, away from the type section in the Bass Islands. It is, therefore, mapped and logged as a single unit. (For the most recent definition the reader is referred to Sparling, D.R., 1970, The Bass Islands Formation in its type region; *Ohio J. Sci.*, vol. 70, No. 1, pp. 1–35.)

Distribution

The Bass Island has an areal extent of about 75 square miles in the map-area. The outcrop area forms a northwest-trending band about 2 miles wide that extends from the southern boundary of the area to Southampton. Outcrops are almost wholly confined to the valley of Saugeen River, and may be seen to advantage on a small creek directly above the Canadian Pacific Railway track half a mile south of highway 4 at Walkerton (Appendix A, section 27); on an intermittent stream entering Saugeen River from the west in lot 3, concession VII, Brant township (Appendix A, section 26); on a small creek on the west side of Saugeen River, 1.8 miles north of Dunkeld (Appendix A, section 28); on Teeswater River a mile north of Pinkerton; and on the creek a mile east of Bradley.

Thickness and Lithology

In two wells, 23 miles apart (lot 5, con. VIII, Culross tp., and lot 60, con. A, Kincardine tp.) the thickness is 133 and 162 feet. Thickness of the formation increases northwesterly; in the adjoining area to the south, however, it varies locally (Caley, 1943). The disconformity north of Walkerton suggests that this variation in thickness is due largely to differential erosion of the Silurian strata. Near Dunkeld the outcrop is 134 feet thick.

Bass Island strata consist of buff and brown weathered, buff, cream and brown, fine-grained dolomite in even, vertically jointed beds from 2 to 12 inches thick. At some localities more massive beds are as much as 2 feet thick. This unevenness may be affected and in part produced by algal concretions. Also, mineral moulds, which appear as needle-like cavities, occur in the formation. Their size ranges from about half a millimetre to about 5 millimetres, and many of them are filled with crystalline material such as anhydrite and celestite. Near the top of the formation dark bituminous streaks impart a ribbon-like appearance to some of the beds. In addition, as markers are two 'medium' oölite zones, 55 and 90 feet above the base of the unit. They are separated by about 35 feet of dolomite and themselves may comprise about 3 feet (upper) and 14 inches (lower) of very evenly textured oölitic dolomite.

In well-cuttings, the Bass Island presents a uniform appearance. The lithology is essentially a buff and cream, fine-crystalline dolomite. Also observed in the samples are the black bituminous streaks, pyrite, mineral moulds, and oölites. The persistency of the oölite is remarkable, the two zones extending beyond the Walkerton area. Careful examination is generally necessary to detect the oölites, and the second zone has sometimes been recognized only upon re-examination.

Contacts

Essentially, the lower contact of the Bass Island Formation is drawn so that the highest red or greenish shale would be arbitrarily retained in the Salina Formation. This was the premise on which the outcrop was mapped. In the subsurface, however, the top of the Salina is generally placed at the highest occurrence of anhydrite associated with grey shaly dolomite. Overlying it, there would be the mineral moulds, oölitic dolomite, bituminous streaks, and buff dolomite section of the Bass Island Formation.

Within the outcrop area the overlying formation is the Bois Blanc. Thus the contact is one between lower brown dolomites of the Bass Island and cherty grey, fine-grained, greyish brown limestone of the Bois Blanc. The lowest few feet of the Bois Blanc may contain some bituminous partings, but they are impure, containing silt and sand residues in addition to the easily detected chert fragments.

Stratigraphic Relations, Correlation, and Sedimentary Environment

In Michigan and Ohio the rock unit above the Salina Formation was called the Bass Islands series. This term was proposed for the Lower Monroe division of Grabau's (1908,

p. 622) restricted use of the original Monroe beds of Lane. As so defined, the Bass Islands series occupied a position between the Salina and the Sylvania sandstone above. In Ohio, the Sylvania was placed in the Devonian by Carman (1936) and believed to disconformably overlie the Bass Island series. In the Bruce Peninsula map-area the Bass Island Formation is directly overlain by Devonian strata, so that it occupies the same stratigraphic position as the Bass Islands series. Apart from the varied history of the term and the ensuing difficulties that have arisen, the Bass Island occupies the stratigraphic position of the Bertie–Akron, which formation Caley (1940, 1941, 1943, 1946) traced westward from the Niagara Peninsula. As used in Ontario, however, the term Bertie–Akron is now restricted to strata exposed in the Niagara River area.

Fossils have been found only in the lowest few feet of the Bass Island. The total fauna includes ostracods and brachiopods. The lithic equivalent of the Bass Island also is found at an abandoned quarry near Innerkip and in the rocks forming the Canadian islands and reefs west of Pelee Island, a short distance from the Bass Islands. Caley (1941) assigned the Silurian strata of the Innerkip quarry to the Bertie–Akron in lieu of a detailed examination of the quarry, which he was unable to make because of caving and flooding conditions. Williams (1919, pp. 90, 91) assigned the same rocks to the Akron and correlated them with the Raisin River dolomite, an oölitic-bearing member of the Bass Island series in Ohio and Michigan. This correlation was based on the presence of the brachiopod *Whitfieldella prosseri*. The Bass Island of Bruce Peninsula map-area is believed to be the lithic equivalent of the Innerkip quarry rock. Oölites in the dolomites around Walkerton may be a further link between this unit and the Raisin River member of the Bass Island series.

The Bass Island Formation is part of the evaporite series of which the Salina Formation is the lower unit. Indeed, it was unit H in Landes' subdivision of the Salina in 1945. Certainly the Bass Island represents the return of the carbonate lithosome if gross lithologies are considered. Whereas mineral moulds and oölites are indicative of saline conditions, algal concretions, up to 10 feet in diameter, and marine fossils (i.e., ostracods and brachiopods) indicate a carbonate lithosome and normal marine conditions.

Devonian

Devonian Nomenclature

In the Brantford area, Caley (1941) mapped the pre-Hamilton Devonian as a single unit under the term Norfolk Formation, which term was used to designate all rocks previously mapped as Delaware and Onondaga, together with any intermediate or underlying conformable Devonian strata of the same general character. The term was adopted owing to failure in recognizing with certainty Onondaga strata as separate from the Detroit River Formation. It was equally difficult to delimit the Delaware and the Onondaga. This scheme was followed westward into the London and Windsor–Sarnia areas (Caley, 1943, 1946). The premise was based on the supposed equivalency of the Onondaga with the Delaware, a misleading interpretation that had become imbued in the literature. In 1941, it was not understood whether true Onondaga underlay or overlay the Detroit River Formation, or the areal extent and stratigraphic relations of the Detroit River Formation. In the Windsor–Sarnia area, when Caley referred to the Devonian limestones lying disconformably beneath the Onondaga as pre-Norfolk, he was referring actually to the pre-Delaware sequence of the stratigraphic section, i.e., below the Delaware = Dundee = 'Onondaga' = Big Lime. The problem was solved (1) by the sequence in lithologies in Figure 2, page 48 of the Windsor–Sarnia report

(Caley, 1946); (2) when Caley (1946) referred to the Detroit River Formation as pre-Norfolk, and (3) when Best (1953 MS.) delimited the erroneous Onondaga as meaning the 18-to-29-foot basal unit of the Delaware.

Using the data for and an amplified version of Figure 2 (Caley, 1946), the writers concluded that from the Niagara Peninsula to Windsor in the west and to Walkerton in the north, the same sequence of rock units was everywhere penetrated. One exception, however, was the Detroit River Formation. The writers do not consider the Detroit River to be 'absent' in the eastern area. Rather, the formation merges with the Bois Blanc to become the Onondaga Formation of the Niagara Peninsula and New York State (Table IV). Sedimentary differentiation within the Onondaga permits the delimitation, westward from Long Point, of two formations, the Detroit River ultimately achieving group status in the southernmost counties where the members achieve formational status. The Niagara Peninsula Onondaga must be the Edgecliff and probably Nedrow members. The Detroit River bioherms are probably the equivalent of the Edgecliff bioherms, Oliver's (1954, p. 635) description readily fitting Ontario occurrences: "Evidently Nedrow deposition began early in some areas, while Edgecliff conditions persisted in others. Intermittent areas were alternately subjected . . ." "The Springvale sandstone is present at most localities where the lower contact is exposed . . ." In the western area, the above noted exception has no import.

The sequence of pre-Hamilton rock units comprises cherty dolomite, brown bituminous dolomite, lithographic carbonate, and grey limestone; these lithologies are here over-simplified. It is now known that the lowest cherty dolomite is traceable from the true Onondaga in Niagara Peninsula to a level below the Amherstburg quarry, into the cherty dolomite at Dunkeld Creek near Walkerton and into the Bois Blanc Formation (Landes and Ehlers) in the Mackinac Straits vicinity. This unit has been called the Bois Blanc Formation by Sanford and Brady (1955), Bolton and Liberty (1955, p. 36), and others. The brown bituminous dolomite and lithographic carbonate has been called Detroit River. The upper lithology, grey limestone, is problematical, and has been called Dundee in Michigan and Ontario, Delaware in Ohio and Ontario, Big Lime by well drillers in Ontario, and Onondaga by nearly all workers. Obviously it is not the true Onondaga. The term Big Lime is correct but hardly acceptable for scientific purposes. Similarly the terms Delaware and Dundee are equally correct, at least in so far as they have been used locally. This 'pseudo-Onondaga' is the 'culprit-lithology' that Caley finally included under the term Norfolk (1946). Of prime importance is the similarity of lowest Norfolk strata (lowest 18–29 feet of a total of 160 to 200 feet) to the true Onondaga in the area west from St. Marys. Careful observation with respect to sedimentation, lithology, and chert is sufficient to recognize its true identity; paleontologists, however, would still consider its fauna as of upper Onondaga age.

The term Onondaga has been used constantly in the literature with a faunal connotation. This is unfortunate, but any necessary changes must be first implemented in New York State, i.e., a rock unit name to release the term Onondaga to biostratigraphy. In Ontario, the Detroit River overlies Onondaga lithology (Bois Blanc), and as another 'Onondaga' lithology (Stauffer's Onondaga—Best's lower Delaware member—the present report's basal Dundee unit) was known to overlie the Detroit River, three units were known below the Delaware. As the known faunas of these units are very similar and no qualified key fossils were available for faunal differentiation, the three units were assigned lower, middle, and upper Onondaga. The attempt was accepted as fact, so that workers such as Landes, Ehlers, Stumm, and Caley had to completely restudy the stratigraphy when they came to review and initiate investigations about 1941–42.

Major causes of this stratigraphic problem are (1) repetition of lithology and lack of sufficient care in determining the true stratigraphic position of the lensitic sand bodies within the carbonate sequence; (2) a misinterpretation of structure caused by the incorrect identification of Best's lower Delaware as true Onondaga; (3) insufficiently detailed paleontology, for the key fossil concept can be used: the brachiopods *Amphigenia* for Onondaga, *Prosserella* for Detroit River, and *Brevispirifer lucasensis* for Dundee; (4) insufficient comprehensive stratigraphic research with reference to both subsurface and outcrop studies; information was readily available for a much earlier solution of the problem; and (5) a pattern approach on a regional scale. In a problem of this nature and importance it is necessary to determine the regional pattern with respect to the basins and source areas, to sedimentary differentiation, and facies equivalency.

Bois Blanc Formation

Definition

The term Bois Blanc (pronounced locally Bob-low) is used for the cherty limestones and dolomite that overlie the buff dolomite of the Bass Island Formation and underlie the brown, fine-crystalline dolomites of the Detroit River Formation. The term thus applies to a rock unit and has so been used in most of the Ontario literature.

K. K. Landes and G. M. Ehlers first introduced the term in 1945 in the Mackinac Strait of northern Michigan for cherty limestones and dolomites that overlay the dolomite and dolomitic sandstone of the Garden Island Formation (Oriskany correlative on Garden Island) or the St. Ignace dolomite (Bass Island correlative) where the Garden Island was absent. The formation underlay the Detroit River Formation in northern Michigan. Strata having the same lithological identity and stratigraphic position (above the Oriskany, or the Bass Island where the Oriskany is absent, but below the Detroit River) are known in Ontario. The term Bois Blanc has recently been adopted for these strata (Sanford and Brady, 1955; Bolton and Liberty, 1955; and Caley and Liberty, 1957), but is used only in that area west of the Niagara Peninsula.

The type section is on Bois Blanc Island in Lake Huron slightly less than 2½ miles southeast of Mackinac Island. Reference sections in Ontario are the Innerkip quarry near Woodstock and the creek section 2½ miles southeast of Dunkeld, northwest of Walkerton.

Distribution

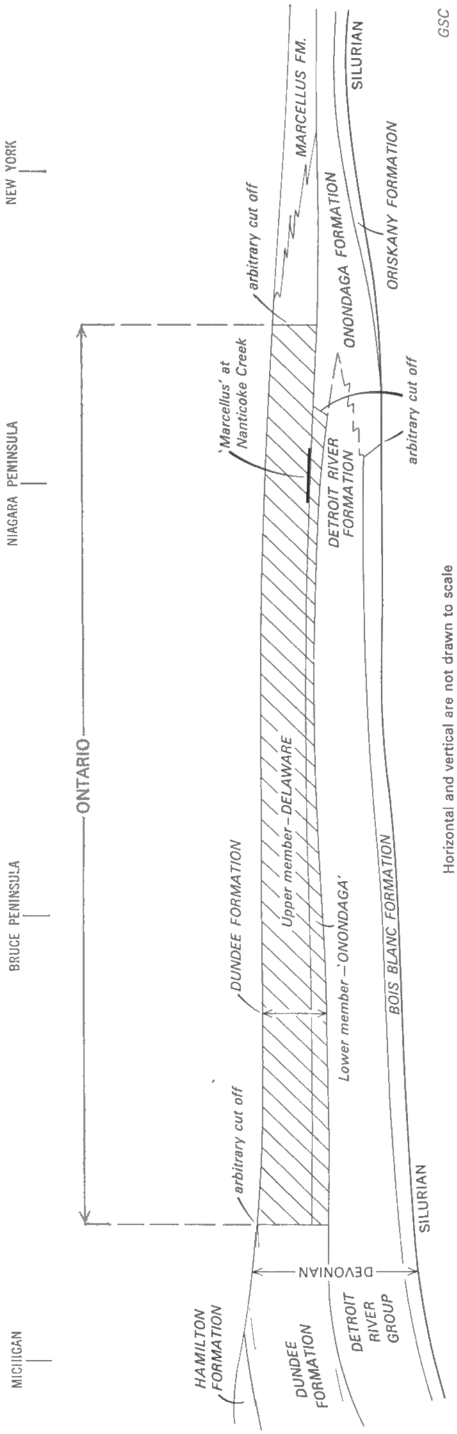
The formation has an areal extent of about 140 square miles, forming a northwest-trending band from the southern boundary of the map-area to Lake Huron. Outcrops are relatively scarce. They commonly exhibit only a few feet of strata, but the formation can be seen to advantage on a stream on the west side of Saugeen River in lot 2, concession VII, Brant township; on Teeswater River at several localities between Chepstow and Pinkerton; and on the shore of Lake Huron about 5 miles south of Port Elgin.

Thickness and Lithology

The total thickness of the formation in the map-area can only be determined from well-cuttings. A thickness of about 150 feet is fairly consistent in the Bruce Peninsula region. As seen in outcrop, the formation consists of grey, brownish grey, medium- to fine-grained, fossiliferous limestone that weathers grey and into irregular beds from an inch to over a foot thick. White weathering chert occurs as nodules, thin lensitic and anastomosing layers, and in thick beds, and is the most characteristic feature of the formation.

In the well-cuttings, chert is the most characteristic feature of the formation. The limestone and dolomite appear to vary from crypto-crystalline (lithographic) to fine crystalline. Also in the cuttings the possibility of finding the tiny amber-coloured spore cases of *Tasmanites* sp. is greater. These have not been found below the stratigraphical level of the Bois Blanc.

TABLE IV | *Facies chart for Devonian of southwestern Ontario.*



Contacts

The lower contact marks the boundary between the Silurian and Devonian Systems and represents a disconformity. The lowest few feet are darker coloured and comprise thinner lensitic beds with dark coloured anastomosing partings. These strata are impure and contain silt and sand residues of quartz as well as glauconite and chert fragments. This lower contact is marked by the change from buff to light grey, fine-crystalline dolomite of the Bass Island to cherty brownish grey limestone and dolomite of the Bois Blanc. The restriction of *Tasmanites* to the Bois Blanc may be used also to distinguish these formations.

Definition of the upper contact with the Detroit River Formation has proved difficult. Some investigators continue to log the Bois Blanc and Detroit River Formations together, others limit the Bois Blanc to the cherty dolomite, despite the anomalous thicknesses so obtained. In this report the upper contact is drawn to retain the Bois Blanc as the lower cherty dolomite.

Stratigraphic Relations

Subsurface studies have confirmed that the cherty Bois Blanc strata can be traced from the Mackinac Straits area of Michigan across Ontario into part of the Onondaga of New York State (Table IV). Throughout this area the Bois Blanc cherty dolomite unit consistently retains a lower position, subjacent to an upper new unit, which achieves formational identity from inherent characters within the Onondaga. Eastward from the longitude of Long Point the upper unit is but a phase—not even a member—simply becoming less and less distinctive and finally coalescing with the Bois Blanc into the Onondaga Formation of New York State. Only in the longitude of Long Point does this upper lithologic unit achieve final sedimentary differentiation to obtain formational status as the Detroit River. These two units, combined, lie between the same lower and upper boundaries as the Onondaga, i.e., Oriskany and the Hamilton (the Delaware Formation is the correlative of lowest Hamilton in New York State). The spatial relationship is similar to that in the reefal Silurian. Small reefs are present in the Onondaga. Large reefs and their associated sediments comprise the Detroit River Formation and originated on a platform area. The subjacent cherty unit (Bois Blanc) is the extension of the Onondaga thoughout southern Ontario and acted as the 'matrix' facies in which the Detroit large reefal areas were developed.

Because of such stratigraphic relations it seems best to restrict the term Onondaga to strata in the Niagara Peninsula and New York State, where it can be used in both a biostratigraphic and a lithic sense. In reality, the term Onondaga should be assigned a biostratigraphic role with a new (rock unit) term proposed for the New York–Niagara Peninsula strata. The term Bois Blanc can be applied in a formational sense to strata west from Long Point (in Lake Erie), where sedimentary differentiation has produced readily mappable rock units.

With respect to possible anomalies in this section, Springvale sandstone lenses occur at several levels within the Onondaga (Bois Blanc) in the Niagara Escarpment area, and accordingly no member connotation is here applied to this unit as suggested by previous workers. Similarly there is the unrelated Sylvania sandstone in the western area, which lies at the contact of the Bois Blanc and Detroit River. The latter is discussed under the Detroit River Formation.

Correlation

With the foregoing in mind it can readily be understood why the reported 'Onondaga fauna' in the Detroit River Formation has led to considerable confusion. Both the Bois Blanc and Detroit River are correlated with the Onondaga of New York, but only the Bois Blanc is the lithic equivalent of the Onondaga. The Bois Blanc is correlated with the lower Onondaga on the basis of the enclosed fauna, particularly *Amphigenia elongata* (Vanuxem). That it is the eastern extension of the Bois Blanc of the Mackinac Straits is indicated by the characteristically cherty unit occupying the same stratigraphic position and enclosing *Syringopora hisingeri* Billings, "*Spirifer*" *duodenarius* (Hall), and *Proetus crassimarginatus* Hall.

Sedimentary Environment

The Bois Blanc is essentially a carbonate unit with large amounts of chert. Preliminary work indicated that thicknesses of the cherty dolomite, as logged in wells, were wholly anomalous. Thicknesses obtained by combining the Bois Blanc with the overlying Detroit River are complementary and present a more readily understandable pattern. The Detroit River and Bois Blanc together are the equivalent of the New York Onondaga and reefs near Formosa lay wholly within the Detroit River Formation. The details of these reefs, the rock units of the Detroit River, and their areal geology formed a pattern, especially when compared with the Silurian reefs on the Bruce Peninsula and Manitoulin Island. The writers, however, do not consider the Bois Blanc to be essentially biostromal. Nevertheless, the chert inclusions suggest that the Bois Blanc was the 'matrix facies' upon which and within which the Detroit River's large reefal areas were developed. Under these areas the Bois Blanc is thin (i.e., its normal thickness), but between them the formation has anomalous thicknesses and is stratigraphically equivalent to the reefs.

The chert occurs as small to large nodules, lenses, anastomosing layers and thin to thick beds, and has replaced countless numbers of fossils. On denuded or quarried surfaces layers of chert pinch and swell from fractions to several inches thick. Blobs of chert now separated from the main mass may have in part been connected at one time. To account for the distribution of this chert Liberty suggests that vast quantities of silica were present in the marine waters probably in gel form (Peterson, M.N.A., and Von der Borch, C.C., 1965, *Science*, vol. 149, p. 1501). Deposition alternated with that of the limestone and dolomite, and the gel was moved and squeezed along the various layers according to the dictates of fracture, load, and slope. In this manner the silica gel could invade and replace the fossils and other porous units. Where no porous units existed the gel would intrude as a mass parallel to bedding and would pinch and swell according to the dictates of load and other factors. This interpretation of the origin of the chert in the Bois Blanc Formation appears best to fit the data now available, and though differing from the interpretations of Laird (1945) and Best (1953, MS.) agrees essentially with that of Smith (1959). The Bois Blanc Formation was deposited in a quiescent shallow sea that supported abundant life, and where siliceous gels were next in importance to the carbonate.

Detroit River Formation

Definition

The term Detroit River is defined and used as it was by Caley (1943, 1946). It was first used by Grabau (1908). The formation in the type area along the Detroit River embraces strata that lie above the cherty limestones and dolomites of the Bois Blanc Formation and below grey and light buff, fine- to medium-grained limestone that has been termed variously Delaware, Dundee, Big Lime, and Norfolk (Table IV). The Detroit River is a rock unit embracing a reefal phase.

Suggested reference sections are Amherstburg and St. Marys quarries; Maitland River section at Goderich (Appendix A, section 30); the quarries along Thames River between Woodstock and Ingersoll; the Formosa exposures; and the road-cut 2½ miles north of the village of Formosa (Pl. VI).

Distribution

The Detroit River strata have an areal extent of about 400 square miles, and form a northwest-trending band that averages about 11 miles wide, parallel to the Bois Blanc Formation. The formation extends from the southern boundary of the map-area to Lake Huron near Kincardine and Amberley, where it widens and fans westward to the lake. Outcrops are few. The formation can be seen best on the Lake Huron shore from McRae Point to MacPherson Point; on Penetangore River about 2 miles above the mouth; in the Teeswater quarry; on Teeswater River half a mile west of Chepstow; on Formosa Creek in the village of Formosa; and in the road-cut 2½ miles north of Formosa.

Thickness and Lithology

At no one locality can the formation be seen in its entirety. Subsurface data indicate a thickness of between 250 and 500 feet.

In general the Detroit River consists of brown, fine-crystalline and lithographic limestone and dolomite. Several special units within the sequence are referred to as the lithographic S (Southern), crystalline N (Northern), and reefal B (biohermal) facies. As Best (1953 MS.) pointed out the S and N facies interfinger in the St. Marys area, and the B facies seems to be limited to an elliptical area around Teeswater and Formosa.

S (Southern) facies. This is mainly a very fine grained, light brown and grey, high-calcium limestone with some cylindrical corals and stromatoporoids. It does not occur within the map-area, but has been recognized in outcrop farther south in the Beachville area where Best (1953, MS., p. 107) has described it in detail. This S facies unit is well exposed in the quarries between Ingersoll and Woodstock in the Thames River valley and in the Amherstburg quarry. In these areas the Detroit River is assigned formation status.

N (Northern) facies. This unit probably underlies the entire Bruce Peninsula map-area, and extends southward to interfinger with the S facies in the St. Marys area. For the most part it is a crystalline unit and embraces both the typical Detroit River and the granular flank deposits of the reefal B facies.

In general the N facies is buff, brownish grey, brown and cream, fine-crystalline dolomite. Minor amounts of interbedded limestone and fine granular textures have been reported. The deposits are of uniform character with the dolomite rhombs tightly packed and limestone comprising interlocking grains of calcite. Bedding varies from thin even beds to some 12 inches thick; more massive uniform beds up to 20 inches have been observed. Mineral moulds, as much as 1 cm. in size, filled with gypsum and celestite are common. Chert has been recorded on Lake Huron shore at McRae Point, and in minor quantities locally in the subsurface. Black bituminous 'lines' from streak to parting status characterize the unit. A strong petroliferous odour is readily noticeable when the rock is struck and broken. These strata are poorly fossiliferous.

The reefal B (biohermal) flank deposits are developed in this N facies. They are characterized by their unevenness, their truncation against the reef core, and their softer nature with reference to weathering and fossil remains. These strata are generally fine, medium, and coarse granular brown dolomite and dolomitic limestone. The vuggy nature (commonly of small size) and intergranular porosity suggest fossil and reef fragments; at least some of the fossil fragments are composed of dolomite. Similarly included in this N facies are 'biostromes' as exhibited at Goderich, Kincardine, and Wingham. These are at most 9 feet thick and a mile long and consist of dolomite typical of the N facies. They are believed to be of algal origin. Best (1953 MS.) reported that large 8-inch fragments of the reef form 'rare breccia beds' in the flank and interreef deposits.

In subsurface samples the N unit is buff to brownish grey fine-crystalline, fine-grained and fine granular carbonate. This fine granular carbonate is most commonly dolomite. Black bituminous streaks characterize this unit and minor chert has also been recorded. The mineral moulds may also be a definitive characteristic. A notable increase of granular dolomite might be interpreted as flank reef deposits, which are assigned to this N facies.

The strata can be seen to good advantage in the Maitland River section at Goderich (Appendix A, section 30), McRae to Macpherson Points on Lake Huron, and on Penetangore River about 2 miles above its mouth. These are here designated as the reference sections.

B (biohermal) facies. This unit represents the reefal phase of bioherms. Some workers have applied a name to this unit (Best, 1953 MS.; Formosa–Fagerstrom, 1961a, b), but the writers follow the recommendations of the Stratigraphic Code and refer to the unit as Detroit River bioherms. The bioherms, as known, occur within an oval-shaped area that extends between Chepstow and Wingham (about 20 miles) and is as much as 9 miles wide. They are not necessarily restricted to that area, however, for many local structural features in the map-area are considered to be due to similar structures over which the superjacent strata drape. The bioherms appear as patch reefs in the form of resistant hills and cliffs; they range from one acre to several acres in areal extent and up to 500 feet in diameter. The valley areas are considered to be due to softer interbiohermal strata.

In the Formosa area the B facies thicknesses vary. Fagerstrom (1961b) noted 51 feet in a well west of Teeswater (J. B. MacKenzie No. 1—Dominion Natural Gas); Best (1953 MS.) reported 90 feet in a well in Culross township (lot 18, concession V); and outcrop studies indicated 35 to 40 feet. Typically the lithology is light grey to bluish grey, sublithographic to lithographic, hard fossiliferous limestone. The limestone is very pure (99.23 $CaCO_3$, Goudge, 1938, p. 213) and occurs as well jointed, non-bedded (complete lack of bedding), massive carbonate. The weathered surface appears porous and vuggy and irregularly pitted (scraggy). Vugs are generally lined with calcite crystals and may represent fossil moulds. Where fossils are few the limestone is fine grained to sublithographic; very fossiliferous parts 'reduce' the matrix lithology, resulting in a surface comprising stromatoporoids, corals, bryozoans, brachiopods, gastropods, trilobites, etc. Large and small flat stromatolites typify by far the greatest part of the bioherm representing the reef framework. Clastic debris from the fossils is present between individuals within the reef and secondary recrystallization was an important process. Accordingly the matrix between the fossils varies from sublithographic to fine-crystalline to coarse-crystalline and from fine to coarse granular limestone (calcarenites). The flank deposits are of different texture and are readily differentiated. They are included with and discussed in the section on the N facies.

In generalized descriptions of the B facies previous workers have implied the existence of only one reef; the writers, however, agree with Best (1953 MS.) that there are a large number of oval patch reefs (bioherms) in the Formosa area. They are included within the N facies because: 1) the lower contact of the bioherm can be seen in the Formosa north road-cut (2½ miles north of Formosa, lot A, con. IIIS, Brant tp. and lot 72, con. XV, Greenock tp.—Pl. VI), and at Chepstow along the banks and in the bottom of Teeswater River (Appendix A, section 29); 2) the upper contact can be observed in the same river below the falls, 4 miles southeast of Teeswater (in lot 4, con. III, Culross tp.). Thus the stratigraphic relations of the B facies are precisely known and were first noted correctly by Goudge (1938). As Fagerstrom (1961b) pointed out, they do not occur at precisely one stratigraphic level; it would be most surprising if they did. Near the falls of Teeswater River these bioherms occur above, below, and at the same stratigraphic level as the Detroit River N facies strata. Although it is possible for the B reefs to occur anywhere vertically within the N facies, they all lie between 25 and 200 feet above the base of the formation.

Selected reference sections for the Detroit River B facies are 1) the Formosa north road-cut, 2½ miles north of the village, on the boundary of lot 72, concession XV, Greenock township and lot A, concession IIIS, Brant township; 2) the exposures near Formosa; 3) 4 miles southeast of Teeswater at the falls, in lot 4, concession III, Culross township; 4) at Chepstow, along the banks and in the bottom of the Teeswater River; 5) the quarry in lots A and B, concession IIIS, Brant township, south of Greenock Curb; 6) the quarry in Teeswater, lot 15, concession VI, Culross township; and 7) east of the bridge over Formosa Creek in lots 3 and 4, concession XI, Culross township.

In subsurface, the bioherms are light grey to bluish grey, lithographic to sublithographic limestone. The biohermal strata are more massive in the fresh rock than on the weathered surface; this together with the increased density of the rock type makes the rock harder to drill. Accordingly, drilling time for a 5-foot drilling interval would be different from that for the N facies brown dolomite. Solution cavities are commonly encountered in drilling through the bioherms, for joints and 'caverns' are locally very well developed.

Contacts

The lower contact of the Detroit River Formation is delimited so as to leave the main mass of cherty dolomite in the Bois Blanc Formation and the brown dolomites with bituminous partings in the Detroit River. This must be done on a gross lithology basis, for in sedimentation of this sort transitional strata are common. There are a few chert occurrences in the Detroit River.

With respect to the S facies within the Detroit River, its lowest strata are not too unlike the lowest strata of the N facies and similar delimitation is recommended. Its upper contact with the "Columbus Formation", as exposed in the Ingersoll area, is readily delimited as brown, sublithographic to lithographic limestone below the grey and brownish grey, fine-, medium- and coarse-grained limestone with an appreciable quartz silt content.

The N facies presents the typical Detroit River upper and lower contacts. The lower contact is as noted above; the upper is between the brown fine-crystalline, fine-grained dolomite with dark bituminous partings and the Dundee (Norfolk, Delaware–Dundee) light, to medium brown, fine-grained to crystalline limestone. Lowest strata of the Dundee could be more accurately described at the Goderich–Maitland Creek section as medium brown, fine-grained limestone in whose base is a 0.3-foot bed of conglomerate composed of rounded pebbles of Detroit River dolomite and limestone. These were the strata previously and erroneously referred to as 'Onondaga' in the Goderich area, and in which there is certain evidence of a minor hiatus.

Within the buff dolomite of the N facies the B unit's reefal bioherms occur as grey, lithographic to sublithographic limestone. A bluish coloration may be more consistent in the fresh subsurface samples. Thus, the upper and lower contacts of these bioherms should be sharp. Any rock removed by solution, would be the more soluble limestone of the reef. Accordingly upper and lower contacts can be fairly accurately located if solution phenomena are present.

Stratigraphic Relations

Most workers agreed that the Detroit River Formation was a lithic entity of at least formational rank, and that it lay below the Delaware–Dundee strata. The problem was whether the Onondaga lay above or below the Detroit River Formation.

Caley's (1941) introduction of the term Norfolk, as a 'grouping' agent, was the only logical action at the time. Now it is known that the Detroit River lies above the Onondaga of southwestern Ontario and below the Norfolk (Dundee). The lowermost unit of the Norfolk formation was sufficiently similar to the Onondaga of New York that it caused confusion in areas where little or insufficient subsurface drilling permitted alternative sequences to be proposed. Moreover, this same unit could be uppermost Onondaga and include both the Detroit River and Bois Blanc Formations. It is now known that the structure is simple and straightforward and the paleontological data are compatible with the nomenclature herein followed.

Ehlers (1950) corrected the errors in the Detroit River sequence, and Stauffer (1915) did recognize the Detroit River as a formation. Of the regional setting and stratigraphic relations Bolton and Liberty (1955 p. 36) wrote:

> It should be pointed out that tracing of the Onondaga formation of New York into Ontario by means of subsurface studies has confirmed the fact that the Detroit River first achieves its identity as a formation in Norfolk county, north of Long Point. Westward, the cherty dolomite, typical of the Onondaga, consistently retains a lower position, subjacent to an upper new unit which has finally achieved formational identity from inherent characters within the Onondaga. These two units combined lie between the same lower and upper boundaries as the Onondaga formation, in New York and in the Niagara Peninsula. The lower unit has been traced southwest to Windsor and Amherstburg and northwest to Walkerton and Lake Huron. All the evidence supports the conclusion that this lower unit should be called Bois Blanc in accordance with the 1945 investigations of Landes and Ehlers. The upper unit is known as the Detroit River, which thickens into the Michigan Basin where it achieves group status as the individual members emerge with formational connotation.

This pattern accounts for the 'apparent' overlap of Detroit River on the Onondaga in a more logical manner and without the paleogeographic difficulties so implied. All of the Bois Blanc, Detroit River, Columbus, and Norfolk (lower member)—Dundee have been noted as containing an Onondaga fauna.

In the Bruce Peninsula and adjacent London map-areas, the Detroit River should be designated as a formation as no subdivision is possible. Where rock types within this unit are more dominant, consistently present, and considerably thicker, they must be raised to formational status; consequently in Michigan the Detroit River must be raised to group status (Table IV).

Correlation

The Onondaga–Detroit River correlation is accepted. Stauffer (1915, p. 148) was correct in noting the marked resemblance of the biohermal B fauna "to that of the purer portion of the Onondaga limestone". Nevertheless, he considered the fauna to have a preponderance of Hamilton forms and accordingly mapped these strata under the name Alpena. As this biohermal facies lies within the Detroit River, the Upper Devonian term Alpena can no longer be applied. Also, as the associated N facies is poorly fossiliferous it is not possible to determine whether it is the Amhertsburg or Lucas (or both) biostratigraphic unit. In the Ingersoll area, Best (1953 MS.) on the basis of the contained faunas was able to distinguish these two units, but others have been unsuccessful.

Although stromatoporoids are supposed to constitute the main framework of the bioherms (at least 50 per cent according to Best, 1953 MS.), the main structure should be more correctly termed stromatolitic. The fauna of these bioherms is varied and abundant, though facies controlled, with most taxonomic divisions being represented. Some of the more abundant fossils are *Fimbrispirifer divaricatus*, *Leiorhynchus* sp. aff. *L. kelloggi*, *Meristella* sp., *Cystiphylloides* sp., *Favosites* sp., *Siphonophrentis* sp., *Synaptophyllum* sp., *Conocardium monroicium*, *Mourlonia filitexta*. The fauna indicates an Onondaga age (Fagerstrom, 1961b). It should be added that the brachiopod *Prosserella* was found in this unit, corroborating this correlation. Also, the enclosed fauna permits a reasonably good correlation with the reefs in the Anderdon and Amherstburg units in their type areas.

In contrast, the N facies contains a meagre, poorly preserved fauna. Some of the more common fossils are *Clathrodictyon* sp., *Idiostroma nattressi*, *Prosserella lucasi*, *P. planisinosus*, *Conocardium monroicium*, *Cladopora* sp., *Heliophyllum* sp., and *Temnophyllum integumbia*. On the basis of the *Prosserella* fauna, the Detroit River N facies in the Bruce Peninsula area is correlated with the Detroit River of Michigan. Its fauna also indicates a correlation with the Onondaga of New York State. Lithically, the N facies interfingers with the S facies, which in turn is traceable into the Onondaga of New York.

Sedimentary Environment

Within the N facies (at least), the B (biohermal) facies was probably developed in a shelf or platform area specially conducive to reefal sedimentation. Moreover, as the Detroit River evaporites lie west of the Bruce Peninsula map-area in the deeper part of the basin it is suggested that they occur in the N facies and are related to the reefal complex. Best (1953, MS., p. 147) noted that "true evaporites . . . are present only in the upper part of the Lucas formation and in the centre of the Basin".

It is doubtful that a barrier reef as such ever existed around the rim of Michigan Basin. During Detroit River sedimentation the writers envision a reefal environment extending completely across this shallow basin, becoming more complex towards the centre with the deposition of salt. As this central area became depressed and as the margins were warped upward (each being relative and complementary to the other), the existing reefs on the margins impeded circulation. Within such a marginal area the evaporite series could be initiated contemporaneously with reefal growth with respect to a rim development of the reefs; an interfingering contemporaneous relationship between the two facies would exist. Like the basinal reefs in the Middle Silurian, these reefs probably spread completely across the basin until their growth was impeded by the evaporite sediments. The Algonquin Arch in Ontario represents the eastern flank of Michigan Basin, which probably underwent pulsatory movements at least during the time of sedimentation.

Most of the stratigraphic observations in southwestern Ontario and the adjoining states during the past 120 years may now be coordinated and synthesized. It is within the N facies that active reefal growth was most predominant, and available evidence suggests the reefs grew in clear, well lighted, well aerated shallow water conditions of 40 to 70 feet. Around these biohermal patch reefs the granular flank interreef strata exhibit up to 24-degree dip, as near McRae Point and Maitland River.

In discussion of the Bois Blanc Formation, the need for defining rock units for the sake of rock units was stressed, in particular for subsurface tracing and delimitation of anomalous thicknesses of such units. It was further suggested that the Bois Blanc's cherty dolomites were complementary to the Detroit River dolomites, both in thickness and lithology. Also the cherty dolomite of the Bois Blanc may well be the matrix facies upon which Detroit River areas were developed. One such reef area (macro-reef) would be the 'Formosa oval' or ellipse in which the B facies is known to exist. Between macro-reef areas the cherty dolomite would be expected to reach higher stratigraphic levels in the sections and so present anomalous thickness values as interreef strata. Such is their character in other reefal accumulations in Ontario.

If the terms Bois Blanc and Detroit River were defined by faunal content, the two units would be inseparable, for the supposed 'key fossils' are rare and sparse. By defining rock units, the lithic sequence and thickness variations in such strata over a wide area can be determined, and the chert occurrences within the Detroit River more easily explained. Also, the macro-reef idea can be tested. Liberty, not entirely satisfied that the S facies is completely separable from the N facies, considers that future work may indicate a trace-over of lowest N into the southern area. Should the lithographic dolomite of the S facies be proved 'locally controlled' at any time, then the S facies should be re-investigated.

A vigorous shallow sea is envisioned for the depositional environment of the N facies, in comparison with quiescent conditions for the S facies. That the former supported abundant life is well illustrated by forms preserved in the bioherms. In the past the purely biostratigraphic approach used in studying these rocks was the more difficult because the peculiar environmental conditions dictated the fauna and lack of fauna by ecological controls. Thus carbonate chemical precipitates, reefal deposition, and basinal restriction with consequent salinity increase, are considered the essential processes in the sedimentary environment.

Dundee Formation

Definition

The Dundee Formation embraces the strata between Detroit River carbonates and Hamilton black shales. This definition conforms to that of Caley's *final* Norfolk Formation (1946, p. 31, para. 5, line 5): ". . . here restricted to the Delaware–Onondaga part of the pre-Hamilton Devonian." On lithological grounds, it is considered to be a natural unit.

The term Dundee is preferred rather than attempt to reinstate Norfolk; to add a new name to the literature; or to use Delaware. The unit concerned, however, is not the full Dundee of Michigan, either stratigraphically or lithically; neither is it entirely the Delaware of Ohio.

Reference sections are the Maitland River section at Goderich (Appendix A, sections 31, 32) and St. Marys Cement Company south quarry at St. Marys.

Distribution

The Dundee Formation has a very large areal extent in Ontario. In the Bruce Peninsula, it underlies an irregularly shaped area centring around Goderich, with lobes 5 to 12 miles wide extending from 10 to 25 miles long from Goderich. The southwesterly trending re-entrants shown on the geological maps have been inferred in an effort to explain subsurface data.

Thickness and Lithology

At no one locality in the map-area is the Dundee Formation exposed in its entirety. Recourse must be made to the drilling samples in areas of Hamilton bedrock in order to obtain the true thickness. Thus, within the map-area where no Hamilton is present we are dealing with minimum thicknesses. Caley has estimated that between 80 and 100 feet are present. Best (1953 MS.) has estimated about 137 feet for his Delaware (= Dundee of this report) in the Goderich area, assigning 29 feet to the lower member and 108 to the upper. He noted that whereas the lower member thinned to 18 feet at St. Marys it thickened in a northerly direction. The writers suggest that the formation probably thickens in a basinwards direction.

Generally, the Dundee is a grey, brownish grey, medium- to fine-grained, and fine-crystalline to sublithographic limestone and dolomitic limestone. The rock weathers grey and into irregular beds up to 12 inches thick, but may form thick massive beds in a cliff or quarried face. It contains numerous small lenses of bioclastic material, dark carbonaceous partings, and stylolites, and chert is commonly present in the form of nodules and bedded layers, but does not adhere to any particular stratigraphic level. The formation is moderately fossiliferous.

A twofold subdivision into lower and upper members (corresponding to Best's members) is suggested. The lower comprises 18–29 feet of limestone between the Detroit River and the Delaware Formations (as used by Stauffer, 1915) in the Goderich–St. Marys area. The type section is at St. Marys, in the St. Marys Cement Company south quarry (north face). There, 18 feet of the member overlies the Detroit River Formation and grades upward into the upper member. This member is best developed in the northern part of the map-area. The rock is generally a tan to light grey, medium-grained, crystalline limestone with carbonaceous laminae. Bioclastic material is present in lenses, and fossils are common.

The upper member comprises the strata referred to the Delaware by Stauffer (1915), and has generally been considered as the Delaware Formation proper. It is more widespread and thicker than the lower member; Best considered it to be about 175 feet. The type section, like that of the lower member, is at St. Marys in the St. Marys Cement Company south quarry (north face). This is the most complete exposure and shows the relationship with the lower member. The rock is generally fine-grained to sublithographic, grey and brown limestone with perhaps a purplish tint, and occurs in massive, hard beds. Lenses and beds of bioclastic material are present. Chert is also present and varies from grey and black to tan and white. Stylolites are common and pyrite has been observed. The unit is not particularly fossiliferous.

In well-cuttings the Dundee Formation is readily definable, for the contrast with the underlying Detroit River sediments and the overlying Hamilton shales is easily noted. Chert, which may begin about 25 feet or so above the base, the spore case Protosalvinia, and bioclastic limestone also distinguish the formation. The chert is generally light coloured and appears to become more abundant southeastwards.

Contacts

In the general Goderich area the lower contact can be seen at Maitland River section at Goderich (Appendix A, sections 31, 32); in Maitland River at Brussels between the dam and the bridge; and in south quarry of the St. Marys Cement Company. It is defined as between the brown, fine-crystalline Detroit River dolomite (or grey and brown lithographic limestone or dolomite) and the grey, fine-crystalline fossiliferous Dundee limestone. In the Ingersoll area, the "Columbus Formation" may appear similar to the Dundee on initial investigation. Its sandy nature, however, serves to delimit it from the Dundee[1].

The quartz grains and angular pebbles of Detroit River lithology observed in the basal few feet of the Dundee Formation at Goderich are probably present in the formation within the map-area.

Throughout the map-area, glacial drift lies on the truncated surface of the Dundee Formation so that the upper contact is nowhere exposed. The Dundee is, in general, the bedrock formation almost as far south as a line joining Kettle Point, Parkhill, and London (*see* Map 1194A). South of this line, the Hamilton overlies the Dundee and the upper contact is readily definable between the grey, fine-crystalline limestone and the soft, light grey, calcareous shale of the Hamilton. Where a transitional unit occurs an arbitrary contact must be drawn to retain the rock units' gross lithology.

Norfolk Historical Note

Caley (1941, 1943) used the term Norfolk Formation as an emergency measure until sufficient data was accumulated to resolve both the Onondaga and Detroit River stratigraphic problems. Thus, this term was used to group the Onondaga, Bois Blanc, Detroit River, and Delaware–Onondaga strata; the detailed stratigraphic succession for these strata, at that time, was not known with any degree of certainty. In 1946, Caley published a final definition for Norfolk, and clearly stated that this term was applied to those strata above the Detroit River Formation and below the Hamilton Formation. In 1966, Liberty attempted,

[1]R. J. Beards (Ontario, Dept. Energy and Resources Management, Paper 67-2, Guide to the subsurface stratigraphy of southern Ontario) notes that "Columbus" strata are retained in the Detroit River Formation in the Woodstock–Ingersoll area.

unsuccessfully, to reinstate the term Norfolk as defined by Caley in 1946. It seems more appropriate to use the term Dundee, with the same definition, and in Ontario to discontinue use of the terms Norfolk and Delaware.

Stratigraphic Relations

The lowest strata of the Dundee are considered to be a basal unit of clastic limestone that would typify a transgressing deposit. The abundant angular fragments in it are Detroit River dolomite, chert, and fossils. So similar is this basal unit to the Onondaga that Stauffer (1912a) and Grabau and Sherzer (1910) termed it 'Onondaga', and thus the problem arose as to whether Onondaga strata overlay or underlay the Detroit River. At that time, this basal unit was reputed to enclose an Onondaga fauna. Best (1953 MS.) indicated that this unit was present only in the area of St. Marys and northwestward, but the writers suggest that these strata are approximately contemporaneous with the 'Nanticoke beds' to the south (i.e., beds at Nanticoke and Cheapside that are considered by most workers to be Delaware). Thus, in preference to Best's hypothesis of overlap and wedgeout of this basal unit south of St. Marys, a thinning of the section southeastward is suggested with an associated facies change from the clastic beds to the carbonate lithosome with which the Marcellus lithology interfingers and within which the "Marcellus fauna" is found, i.e., the brown shale and *Styliolina fissurella* and *Tentaculites gracillistriatus*. Thus the writers assign the 'Nanticoke beds' to low Dundee (= low Delaware). The basal few feet of this formation could very easily contain the Onondaga fauna.

In considering that the Detroit River and Bois Blanc merge into the Onondaga Formation just east of Long Point (see discussion under Detroit River) and that the Dundee is thinning in this same direction, it is no longer meaningful to stress an easterly overlap of the Dundee on the Columbus, the Detroit River and Bois Blanc, as Best (1953 MS.) has done. The simpler interpretation presented in the previous paragraph is preferred for it readily fits into the pattern of thickening westwards, and also explains sedimentary differentiation of the smaller units in that direction (Table IV). To reason otherwise requires the presence of important unconformities and phenomena, which are not known.

Thus, the Dundee forms one lithic unit, extending from Lake Erie to Lake Huron. In its westernmost localities it compares favourably with Dundee lithologies and faunas, whereas in its easternmost localities it displays Delaware lithology and fauna. The existence of Marcellus lithology and fauna in its lower strata is perhaps the most important item with respect to its correlation, for the Delaware of Ohio is traceable into the Marcellus of New York. As the Marcellus is the lowest formation of the Hamilton Group the interface between the shale (Hamilton) and limestone (Delaware–Dundee) lithosomes is shifting vertically, the lowest black shales becoming progressively younger in a westward direction.

Unconformable relations occur between the Detroit River and the Dundee Formations; at Goderich and Brussels the sand and conglomerate encloses pebbles of Detroit River lithology. Nevertheless these aspects should be minimized, for despite the abrupt contact and local relief, structures in the Detroit River are reflected in the overlying Dundee sediments. Two points are worthy of note: (1) complex sedimentation can occur in reefal complexes; and (2) unfossiliferous strata or strata lacking the key fossils can still represent a time interval which paleontologically cannot be proven. Thus an unconformity defined merely by means of a sharp contact, lack of a key fauna, or a distinctly thinner section is unsound. The last mentioned becomes immediately important with respect to the Dundee in the western area. An unconformity between the Dundee and the overlying Hamilton is difficult to determine. That the Dundee is considerably thinner than the Dundee in Michigan does not pose a serious problem, for the unit would be expected to thicken in that direction and new units would be added to the section. Best (1953 MS.) suggested 200 feet for the thickness of strata (herein called Dundee) in the map-area. From well-cuttings it is known that the upper contact is not one of limestone to black shale but rather limestone to interbedded shale and limestone, suggesting transitional relations. This may well be the rule rather than the exception, considering the basinwards position of the map-area from the Algonquin Arch. Furthermore, whereas the Dundee is upper Eifelian and the Hamilton is lower Givetian, any disconformity at the top of the Dundee cannot have any great time significance.[1]

The following fossils support a Delaware correlation for the Dundee formation: *Brevispirifer lucasensis*, *Chonetes deflectus*, *Leirorhynchus* sp., *Longospina mucronata*, *L.* (?) *maconensis*, "*Martinopsis*" *maia*, *Mucrospirifer consobrinus*, *Protoleptostrophia perplana*, *Agoniatites vanuxemia*, *Gigantoceras inelegans*, and *Styliolina fissurella*. Neither "*Martinopsis*" *maia* nor *Styliolina fissurella*, however, are found in the lowest few feet of the formation in the area west from St. Marys. Nevertheless, *Brevispirifer lucasensis*, *Megastrophia concava*, and *Proetus planimarginatus* are common throughout the Dundee Formation in both the Lake Erie and Lake Huron areas, as well as in both the type Delaware and Dundee.

Sedimentary Environment

The Dundee limestones originated as lime muds, as is evidenced by the texture and paleoecological indications of the enclosed fossil forms. Quiescent conditions postulate the lack of fragmentation. There must have been brief periods of non-quiescent conditions or active bottom currents to account for the lenses of bioclastic crinoidal material, which locally make up a considerable proportion of the lithology. The basal unit seems to have been deposited in a shallower environment, probably a local area of moderately large extent. These beds appear to be of clastic origin, although the matrix cement was probably a lime mud also, which could be masked by the influx of fragmental remains.

The chert within the Dundee Formation is of special interest. All occurrences (small to large nodules, lenses, anastomosing layers, thin to thick beds) are considered to be of the same origin. It is postulated that the sea depositing the Dundee strata contained vast quantities of silica in gel form. This gel would alternate with the carbonate, would move and be squeezed laterally and vertically, and could be forced to invade porous units–replacing any enclosure. Where no porous units existed, the gel could only pinch and swell along the bedding planes. This interpretation satisfactorily explains the variations between bedded and nodular chert that have been observed, and no recourse to the introduction of material from siliceous springs is necessary. Thus the fossiliferous and unfossiliferous chert, the similar textured cherts, the lateral replacements of the original rock, and the bedding thickness could be most easily explained. Solidification is believed to have been late in the diagenetic phase.

Dolomite constitutes a small proportion of the formation. It occurs in the form of large to small rhombs, mostly restricted to the cement. Liberty suggests that the rhombs represent dolomite that separated as a late faction from the intimate admixture of dolomite and calcite in the precipitate carbonate mud. The size variation observed is similar to digitate forms and lends some credence to this idea. Replacement of fossil edges by rhombs is considered fortuitous.

The moderate argillaceous content seems to be fairly constant both vertically and laterally. An argillaceous sea bottom replete with pyrite seems compatible with the available evidence, permitting a period of essentially quiescent reducing conditions when life abounded.

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[1]*See* Devonian of Ontario and Michigan *by* B. V. Sanford, p. 976, *in* International Symposium on the Devonian System; *Alberta Soc. Petrol. Geol.*, vol. 1, 1968.

Sedimentation and Paleogeography

Both a major source area to the southeast (Appalachian) and a secondary northern source in the Canadian Shield may be postulated. This was not the Shield *per se*, but rather the Paleozoic veneer of carbonates (essentially) that covered large parts of the Shield during Paleozoic time.

Although the southern Ontario sedimentary area is considered, for the most part, intermediate between the Michigan and Appalachian Basins, such an area is interpreted as not so much 'shelf' but 'platform'. The Bruce Peninsula map-area, is almost wholly within the Michigan Basin. The Owen Sound flexure (*see* Fig. 4) limits the southeastern edge of the Michigan Basin, and the Algonquin Arch acts as the divider between the Michigan and Appalachian Basins. This platform is traceable into southwestern Ontario and coincides, approximately, both with the southwestern peninsula (between Lakes Erie and Huron) and the trace of the Algonquin Arch. This platform is the areal unit in which, for example, the Delaware–Dundee nomenclature problem has arisen. On either side of the platform subsiding basins contain sediments up to and including Pennsylvanian. Of the sediments, the carbonate lithosome is the most predominant. The shale lithosome is secondary, the sandstone being minor so far as a quantitative evaluation is concerned. In the Silurian, the shale lithosome comprises about 19 per cent of the section, there being no sandstone. In the Cambro-Ordovician section, 49.6 per cent is carbonate, 48.7 per cent is shale, and 1.7 per cent is sandstone. The Devonian is carbonate within the map-area. Towards Manitoulin Island and northern Michigan the Silurian's carbonate content increases markedly. More precisely the nature of the sequence might be listed, Cambrian, sandstone with some shale and carbonate; Middle Ordovician, limestone essentially; Upper Ordovician, shale 87 per cent, carbonate about 13 per cent; Lower Silurian, shale 57 per cent, carbonate 43 per cent; Middle Silurian, carbonate with very minor shale; Upper Silurian, carbonate 85 per cent, shale 15 per cent; Middle Devonian, carbonate essentially. The carbonate lithosome is the more prominent, by far, and the writers consider this aspect to be very important in further considerations.

Outliers of post-Precambrian strata within the Canadian Shield are important, for they indicate not only that large areas of the Shield were covered by Paleozoic seas but also that the Shield was not the positive stable area many authors have claimed. That the outliers are predominantly carbonate indicates the probability that the Paleozoic veneer over parts of the Shield was consistently carbonate. When the outliers are plotted on a small-scale geological map of Canada, the resultant pattern indicates the probability that most of the Shield was covered by Paleozoic sediments at least in Ordovician and Silurian, and possibly in Devonian times.

These outliers provide important information on source areas. The carbonate veneer in the central and northern parts of Ontario has been removed and only remnants (by which we can join the Hudson Bay Lowland to the Michigan Basin) remain. The erosional products of this veneer produced the clastic carbonates of the Silurian (and higher) strata of the Michigan Basin. Here then is the explanation hinted at, but never clarified by so many workers, for a postulated necessary northern source area for much of the basinal sediments. To reiterate, most of the Canadian Shield in Ontario was at one time or another covered by a veneer of Paleozoic strata; in all probability this condition was never attained at one time. Erosive products were carried into both the Hudson Bay Lowland and Great Lakes basinal areas; similar rock types (i.e., the formations and formational sequence for the same time intervals) resulted.

As the formations described are rock units, some usual biostratigraphic terms are not employed for the map-units. In this manner possible transgression of time-lines by rock units is not masked, for the biostratigraphic units themselves do in no way give the pattern. It is believed that in sediments deposited in a shelfward or platform area, delimitation of units in carbonates is accomplished more easily because clastic content derived from source areas will be at a minimum. Also the stability of such an area permits demarcation of carbonate entities and facies equivalents; disconformities will be more pronounced and will disappear basinwards. Conversely it is conceivable that whereas unconformities may have occurred in the basinal area, there may have been less severe conditions varying to continuous sedimentation in platform areas. It is more practical to trace the delimited carbonate units into basinal deposits and their shale equivalents than to set up the reference units in the more argillaceous section and attempt to trace them shelfwards, as has been the practice until recently.

The pattern is one of progression from Cambrian clastic strata in depression areas of Precambrian rocks to the epicontinental sea sedimentation of the Middle and Upper Ordovician limestones and shales. There, biostromes made their first appearance, the Bobcaygeon Formation being developed within the carbonate sequence and the thin Kagawong biostromes extending southward from the Manitoulin carbonate area into the shale lithosome (Queenston Formation) within the map-area. In Silurian time the Bruce Peninsula was on the brim of a reefal complex, which embraced at least the sediments of the lower and middle parts of that system. The Upper Silurian is considered a part of this complex, in that the Salina Formation resulted from the lack of circulation caused by the 'encircling' reefs of the basin. This Upper Silurian series was contemporaneous with a part of the reef growth and was instrumental in controlling the growth of the complex. By Mid-Devonian time another similarly controlled reefal complex was in existence in the map-area.

Most workers consider the Michigan Basin to have been in existence or to have come into existence for Salina deposition (Upper Silurian). The negative area needed for such a basin in all probability was initiated in the Niagaran for the reefs to have been developed to such a marked degree on the rim. If the reverse is so then the reefs should be equally developed completely across the Michigan Basin to the Chicago 'Illinoian' area. Dating would then be Middle Silurian. From such a time onwards instability of such a basin could account for the observed sedimentation and stratigraphy.

Prior to the Middle Silurian the Algonquin Arch may have had sufficient relief to produce a basinal effect, at least on the eastern side of the present Michigan Basin. Thus the Arch was merely in later time a platform area, the Algonquin Platform. Apart from certain pulsations of the Arch during Ordovician time it must have been moderately quiescent and of moderate relief only, for little or no effect in sedimentation has been detected. The carbonate and shale lithologies concerned have much greater tolerance with respect to angle of deposition than in the case of sandstone. Thus any relief could be more readily 'absorbed', not indicating thereby any sedimentary differentation due to such an influence. The steepest dips on the flanks of the Arch are about 60 feet to the mile at the most. Such a feature would serve admirably as a platform.

The incipient features of the Michigan Basin may have been effective in late Precambrian–early Cambrian time in order to provide the necessary relief and drainage pattern for the known distribution of Huronian and Cambrian sediments outside the centre of the basin. It is inconceivable that the parallelisms and pattern of the Great Lakes is fortuitous, especially with the Cambrian deposits being in the base of such depressions and the noteworthy thickening of most formations as the southern lake depressions are approached. Although the underlying cause of the Michigan intracratonic basin can only be guessed at, the incipient features were active in early Cambrian times at least.

With the exception of the Cambro–Ordovician and Siluro–Devonian stratigraphic breaks, there was essentially continuous sedimentation during the early Paleozoic in the Bruce Peninsula. For this reason contact phenomena have been difficult and arbitrary definitions have had to be made. The unconformities that are recognized may be more prominent owing to their proximity to the Algonquin Arch and their shelfward position from the basin.

Chapter III

STRUCTURAL GEOLOGY

(*B. A. Liberty*)

The glacial drift that covers the bedrock surface varies from a thin veneer on the top of the cuesta and north of Owen Sound (absent in some areas) to several hundred feet south of Owen Sound and below the Niagara Escarpment. Although the lower swampy areas on the cuesta overlie lacustrine clays for the most part, the deposits in the adjacent lowland area vary from talus and ice-shore deposits at the base of the escarpment to 'drift' fillings of pre-glacial drainage channels. Few rivers and creeks show key exposures. The finest structural feature is the Niagara Escarpment, which permits continuous outcrop over long distances. Other structural data obtained by outcrop mapping are few.

Topography is bedrock controlled, except where the glacial drift is exceptionally thick. Attitudes of Paleozoic strata, relative to the Precambrian surface, are those of initial depositional dip; locally, compactional processes played a minor role in the steepening of those dips. Regionally, the dip is a few degrees south of southwest at 25 to 40 feet to the mile. Thus, local exposures present flat-lying strata, with local attitudes measurable only in a few feet to the mile.

The areal distribution of the formations shows the broad regional structure to be essentially monoclinal. In the southwest, the regional slope contains gentle rolls striking parallel to the trend of the formations, in the north gently undulating features are transverse to the regional strike. Although small crumples and minor folds are present locally, the formations have not been subjected to any severe deformational forces.

Little information is available on the detailed topography of the Precambrian surface. Although several wells penetrate the entire sedimentary succession (Table V) they are practically confined to the northeastern part of the area, and in general are so widely distributed as to indicate only the more regional character of the Precambrian surface. Regionally this Precambrian surface slopes southwestward from an elevation of 216 feet above sea level east of Collingwood on Nottawasaga Bay to about 2,327 feet below sea level at McRae Point on Lake Huron—a distance of about 75 miles. Southeastward across the area, the Precambrian surface rises from about 980 feet below sea level in Eastnor township to 21 feet below sea level at Glen Huron, after which it apparently falls in the adjoining area to the southeast. The Owen Sound area is situated on the northwest slope of a wide, low, southwesterly plunging area of the basement complex known as the Algonquin Arch.

A terrace on the northwest flank of Algonquin Arch just southeast of Owen Sound is readily observable on structural contour maps drawn both on the top of the Simcoe Group (Fig. 3) and on the Precambrian surface. On the latter map this terrace is about 20 miles wide and represents a very distinct change in gradient. Southwesterly across this terrace as far as

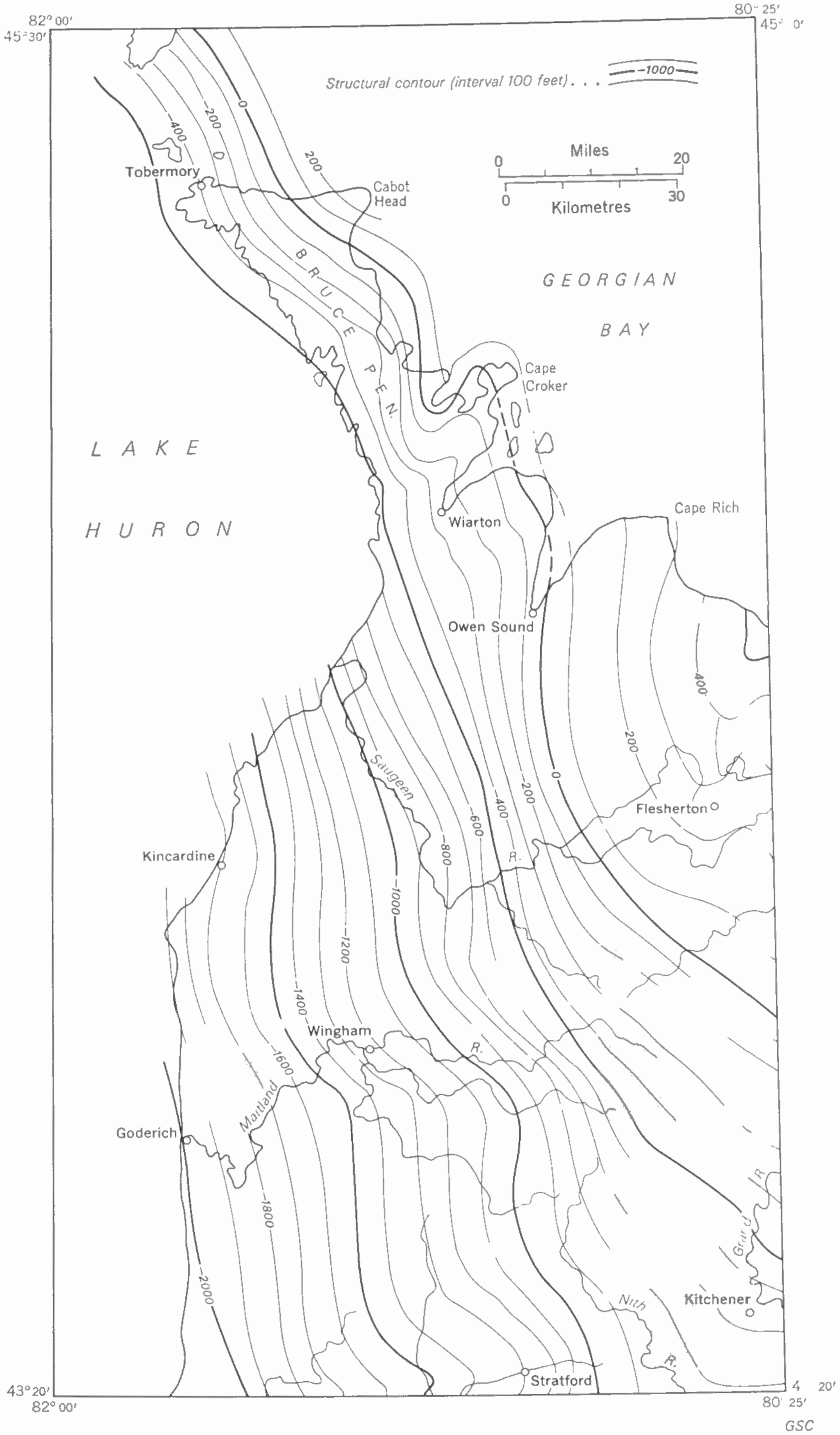

FIGURE 3. Structural contours drawn on top of the Ordovician, Simcoe Group.

TABLE V | *Well Data*

Tp.	Lot	Con.	Surface elevation (feet)	Total depth (feet)	Year completed	Elevation top of Simcoe Group	Remarks
1. Albermarle	3	3EBR	648	1,579	1955	−292	Prec. test, dry hole
2. Amabel	1	10	707	1,650	—	−188	Prec. test, gas 1405
	2	10	700	1,440	1919	−330	Simcoe test, show gas
	3	6	711	1,678	1901	−381	Prec. test, dry hole
	3	9	706	1,440	—	−340	Simcoe test, gas 1409
	4	7	742	1,476	1935	−320	Simcoe test, show gas 1435
	5	9	692	1,495	1936	−368	Simcoe test, dry hole
	4	11	692	1,500	1936	−356	Simcoe test, gas 1402, 40 MCF
	6	11	698	1,471	1902	−358	Simcoe test, gas at 1415
	6	8	698	1,728	1935	−397	Prec. test, dry hole
	10	10	631	1,510	1919	−424	Simcoe test, gas show 1440
	14	10	603	1,500	1919	−459	Simcoe test, gas show 1450, 1475
	33	2S	720	1,421	—	−337	Simcoe test, gas 1407, 20 MCF
	52	NCD	686	1,645	1955	−354	Prec. test, dry hole
	2	21	652	1,300	1901	−284	Simcoe test, dry hole
3. Artemesia	Flesherton		1,559	1,900	1916	−279	Prec. test, dry hole, at coop Stn
	135	35W	1,395	1,873	1921	+ 40	Simcoe test, gas show 1645
	180	2SW	1,610	1,970	—	+289	Prec. test, dry hole
4. Culross	18	5	1,039	2,859	1942	−1,145	Prec. test, dry hole
	18	13	928	2,384	1941	−1,239	Simcoe test, dry hole
5. Eastnor	17	4WBR	607	1,600	1924	−421	Prec. test, dry hole
	31	1E	658	1,155	1954	−333	Prec. test, dry hole
6. Glenelg	13	4	1,282	1,962	1956	+ 10	Prec. test, dry hole
7. Keppel	1	9	719	1,485	—	−336	Simcoe test, dry hole
	22	2S	790	1,632	1955	−250	Prec. test, gas show 1408
	30	8	786	1,370	1911	− 70	Simcoe test, gas show 1290
	31	2S	717	1,438	1935	−325	Simcoe test, dry hole
	38	2N	721	1,500	1902	−468	Simcoe test

8. Kincardine	60	A	607	2,923	1941	−1,675	Basals test, dry hole
9. Kinloss	69	1	973	3,351	1956	−1,667	Prec. test, dry hole
10. Lindsay	20	2WBR	667	1,582	1951	−378	Prec. test, dry hole
	36	4E	732	1,438	1955	−271	Prec. test, dry hole
11. Osprey	10	19	1,545	1,801	1905	+385	Prec. test, gas 1361, 25 MCF
12. Proton	10	19	1,562	2,300	1955	− 82	Prec. test, gas show 1945
13. Sarawak	10	3	596	1,254	—	− 87	Simcoe test, gas show 1050
	28	1	736	1,366	1938	− 22	Prec. test, salt water 1365
	29	3	713	1,210	1948	+ 23	Simcoe test, oil shows 547, 1063
	28	3	717	1,320	1938	+ 2	Prec. test, oil show
	31	2	749	1,190	1948	− 46	Simcoe test, dry hole
	32	1	738	1,204	—	+ 3	Simcoe test, dry hole
14. St. Edmund	44	1EBR	676	1,615	1955	−387	Prec. test, dry hole
15. St. Vincent	23	6	594	835	1919	+269	Simcoe test, gas show 700
	24	7	632	846	1919	+364	Simcoe test, gas, oil show 700, 720
	25	7	648	854	1921	+367	Simcoe test, gas, oil show 710, 812
	25	7	751	976	1921	+416	Prec. test, gas show 865, oil show 625
	29	9	1,040	1,045	1930	+225	Simcoe test, salt water 1156–60
16. Sydenham	23	C	737	1,160	1948	+137	Simcoe test, oil show 670
	32	2	881	1,161	1948	+236	Simcoe test, gas show 990

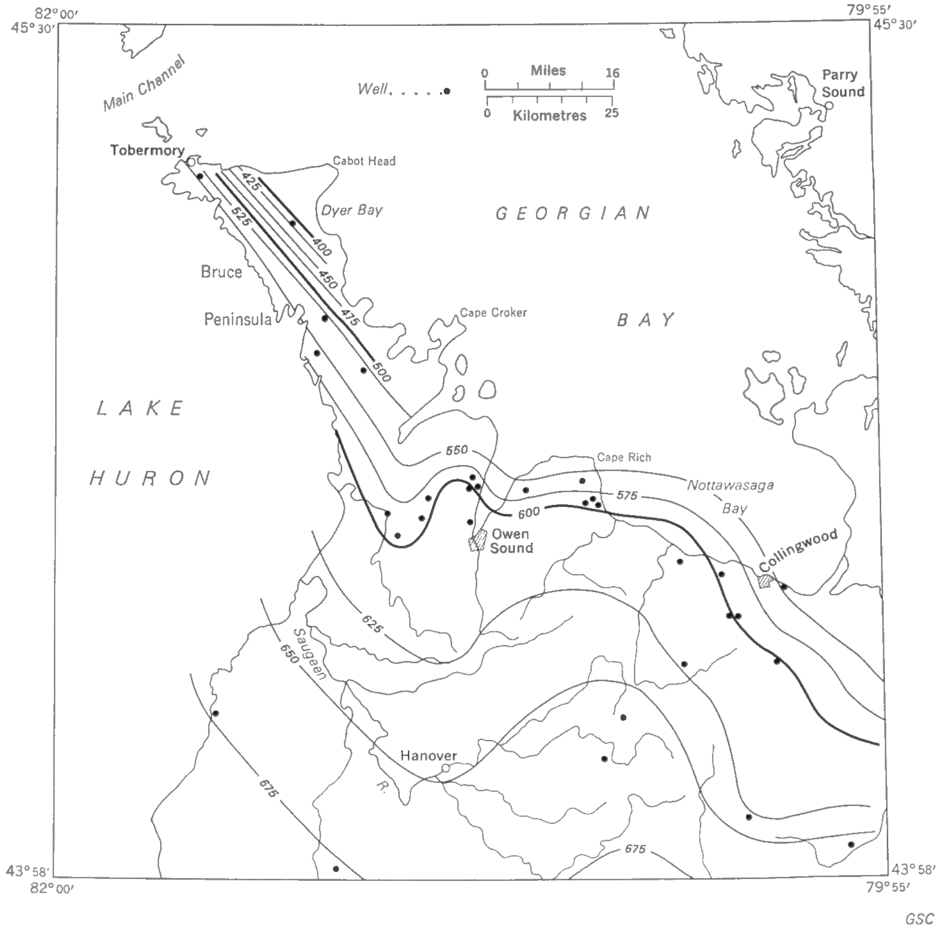

FIGURE 4. Isopach map of Simcoe and Basal Groups interval.

the McRae Point well, thickening is at the rate of about 1½ feet per mile in contrast with 10 feet to the mile towards the 'apex' of the arch. Thus thickening of the Paleozoic section by truncation (down dip) in this last area is indicated. Similarly, the thickening increases in that area nearest the McRae Point well where the Cambrian formations exist.

Extrapolation southeastward of structures on Manitoulin Island (Liberty, 1957) suggests the existence of a structural terrace that trends the length of the Bruce Peninsula paralleling the strike of the strata and an anticlinal roll down-dip from and parallel to the escarpment crest. This is embodied in the structural contour map (Fig. 3), which shows a shallowing of dip near the Georgian Bay and Lake Huron shores, in comparison with the steeper dip in the centre of the peninsula. Against such a steeper area, the basal sediments may well truncate and/or wedge out. Well density is such that the necessary structural contour pattern could be completely masked. The existence of outliers on the east side of Georgian Bay, however, demands a flattening of the 'Bay' strata. This and the bayward dip of cuestal strata supports the existence of the crestal anticline. The impact of these two structures on petroleum accumulation could be considerable: truncation of clastic beds against the terrace, and an inhibition of hydrocarbon loss to Georgian Bay owing to lack of truncation of beds into the waters of the bay. Both features would be capped by the lithographic limestone of the Gull River Formation, which lies at depths of 1,250 and 1,300 feet (latitude of Cape Croker) below the surface.

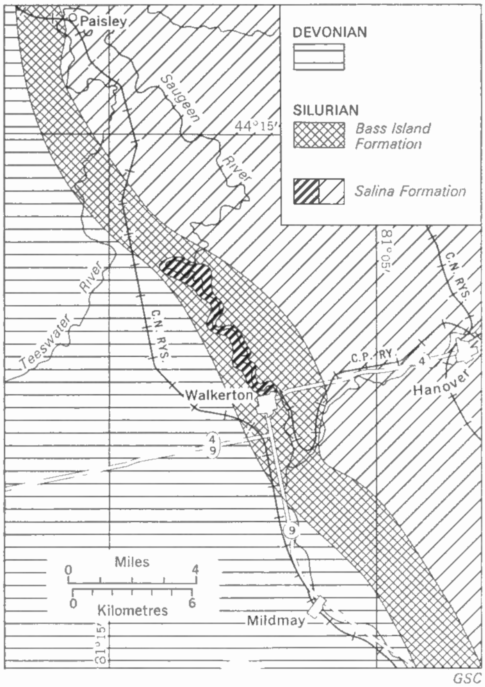

FIGURE 5
Walkerton structural inlier of Salina Formation (Upper Silurian).

Areal mapping has showed the Silurian Salina Formation to be present in the form of a 'window' in the lowermost part only of Saugeen River, and north from the southern limits of Walkerton for about 6 miles (Fig. 5). Topography is not a sufficient explanation for this occurrence. On Dunkeld Creek about 134 feet of Silurian Bass Island strata fit into a vertical interval of 40 feet in 2,200 horizontal feet, indicating a fairly steep westerly dip of $2\frac{1}{4}$ degrees. Two miles along strike and a mile across the river a 40-foot section of Bass Island strata fits into a vertical interval of 90 feet over a quarter mile horizontal distance, which indicates a much shallower dip, less than one degree, in the same direction. Data definitely suggest a westerly steepening of dip, but sufficient data are not available to define this structure more precisely. A monocline is indicated, but the underlying cause may be a fault (*see* Faults). A monoclinal structure also would explain the Walkerton 'big bend' in the drainage pattern of the Saugeen River. It is interesting to note that the Walkerton inlier is confined to the 'big bend' and parallels the strike of the Paleozoic formations. To the writer's knowledge this structure has not been investigated in detail nor has it been drilled for oil and gas.

Isopachous maps (Fig. 4) indicate that a belt of strata thins northward from the 600-foot contour. This belt includes the Hepworth gas field, the Meaford wells, and the Collingwood oil wells in adjacent areas. It strikes the Cape Rich and Cape Commodore headlands, with a narrow swell southwards from Wiarton on the latter, and finally extends northward the length of the Bruce Peninsula. South of the 600-foot contour the gradient decreases. This belt may possibly express a rising Precambrian topography to the north, at the time of deposition of the Simcoe Group formations.

Certain basic bedrock structures in the Bruce Peninsula area, i.e., the deep notches in the escarpment face, the underlying Precambrian surface, etc., are of prime importance. With respect to the symmetry of the Michigan Basin, the Bruce Peninsula is to Georgian Bay and Lake Huron what the intervening peninsula is to Green Bay and Lake Michigan to the west. Certainly Georgian Bay is the extension and part of the Kawartha lineament (Liberty, 1969). Westward on the Lake Huron side, dip accounts for the structure contours, but on the east the explanation lies in the origin of the Niagara Escarpment and Georgian Bay.

The Kawartha lineament, extending across central Ontario from Kingston (Liberty, 1969), is structurally controlled by a gradient, which is perhaps based by Precambrian topography and structure. Though factual data are sparse, the lineament of lakes is believed related. Certainly the lineament may be projected at least to the southern embayment of Georgian Bay. Liberty has suggested a slight steepening of dip as the cause of the Kawartha lineament. Thus, terracing and the shallowing of dip in the crestal strata of the Niagara Escarpment may be most simply explained. This steeper dip is considered to be the controlling factor in the location of the Niagara Escarpment itself. Though there is no direct evidence of fault control, flexural control is strongly indicated. Liberty disagrees with Hough's (1958) statement that the Great Lake basins were located in zones of weaker sedimentary rocks. This explanation of the Great Lakes is acceptable to a point only, but with the symmetrical relationships of bays and peninsulas throughout that area, the probability is that the symmetry results from the dictates of the underlying structure. The cuestas are believed to indicate terraces on the flanks of the Michigan Basin itself.

A. W. G. Wilson (1904) has discussed the effect of the Precambrian peneplain on the overlying Paleozoic sediments. His thesis was corroborated in the Lake Simcoe area (Liberty, 1969), thus explaining: 1) the inliers of Precambrian strata within the Paleozoic belt; and 2) the terracing and occasional reversal in dip in the areas between the old river courses. Combined evidence suggests that the upper surface of the Precambrian is irregular, but nonetheless decreasing in elevation southwesterly into the Michigan Basin.

Ehlers has observed "radial linear folds" in Michigan, for he noted (1929 MS., p. 52):

> Such folds according to Dr. Robinson, are found near the periphery of large basin structures with their axes pointing towards the centre of the basin; they are the result of subsidence of a control area resulting from a crumbling of the peripheral portion just as an unfolded filter paper crinkles when pressed into a funnel. The axis of the Seul Choix Point anticline and apparently the axis of the Drummond Island folds point towards the more or less central part of the basin-like structure of the southern Peninsula of Michigan. As the result of the subsidence of the deposits in this basin, especially during Palaeozoic time, the radial linear folds of Seul Choix Point and Drummond Island were produced as peripheral structures.

Similar features are believed to exist in Ontario, and their axes may well point towards the centre of the Michigan Basin. The highs on Drummond Island, at the east end of Manitoulin Island, and south of Owen Sound are examples; the last mentioned high is part of the Algonquin Arch. That this arch exists as such is indicated by the lowest outcropping formations in the base of the cuesta: Queenston in the Niagara Peninsula north to Hamilton, Whitby's lower and upper members on Georgian Bay, Manitoulin to Dyer Formations along the Bruce Peninsula, and finally Lockport and Guelph Formations near Tobermory. The surface elevation (Lockport Formation) in the Collingwood area is 1,700 feet in comparison with 550 and 600 feet at St. Catharines and 700 feet along the Bruce Peninsula (Fig. 6). In plan view there is the nose-like projection of the escarpment northeastward towards Lake Simcoe, the Algonquin Arch itself probably being responsible for the bedrock barrier between

Lake Simcoe and Georgian Bay. Northward from this arch, on its flank, the deep notches and high northeasterly trending peninsula headlands alternate. These deep notches, i.e., Owen Sound, Beaver Valley, Colpoys Bay, etc., appear to be an integral characteristic of the cuesta throughout the Great Lakes area. As a result the striking feature of the whole is that of a radial pattern whose focus is about the centre of the Michigan Basin. A pre-glacial origin is considered to account for the depth and extent of the notches. Indeed, there is general agreement with Putnam (1955) and Ehlers (1929 MS.) as to the notches representing Tertiary radial drainage from the centre of the basin. Liberty considers them to be the result of erosion by drainage waters that sought out the structural pattern during the course of their flow. This aspect presupposes a high area in the central part of the present Michigan Basin from which rivers could drain outwards.

To the writer's knowledge there are no Tertiary deposits in the Michigan Basin. With the present distribution of known deposits, either post-Pennsylvanian strata were deposited and removed by erosion or they were never deposited. Mesozoic[1] sediments might well have been deposited and removed during Tertiary time, when the whole area must have achieved a fair degree of positiveness. The deep channels (Mackinac Straits), the escarpments (Niagara and Simcoe), and the incised drainage (Laurentian River) were produced during this interval. It must be postulated that the erosional period was initiated in the Great Lakes area in late Paleozoic time, continued through the Mesozoic, and reached final development in the Tertiary. Though the writer favours the former, relying heavily on outlier data, the fact that the Great Lakes area was positive in the Tertiary is inescapable.

The deep notches in the Niagara Escarpment and its extensions are considered to be preglacial and their pattern of occurrence to represent a reflection of the underlying bedrock structure, i.e., synclinal areas. These synclinal areas are considered to be the complement of the prominent headlands that project northeasterly into Georgian Bay. Conversely the headlands are in all probability anticlinal. As noted above, however, the structure from north of Owen Sound to Cabot Head is that of the north flank of the Algonquin Arch. The general concept of this northern flank is one of rolls, which are controlled by the underlying Precambrian terrain; the axes of these rolls point towards the centre of the Michigan Basin. As the Algonquin Arch moved more positively, these flank rolls moved upwards.

Each headland is believed to represent the apex of one of these anticlinal rolls and for each headland on the east side there is a complementary embayment (perhaps less well defined) on the Lake Huron side. The rolls plunge at about 20 feet to the mile and strike across the peninsula southwestward. Regionally in the Bruce Peninsula, the strike is north-northwest and true dip is about 50 feet to the mile. The foregoing data are not incompatible even though they may appear so. Rather, these nebulous structural features cannot be tied down owing to the flat-lying nature of the strata and to an insufficiency of data where it is needed. It is suggested that Stokes Bay (Cape Chin), Pike Bay (Lions Head), and Red Bay (Cape Dundas) owe their existence on the Lake Huron shore to erosion of the anticlinal areas into embayments in which the underlying Lockport 3c Eramosa and 3c biohermal strata were then exposed. In contrast, Cape Commodore, which is very close to the apex of the Algonquin Arch, has wide areas of 3c Eramosa and bioherms exposed on its crest. It trends southwest and controls the Lake Huron shoreline to Port Elgin and McRae Point. The Cape Croker headland expresses its structure by means of the eroded crest from which the Guelph cap-rock has been removed. This headland is considered to be using the flexure in the coastline for its expression on the Lake Huron side. To the north, the Cape Dundas and Lions Head rolls show erosional limitations of the Guelph on their crests. Both the Cape Chin and Cabot

[1] Jurassic–Stratigraphic succession in Michigan; Chart 1, Michigan Dept. Conservation, 1964.

Head rolls retain the Guelph cover from Lake Huron to the Niagara Escarpment probably because of the low dip.

The writer believes that these rolls exist (and in the direction indicated); to date no drilling has tested this concept. A shallow test hole program to the base of the Lockport would serve to delimit such structures and finally prove or disprove their existence. The existence of such rolling features would not be incompatible with the known Precambrian surface topography. Only shallow drilling will determine whether or not they represent anticlinal rolls or knolls. One will then be able to decide whether or not the peninsulas into Georgian Bay are the structural complement of embayments on the Lake Huron shore and whether the rolls are a perpetuation of Precambrian 'lows and highs' owing to drape of the Paleozoic strata on their flanks.

Whatever the explanation for the headland phenomena, there is no doubt as to movement of the Algonquin Arch in Middle Silurian time. Stratigraphic data demand this interpretation, and there is general agreement amongst Michigan Basin investigators. First movement that can be substantiated occurred in the Ordovician Period at the end of Lindsay (Cobourg) sedimentation, at least in the Georgian Bay area. Movement may be inferred even previous to this time by means of the known distribution of the Cambrian sediments. These formations are now limited essentially to the lake basins, and yet overlap conditions and peculiar distribution phenomena may be interpreted with respect to the arch. Such data suggest that there was at least a considerable modification of the areal distribution of the Cambrian formations during the erosional interval between the Cambrian and earliest Ordovician sedimentation. The final result is the positive position the arch obtains today.

A northwesterly post-glacial recovery also affected this area; its gradient is about 18 to 25 feet to the mile. This may have been due either to release from the great weight of the ice that formerly rested on the bedrock surface or to continental warping. Both agencies may have been effective, but in unknown proportions. Certain evidence suggests, however, that at least some of the faulting, and resultant linears, both in the map-area and adjacent areas, occurred in the time interval subsequent to the ice removal. There is positive evidence that some of the faulting occurred due to decreased load. Such a structure developed in eastern Ontario in the Marmoraton Pit, at Marmora in 1952, following the removal of about 120 feet of limestone.

Both McLachlan (1951) and Liberty (1957) have observed deformation of Pleistocene beaches in the Lake Huron–Georgian Bay area. These data suggest that the final migration time of any enclosed petroleum must be dated as post-Lake Algonquin. Thus, the search for petroleum accumulation sites is a most complex one as there has been ample opportunity for migration of petroleum from the initial sites into secondary ones, which in all probability are stratigraphic traps. Whether or not the rebound of Pleistocene beaches is sufficient to affect potential pour points is a moot question. It is known, however, that the present regional uplift on the beaches closely approximates the regional dip of the Paleozoic strata. It might be logical to infer that with the two counter-balancing each other the Paleozoic strata were deposited virtually horizontally (Liberty, 1969). Whereas studies with respect to initial deposition attitudes in carbonates have not been completed, such an idea might well be important in the location of petroleum accumulations. For example, it may well explain why one reef deposit is dry, with respect to another whose pour point (Gussow, 1954) was at a more optimum level. The latter would not be drained in the course of structural movement. Similarly, this explanation could conceivably explain why the outcropping bioherms exhibit oil staining and residues only, while the interreef strata are dyed black and brown (petroliferous black dolomite of the Lockport 3c Eramosa unit) and show 'live' oil when initially broken with the hammer.

Sedimentation and Structure

Silurian sedimentation has been described in many ways for the map-area. Reference must be made to the structural barrier of the Cincinnati or Cataract Axis (Cumings, 1939). This axis was supposed to separate laterally northern faunas from southern faunas, northern lithologies from southern lithologies; moreover an important unconformity was postulated. Bolton (1953, 1957), Bolton and Liberty (1955), and Liberty and Bolton (1956) have corroborated the suggestions of Nowlan (1935 MS.) and Ehlers (1929 MS.) that rapid facies changes occurred in the marginal areas of a narrow shelf-like platform (Fig. 2). Whereas the term platform usually infers a large area, the Algonquin Arch was in reality both shelf and platform, a gentle broad area over which a carbonate blanket was deposited. In Ontario, this arch separates the Appalachian clastic sediments on the south from the clastic but more strongly carbonate facies of the Michigan Basin. Although the arch separates the two, it should be realized that along the Bruce Peninsula one is passing directly, yet obliquely, into the Michigan Basin proper. Thus, in contrast to a formidable axis-barrier, detailed lithological tracing and detailed paleontological studies from two directions indicate wedge-out, facies change, and faunal variations from the Appalachian and Michigan Basins proper into a platform carbonate facies. Across this threshold, which extends from Owen Sound south to Hamilton, two units were deposited, which have been traced successfully: 1) the Lockport member 2 (Bolton's Fossil Hill Formation), which traces laterally into the Reynales Formation; and 2) the Lockport member 3 (Bolton's Amabel Formation), which traces into the Lockport just north of Hamilton. The latter relationship is further evidenced in that some members also can be traced across the platform. The structure-relief involved is illustrated on Figure 6, a cross-section based on a large number of control points. In the nomenclature used, the Fossil Hill Formation is included in the base of the white weathering Lockport. Whereas the lowest apparent dips on this line of section are computed at 7 to 10 feet to the mile in the Niagara Falls north and Wiarton north extensions, steeper ones of 22 to 25 feet to the mile occur south of Owen Sound and north of Hamilton. The Algonquin 'platform' is coincident with the facies changes to the degree that the position of their wedge-out points was controlled by the arch's effective position, which would vary through time. On the other hand, the arch did not have sufficient relief to affect thickness variation in the Lockport sediments being deposited over it. It should be remembered that this blanketing carbonate 'cover' was widespread throughout the Great Lakes area. In such a case, as has been determined over the arch, the Clinton sediments need not be clastic but may be carbonate, thus accounting for thickenings of the Lockport section noted in the platform area.

Possible reefing control is another aspect of sedimentation and structure. In mapping the Bruce Peninsula area, it was found that the higher areas were reef masses, and the wide low-lying flats were the interreefal areas. Correspondingly the Guelph reefal masses were better developed on the headlands that extend into Georgian Bay; indeed these masses often extend into the headland itself, or appear as outliers on the headlands. In addition, it was determined that the headlands also presented reefal masses within the Lockport 3b unit. From this evidence it was concluded that certain of these peninsulas were considerably more important than others, i.e., Cape Croker and Cabot Head. Southwestward and down dip, the Guelph strata became sufficiently thick, reefing became sufficiently prominent and complex, and lithology became sufficiently distinctive that the Guelph could be treated as a formation. However, structurally the headlands remain very important, for reefal growth had a definite preference for such locations. Reefal growth was maximum on sites of Precambrian rolls whose relief was 'reflected' through the overlying formations. Such structures could have been accentuated by arch movement in Middle Silurian time. Indeed, as reefal growth progressed this far easterly, we may have herein a clue as to the amount of depositional dip (post-ice recovery gradient counterbalances the present regional dip). In consideration of this recovery gradient it is just possible that these transverse basement rolls may have been uplifted evenly (i.e., horizontally in a direction transverse to the peninsula) as the Algonquin Arch moved more positively, for the line of the Niagara Escarpment between Collingwood and Cabot Head is roughly transverse to the direction of maximum uplift. It is suggested then, that the transverse rolls that would be most effective in trapping the final movement of petroleum (without regard to amounts) would be those now marked by the headlands of Cape Rich, Cape Commodore, Capes Croker-Paulett-Dundas and Cabot Head. The southernmost ones are structurally higher and would tend to have more closure. Due to this aspect, there would be far less opportunity for the lip position to be attained and thus have any contained petroleum migrate from the trap to a new location. In Lockport 3c Eramosa beds south of Wiarton, this explanation of petroleum is considered to be applicable, for not only is oil present but the dark staining of the strata is indicative of the high amount of hydrocarbons present. The origin of the bitumen in the Lockport 3b may have been similar.

The reefal pattern of subsurface formations, however, may provide a clue to stronger relief that would be effective on the Simcoe Group formations of Black River–Trenton age. Whether or not there is sufficient relief to force pinchouts or truncation in these lower strata (and underlying Cambrian strata) is not absolutely known, but it is strongly suggested. Of greatest importance, perhaps, would be the possibility of anticlinal 'plays' over these transverse rolls, for the sediments would perpetuate that roll (if present) into an anticlinal structure, by means of initial dip and compaction. Subsequent movements of the bedrock strata might serve to consolidate such structures as petroleum reservoirs.

The outcropping formations on the apices also are of interest. Locally, there has been sphalerite mineralization at and just below the Guelph–Lockport contact. As the areas of mineralization are located on the apices of the transverse rolls, dolomitizing solutions might also have had an effect if a hydrothermal origin is postulated, i.e., the carbonate sediments of the Simcoe Group formations. The location of dolomite in these units below the mineralized Lockport could be of considerable economic importance.

Faults

Although no faults are known within the map-area, there are two places where they seem highly probable. The first is the underlying structure for Walkerton's Salina inlier: as suggested earlier a fault is one of the few structures possible to explain the inlier. The westward 'big bend' in the Saugeen River also supports such an interpretation. Down-faulting to the west would steepen the strata and if such were on a dome or nose, the eastward part could well stand as a buttress to be etched out by drainage waters. The second is related to data concerned with the Proton well (White No. 1, lot 10, con. XIX, Proton tp., Grey co.). In this well, the Gull River Formation is almost wholly dolomite in contrast with a normal sequence of limestone less than 5 miles away in the Flesherton Village well. The most logical interpretation is dolomitization by hydrothermal solutions intruding the formation by means of a fault. Such a process is considered probable for the dolomite controlling many petroleum trends and pools in Michigan (Scipio trend) and Ontario (Dover field).

Faults have been mistakenly identified on several occasions by geologists unfamiliar with reefal sedimentation and biohermal shapes. Erosion is the master sculptor in modifying those shapes and incising drainage channels on the flanks.

Radial faults peripheral to the Michigan Basin should be expected in the area, however. One of these may well be in the structural low and very deep trough between the Bruce Peninsula and Manitoulin Island. Faults peripheral to the basin may also be present. An expected zone for this type of fault would be the inner flank of structures similar to the Algonquin Arch. The repeated movements of this arch throughout geological time would present optimum flexure areas on this inner flank where tensional stresses would increase. Perhaps there are no better diagnostic features of this flexure belt than the wedge-out points for the Michigan Basin formations against the Algonquin Arch platform's northern edge, i.e., Dyer Bay, etc. It is suggested that the arcuate line joining Michigan's Scipio trend, Dover field, Proton well, and the Hepworth gas field, might not be completely fortuitous, but lie in this peripheral zone or parallel to it.

If faults are present, in all probability they are of the normal gravity class. In a marginal area, tensional releases are to be expected, most probably either radial to the basin or paralleling the margins.

Unconformities

The importance of unconformities must not be minimized. As a result of an unconformable surface a higher area may be flanked by outward dipping truncated strata dipping away from it. Sediments eroded from such a positive feature may produce lenses of porous clastic rocks (carbonates) on the flanks or in adjacent areas into which petroleum may migrate. Subsequent deposition of strata on such flanks may produce a variety of petroleum sites.

Eight unconformities were noted earlier under the formations involved. Perhaps one of the newest possibilities to be realized in Ontario, petroleum from basement rocks, recently received additional publicity by K. K. Landes (1960), who considered an approach that has received but scant attention in the past. That the Algonquin Arch is basically Precambrian and that it has undergone movement in the past, there is no doubt. Should a consequent fracture porosity have been developed and water conditions be suitable, then the flanks of the arch would be the optimum area for oil accumulation. With proven petroleum production in the basal group on the south side, both north and south sides of this Precambrian arch should be evaluated.

Linked closely to this unconformity would be the Cambro–Ordovician hiatus. Evidence includes the 'Jacobsville' logged in the Flesherton and Sarawak wells. The duration of this hiatus can only be indicated: 1) by the youngest Cambrian remaining and the oldest Ordovician (Pamelia age of the Shadow Lake Formation); and 2) by the limited geographic distribution of the Cambrian formations on the flanks of the Algonquin Arch. Stratigraphic relations include a progressive overlap of the Precambrian surface, with the Mount Simon 'holding' to lower levels and embayments. The relation between the distribution of these formations and the locations of oil and natural gas high on the arch flanks may possibly indicate an unfractured condition of the Precambrian arch. The erosion pattern suggests that the arch was positive at the time, and continued positive up into the Devonian. Undoubtedly the Cambrian formations originally extended farther over the arch, but the present distribution represents the net product of the erosion during the hiatus and would indicate the amount of uplift on the arch. Stratigraphic evidence indicates that Ordovician sediments were deposited over the arch, whose topographic relief was such that neither truncation nor thinning occurred on the flanks. Even with today's positiveness, the relief transverse to regional dip averages 10 feet to the mile, the steepest being 22 feet in the Georgetown–Caledon area (about a quarter degree).

Certain evidence may be interpreted as supporting a minor hiatus in local areas at the contact of the Gull River Formation with the Bobcaygeon, but outcrop studies indicate it to be mainly a corrosion zone. Certainly it does not represent an important break as no great thickness of Gull River has been removed.

With respect to the so-called important 'break' between the 'Black River' and the 'Trenton' it is suggested that continuous sedimentation occurred across this time line, wherever it may be drawn within the Bobcaygeon Formation. In the terminology of this report, this time line is within the lower member of the Bobcaygeon. Physical evidence, to which other workers have referred, relates to lithic change between members within a single lithogenetic unit.

In the Lake Simcoe area, Liberty (1969) favoured a biostromal interpretation for this lithogenetic unit across Ontario. The similarity between Hadding's (1941) Silurian reefing in Sweden and this unit is remarkable. Biostromal phenomena explain best and most simply the observed facts in this sequence, even to the point of sharp contacts, thin units wedging out, thick local developments of calcarenite, and varying water-depths. Though there must be erosional aspects, they need not preclude the interpretation of an important unconformity. As has been pointed out before, a broad, regional lithogenetic approach is necessary in Ontario's stratigraphy with both bio- and lithostratigraphic elements being weighted into this context in equal importance. This last point proves beyond doubt that paleontology must be fully treated in any investigation on sediments of this nature.

Within the map-area all information about the contact of the Simcoe and Nottawasaga Groups must be obtained from the subsurface. All that is indicated is an abrupt change from the grey limestone (calcareous claystone) of the Lindsay Formation to the black shale of the Whitby's lower member. Evidence of the unconformity is forthcoming from the Collingwood area to the east and from Manitoulin Island to the north. As noted in the Lake Simcoe report, a southward lessening in intensity of such relations was suggested into and across the map-area. It is not known whether the basal conglomerate, the dolomite unit, or the mineralization phenomena are present in this area. It is suggested that these aspects are effectively present, at least, in that marginal area to the arch proper.

Very little is known about the postulated break of sedimentation with the Whitby Formation between the lower and upper members. Thickness of the Whitby in Sarawak township is 133 feet, a much thinner section than at Collingwood (about 170 feet). It is interpreted that the middle member of the Whitby Formation is not present and that the sedimentary break may still be effective.

The erosional break between the Ordovician Queenston and the Silurian Manitoulin Formations is of moderate importance. It is true that the Queenston fades laterally into a northern carbonate sequence, that a lithosomal shift is present at this contact for the Bruce Peninsula and Manitoulin Island areas, and that within the Ordovician–Silurian carbonate sequence in the latter area continuous sedimentation has been recognized. Nonetheless, erosional phenomena have been recognized at this contact (Foerste, 1916, p. 166). With large shortlived natural gas pockets being known in the Georgian Bay Formation it is more than possible that gas might have migrated vertically to be trapped in porous Lower Silurian strata (i.e., Manitoulin and Whirlpool Formations) farther south.

The Middle Silurian unconformity suspected by Cumings (1939) is considered to be minor, with the observed data more easily explained by facies change.

The Guelph–Salina unconformity has also been discussed at some length under the Guelph Formation. Erosional relations no doubt exist, but there are differences of opinion as to the intensity of the erosion. The noted phenomena may more easily be explained as a minor disconformity, and may have been produced by normal subaqueous erosion on bioherms. The patterns interpreted on the structure contour maps could as easily be the dendritic scheme observable on the plan view of the top of a reefal complex at any given time. Thus an erosional hiatus at this level cannot be considered of serious import with respect to time or processes.

Within the map-area, the Silurian–Devonian contact is but rarely seen. The effective area for such a disconformity is distinctly limited: south of Kincardine, west of Palmerston, and north of 44°30′ latitude. Elsewhere in Ontario where this contact is exposed (Caley, 1940, 1941) there is evidence of an erosional interval. Considerable variation in Bass Island Formation thickness and the glauconite and sand in the base of the Bois Blanc Formation point to an erosional interval at that stratigraphic position. Similar evidence is found in the Bruce Peninsula area, but apart from outcrop thickness corresponding to subsurface thickness of the Bass Island Formation little can be added. It is considered improbable that the Oriskany was ever deposited over this area, with the carbonate lithosome being in the same position for both the termination of the Silurian and initiation of the Devonian. Perhaps the intensity of this disconformity may not have been great, and accordingly import as to time and processes involved is not major.

As to the erosional phenomena at the base of the Dundee Formation, as observed in the Goderich section, there is no reason to doubt that subaqueous erosion produced this conglomerate. Importance attached to these data varies. With the small pattern of Dundee distribution, availability of much additional data is unlikely. The unconformity is considered of slight importance, indicative of a minor erosional break only.

Finally, there is the important break between the Paleozoic strata and the Pleistocene deposits. The relief of the Paleozoic terrain can be considerable, with most of the sculpturing probably in late Mesozoic and pre-Pleistocene Tertiary times.

TABLE VI *Chemical Analyses for Carbonate Formations*

(from Goudge, 1938, but with stratigraphy updated)

Sample	SiO_2	Fe_2O_3	Al_2O_3	$Ca_3(PO4)_2$	$CaCO_3$	$MgCo_3$	Total	S	CaO	MgO	Ratio of CaO to MgO	Stratigraphic notes
251	7.80	1.17	1.14	0.07	50.62	39.11	99.91	0.11	28.39	18.70	1.51 :1	Manitoulin Fm.
249A	13.68	0.65	1.53	0.04	46.55	36.16	98.61	nil	26.09	17.29	1.51 :1	Lockport 2 = Fossil Hill
236A	2.44	0.26	0.24	0.07	53.41	42.91	99.33	0.02	29.95	20.52	1.46 :1	Lockport 2 = Fossil Hill
249	0.76	0.31	0.23	0.02	54.30	43.79	99.41	nil	30.42	20.94	1.45 :1	Lockport 3
235A	0.42	0.12	0.20	0.02	55.23	44.28	100.27	nil	30.94	21.17	1.46 :1	Lockport 3b
247	1.20	0.48	0.50	0.39	54.57	42.66	99.80	0.01	30.77	20.40	1.51 :1	Lockport 3c = Eramosa
233	0.40	0.15	0.17	0.04	54.91	43.86	99.53	nil	30.77	20.97	1.46 :1	Lockport 3b
234	0.82	0.26	0.40	0.06	55.50	42.77	99.81	nil	31.13	20.45	1.52 :1	Guelph Fm.—lowest
230	0.36	0.11	0.19	0.04	55.00	44.67	100.37	nil	30.82	21.36	1.44 :1	Guelph Fm.—middle
230A	0.08	0.10	0.08	tr	54.93	44.94	100.13	nil	30.76	21.49	1.43 :1	Guelph Fm.—middle
230B	0.18	0.11	0.14	0.02	54.64	43.86	99.95	nil	30.66	20.97	1.46 :1	Guelph Fm.—middle
257	0.12	0.18	0.11	0.02	55.23	43.96	99.62	nil	30.94	21.02	1.47 :1	Guelph Fm.
257A	0.14	0.19	0.07	0.02	55.64	43.69	99.75	nil	31.18	20.89	1.48 :1	Guelph Fm.
240	0.44	0.14	0.16	tr	55.04	43.82	99.60	0.01	30.82	20.95	1.47 :1	Bass Island Fm.
240A	0.56	0.12	0.20	tr	55.45	43.29	99.62	0.01	31.05	20.70	1.50 :1	Bass Island Fm.
272A	5.42	0.42	0.58	0.04	53.99	39.30	99.75	0.04	30.27	18.79	1.61 :1	Detroit River Fm.
239	0.42	0.09	0.12	0.02	56.95	43.42	101.02	nil	31.90	20.76	1.53 :1	Detroit River Fm.
239A	0.14	0.06	0.14	tr	88.27	11.77	100.38	nil	49.43	51.63	8.8 :1	Detroit River Fm.
246	0.26	0.21	0.09	0.02	56.86	42.28	99.72	0.03	31.85	20.22	1.57 :1	Detroit River Fm.
246A	0.18	0.20	0.06	0.01	56.50	43.02	99.77	0.01	31.64	20.57	1.54 :1	Detroit River Fm.
246B	0.34	0.18	0.14	tr	56.25	42.77	99.68	0.01	31.50	20.45	1.54 :1	Detroit River Fm.
267B	1.28	0.50	tr	0.02	90.59	6.71	99.10	0.13	50.74	3.21	16 :1	Detroit River Fm.
269	0.36	0.20	tr	tr	56.00	42.85	99.41	0.01	31.36	20.49	1.54 :1	Detroit River Fm.
242	0.20	0.10	0.04	0.02	98.75	0.61	99.72	0.01	55.31	0.29	1.91 :1	Detroit River Fm., reef facies
243	0.12	0.08	0.06	0.02	99.20	0.59	100.07	0.01	55.56	0.28	1.98 :1	Detroit River Fm., reef facies
244	0.14	0.12	0.02	0.02	99.23	0.55	100.08	0.01	55.58	0.26	2.14 :1	Detroit River Fm., reef facies
243A	0.90	0.12	0.23	0.11	56.07	42.89	100.32	nil	31.46	20.51	1.53 :1	Detroit River Fm., sub. reef.
267A	1.64	0.43	0.13	0.04	93.46	4.47	100.17	0.03	52.36	2.14	24 :1	Dundee Fm., l. mbr.
271A	1.22	0.28	0.64	0.13	95.70	1.24	99.21	0.08	53.66	0.59	91 :1	Dundee Fm., l. mbr.
272	33.62	0.91	0.23	0.04	56.36	7.45	98.61	0.04	31.58	3.56	8.9 :1	Dundee Fm., l. mbr.
267	1.34	0.32	0.38	0.07	94.95	2.89	99.95	0.05	53.21	1.38	39 :1	Dundee Fm., u. mbr.
271	1.46	0.28	0.52	0.07	95.25	1.57	99.15	0.05	53.38	0.75	71 :1	Dundee Fm., u. mbr.
268	1.06	0.40	0.14	0.09	95.96	2.32	99.97	tr	53.79	1.11	48 :1	Dundee Fm., u. mbr.

Sample 251 Owen Sound, east quarry.
249A Owen Sound, west quarry—lower 10 feet cherty Lockport.
236A Colpoys Bay, bottom 25 feet of cliff at village.
249 Owen Sound, west quarry—top 30 feet.
235A Wiarton, upper 50 feet of road-cut.
247 Shallow Lake, quarry east of railway station.
233 Lions Head, dolomite in upper 120 feet of cliff on shore.
234 Wiarton, Cook quarry—Guelph Formation.
230 Tobermory, southeast of village—highest Guelph Formation.
230A Tobermory, 15 feet below above.
230B Tobermory, lowest Guelph exposed on shore.
257 Durham, top 6 feet of Guelph on Saugeen River below dam.
257A Durham, bottom 7 feet of Guelph at same locality.
240 Cargill, basals; 1½ miles SE of village, lot 2, con. VII, Brent tp.
240A Cargill, basals; bottom 24 feet of formation at same locality.
272A Gorrie, Detroit River Fm. under Dundee Fm. in quarry, lot 13, con. VII, Howick tp.
239 Kincardine, Detroit River Fm. in river, 2 miles SE of town.
239A Kincardine, Detroit River Fm., beneath sample 239.
246 Teeswater, Gypsum, lime and alabastine quarry, top 10 feet.
246A Teeswater, Gypsum, lime and alabastine quarry, next 12 feet.
246B Teeswater, Gypsum, lime and alabastine quarry, bottom 21 feet.
267B Goderich, Detroit River Fm., 1½ miles above highway bridge.
269 Belgrave, in bank of Maitland River 2 miles east of village.
242 Walkerton, quarry 3 miles west of village—Detroit River Formation reef.
243 Walkerton, reef in lot 72, con. I, Culross tp.
244 Formosa, 1½ miles SE of village—Detroit River Formation reef.
243A Walkerton, Detroit River Formation under reef in 243.
267A Goderich, 1½ miles above Goderich highway bridge.
271A Brussels, 2 miles south of Brussels.
272 Gorrie, quarry in lot 13, con. VII, Howick tp.
267 Goderich, 1½ miles above highway bridge.
271 Brussels, Maitland River, 2 miles south of town.
268 Benmiller, bank of Maitland River below highway bridge.

TABLE VII *Supplemental chemical analyses*[1]

SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	H_2O	TiO_2	P_2O_5	MnO	CO_2	TOTAL	
8.3	1.4	0.31	0.30	25.9	18.8	0.08	0.90	0.50	0.06	nil	0.06	42.6	99.2	Dyer Bay mbr., north of Dyer Bay.
55.7	17.5	2.3	2.92	2.8	3.6	0.16	5.5	4.9	0.80	0.08	0.06	3.0	99.3	Cabot Head mbr. [restricted]; Inglis Falls, Owen Sound.
7.7	0.72	0.71	0.29	29.6	18.6	0.08	0.28	0.64	0.02	nil	0.09	42.1	100.8	Fossil Hill Fm., Lockport 2 Fm., Inglis Falls.
8.2	1.0	0.28	0.18	28.0	18.6	0.08	0.54	0.47	0.06	nil	0.02	42.3	99.7	Lions Head mbr., Lockport 3a Fm., Wiarton road-cut, north side.
12.7	1.2	0.02	0.50	25.2	18.0	0.08	0.64	0.63	0.07	nil	0.02	40.1	99.2	Lions Head mbr., Lockport 3a Fm., Inglis Falls, Owen Sound.
0.75	0.24	0.02	0.14	30.4	21.3	0.12	0.06	0.51	0.01	0.04	nil	46.5	100.1	Eramosa mbr., Lockport 3c Fm., Cook quarry, west of Wiarton.
2.9	0.28	nil	0.26	29.2	21.2	0.10	.0.14	0.66	0.03	nil	nil	45.4	100.2	Eramosa mbr., Lockport 3c Fm., Sky Lake road-cut, northwest of Wiarton.
nil	0.11	0.11	0.14	30.3	21.7	0.12	0.01	0.35	nil	nil	nil	47.2	100.0	Guelph Fm., bioherm ½ mile west of Brinkman Corners.

[1] Analyses made by the 'Rapid' methods, Analytical Chemistry Laboratories, Geological Survey of Canada.

Chapter IV

ECONOMIC GEOLOGY

(*B. A. Liberty*)

In recent years, interest in the economic mineral potential of the Bruce Peninsula area has not been high and development activities seem to be diminishing. Early activities in the area were reported by Williams (1919), Keele (1924), Goudge (1938), and Caley (1945). Further interest will probably centre around the carbonates, representative samples for which are presented in Tables VI and VII.

Structural Materials

The Manitoulin Formation (dolomite) has been used for foundation stone, rubble, and crushed stone; east of Owen Sound it was quarried for coursing stone, crushed stone, and road metal. Williams (1919, p. 99) noted the stone to be "inferior in toughness and to be suitable only for roads subjected to very light traffic". The unit is generally uniformly bedded.

The Lockport Formation (dolomite) has been quarried as a source of lime, and for building stone, road metal, crushed stone, and rubble. The formation is accessible almost anywhere along the Niagara Escarpment and over large areas of the Bruce Peninsula. Beds about 20 feet above the base have been worked in the Owen Sound west quarry. Strata just below the Lockport's 3c member (Eramosa) were formerly quarried at Shelburne. The 3c member is quarried west of Wiarton in lots 7-8, concessions XXIII and XXIV, Amabel township, by J. S. Cook Quarry Ltd., Ebel Quarries, and Bruce Peninsula Stone Quarry. Owen Sound Ledgerock Ltd., is quarrying the same rock, both at the same location as the above and in lot 17, concessions IV and V of Keppel township, about 3 miles south of Shallow Lake. There, the consistent dark colour and uniform bedding are desirable characteristics for the production of sills, facing stone, and formerly, monument bases. The dark colour presents a pleasing appearance whether rough or polished. Chert nodules in some of the carbonate make it unsuitable for certain purposes (i.e., metallurgical).

The Guelph Formation (dolomite) was formerly quarried extensively for building stone, but it now receives but scant attention. It has also been used for dimension stone, crushed stone, and road metal. The formation varies sufficiently that much care must be taken in evaluating both quality and quantity. The reefal and interreefal phases differ considerably, the latter being evenly bedded, soft, and porous, providing a pleasing and easily worked rock. In contrast, the biohermal masses are massive and irregular and do not have the characteristics of a good building stone. Disinterest in the formation may well be the result of these lateral variations in bedding, texture, and colour.

No shales are now being used for commercial purposes within the map-area. Keele (1924, p. 25) noted that the Cabot Head could not "stand as much fire as the Queenston and

Lorraine shales..." Further, its burned colour was not good enough for roofing tile. In contrast, the Queenston red shale is the better for nearly all purposes, for it is a clay shale, more abundant, and more easily obtained.

Sand and Gravel

As Pleistocene deposits are thin north of Wiarton, most sand and gravel pits are located south of that community. One important exception is the dune sand deposits that blanket the area generally west of highway 6 southwest from Shallow Lake to Lake Huron and southward to Port Elgin. South of these dune sands the gravel deposits become more important. Many of the preglacial valleys are now being re-excavated by streams, and sand and gravel deposits of more than 100 feet are exposed in their banks.

The economic importance of the sand and gravel deposits is limited by the demands of local construction jobs. As a result most of the pits are small and do not merit specific mention. They are commonly located in till, drumlins, and ground moraine.

Salt

The first commercial salt discovered in Ontario was at Goderich in 1866, by Mr. Samuel Platt in the course of drilling for oil. There are reports, however, that salt was previously known in the area. By 1872, after further drilling, several plants were producing; subsequently salt has been produced at other localities such as Kincardine, Wingham, and Brussels, but at present the only producer in the map-area is Sifto Salt Division of Domtar Chemicals Ltd. at Goderich. This company sank an 1,860-foot shaft, penetrating 75 feet of salt (of which 45 is especially good quality) at about 1,750 feet. The company is operating both this mine and brine wells.

The salt is everywhere part of the Salina Formation. It is considered to form a slight embayment in the southwesternmost 1,100 square miles of the map-area (50 miles north of the southern boundary and about 30 miles east from the present edge of Lake Huron at greatest width). According to the old records salt was first encountered at about 1,000 feet depth at Goderich, 1,150 at Clinton, about 1,090 at Wingham, and 970 at Brussels. It may appear in drill records at as little as 200 feet below the top of the Salina. Caley (1945) noted that salt appeared to be confined to that area west of a line joining Teeswater, Brussels, and Seaforth. Its northwestern limit appeared to be near Port Elgin (Alling and Briggs, 1961). Within that area drilling data suggest that a considerable continuity of the salt beds is the rule rather than the exception. In the Port Elgin region, drilling data indicate that the formation in certain localities does not include salt. In all probability such sites are located between the ends of lenses of salt. Such lenses may vary considerably in thickness.

Additional data on the salt deposits in the area are given in Cole (1930), Collings (1961), and Hewitt (1962).

Sphalerite

Sphalerite, or zinc blende, has been known in the Bruce Peninsula area since about 1910. Two zinc prospects are known north of Owen Sound: the Albemarle township occurrence 3 miles northwest of Wiarton in lot 30, concession II, and the St. Edmund township occurrence 12 miles east of Tobermory, north of Umbrella Lake in lots 7 and 8, concessions X and XI. The Albemarle occurrence was found about 1910, and the St. Edmund prospect was discovered about 1936. More pits were opened at the St. Edmund locality in 1943. More recently, the writer found a small showing of sphalerite 7¼ miles south of Ferndale on the east side of highway 6 in lots 4 and 5, concession IIIE, Albemarle township. In addition, small veinlets of sphalerite were noted near Hope Bay on the east side of the Bruce Peninsula and near Pike Bay on the west side.

The Albemarle and St. Edmund prospects occur as pockets in the rock with the sphalerite frequently replacing the fossils. Although the sphalerite appears more as veinlets in the Albemarle pits, it occurs in pockets of fine- and medium-sized crystals in the St. Edmund occurrence. At the latter locality, Williams (1919, p. 103) noted concentrations of sphalerite crystals at the bottom of small depressions where they had been carried by surface water after being detached from the parent mass. He also noted (pp. 102, 103) the rock of the Albemarle occurrence to be "massive, very scraggy, and full of pore spaces and cavities." Furthermore he reported that at least 110 pounds of ore was obtained from this prospect and that a shipment of several hundred pounds was said to assay 69.76 per cent zinc. To the writer's knowledge this is the only assay on record. From the nature of the occurrence, this shipment was probably hand picked, which would account for the high assay value.

At the Ferndale occurrence, the sphalerite occurs in small 1-inch to 12-inch diameter nodules or 'toadstools' that are more resistant to weathering than the 'enclosing' dolomite. Only about six of these are known, but they do indicate the presence of sphalerite in areas other than the main prospects listed above. Whereas each of these mineral nodules is a discrete body (cutting laminations), the sphalerite can be seen to have impregnated the pre-existing dolomite without disturbing bedding features. The sphalerite has not only filled the pore space of the dolomite, but has replaced the dolomite in some places. The spar-like nature of the resulting rock does not obscure the original nature of the sediment; it (the spar) can be noticed usually only under good lighting conditions or physically by the higher specific gravity (i.e., heft). As the showing is so minor, no assay value is presented.

The writer believes the sphalerite to be limited to the uppermost Lockport (Amabel) Formation in each of these three localities: member 3b for the St. Edmund and Albemarle prospects and member 3c for the Ferndale occurrence. Thus far sphalerite has not been found in strata of the Guelph Formation, which is the more porous of the two formations. Moreover, appeal cannot be made to the impervious qualities of the 3c member of the Lockport, for this unit, being interreefal, is not present at either the Albemarle or the St. Edmund zinc prospect. No occurrence of sphalerite is known at a depth greater than 30 feet (from limited diamond drilling data). The sphalerite occurs as interbreccia and intergranular fillings, and as veinlets, geodes, and patches. At Ferndale it is possible that the nodules are satellite bodies to larger mineralized zones.

An origin related to the known reefal growth in Lockport and Amabel strata is favoured. The hypothesis concerns extraction of the zinc from these sediments (whose zinc content is well known elsewhere in Ontario and New York State) by reefal circulating waters, the operational unit being the bioherm and the immediate surrounding area. Deposition of the zinc sulphide would take place where favourable temperatures and pressures permitted, i.e., in breccias, cavities, permeable porous layers. This explanation is supported by the presence of mineralized fossil remains, stratigraphic restriction of mineralization, mineralization of low permeability rocks, simple mineralogy, low temperature of deposition, lack of evidence of igneous activity (surface rocks average 1,600 feet above the Precambrian surface), and apparent lack of migration routes (i.e., faults) for hydrothermal solutions.

With reefal growth being so very extensive, and with zinc mineralization being known at several localities associated with the reefs, the writer considers geochemical surveying to be the logical tool for further exploration.

Asphalt

Asphalt occurs as vug fillings in highest Lockport strata at the schoolhouse section in the southeast corner of lot 5, concession II E, Albemarle township on highway 6. Its composition lies between albertite and liverite, and it appears to be reasonably abundant on the outcrop. The vug fillings range from less than 1 mm to 4 mm in width. The substance is black, brittle, globular to flaky, and conchoidal.

This is the only asphalt locality in the Bruce Peninsula known to the writer, but it is probable that others could be readily found. Similar asphalt is known in strata of the Lockport Formation (Amabel) on Manitoulin Island.

Petroleum

As gaseous and liquid hydrocarbons are associated so intimately some workers combine oil and natural gas under the general term 'Petroleum'; others separate them into petroleum and natural gas. In this report the general term petroleum is used, except when the deposit is noted specifically as oil or natural gas.

Caley (1943, p. 76) included perhaps one of the most comprehensive descriptions on this subject:

> ... a complex mixture of hydrocarbons, chief among which are the paraffins and napthölenes. A small amount of inorganic material is also present. This may or may not be in combination with the hydrocarbon molecule. Natural gas is nearly always associated with oil, and the two together form a continuous series of hydrocarbons ranging from solids to light gases. The chief constituent hydrocarbons in natural gas are methane (CH_4) and ethane (C_2H_6), although varying quantities of propane (C_3H_8) and butane (C_4H_{10}) may be present as gases. In addition there may be certain gaseous impurities such as nitrogen (N), carbon dioxide (CO_2), and hydrogen sulphide (H_2S), as well as traces of oxygen (O), hydrogen (H), and carbon monoxide (CO).

In oil and gas fields natural gas is classified as "dry" or "wet" according to the quantity of gasoline vapours present, and "sweet" or "sour" according to the absence or presence of hydrogen sulphide. If much hydrogen sulphide is present, it must be removed before the gas is used commercially. The "dry" gas is the usual natural gas of commerce and it commonly occurs in reservoirs separate from oil reservoirs.

Petroleum is one of the most economically important substances found in southwestern Ontario. Its production, refining, and distribution from the Paleozoic rocks constitutes a major industry, for with an industrial market readily available for petroleum products very low production rate wells may be classified as commercial producers.

Concerning the definition of 'commercial', with local market available, an operation can be classed as economically feasible, where 1) a property has several wells that may produce only one or two barrels of oil per day but are in sufficient number to make a respectable daily total; 2) with the shallow depths concerned in southwestern Ontario, a well drilled 1,500 feet that achieves a production of 10 barrels of oil per day will pay for itself in about one year; and 3) low open-flow gas wells considered too poor to warrant further work or use of such gas by the company concerned were subsequently adapted in such a manner that the gas production could be piped into the local dwellings for heating purposes. Many such wells have been operating for over 20 years, some for as many as 40 years. Although these examples are drawn from south of the Sarnia–Hamilton line, the underlying principles become very important in the virtually unexplored area north of that line.

Within the Bruce Peninsula map-area commercial production has been obtained only from the Hepworth and Bayfield gas fields. Thus far relatively little concerted effort has been made to evaluate the gas and oil shows. Apart from minor individual efforts, the drilling investigations of Imperial Oil Limited in 1954 and 1955 represent the only recent comprehensive evaluation of the area. The Bayfield gas field was first listed as such in 1958, consisting of two wells that produced from a pinnacle reef in the Guelph Formation.

The Ontario petroleum pattern is sufficiently complex and interrelated that information from related map-areas is very often pertinent and important. This is so in the Bruce Peninsula area, for whereas the Acton gas field in the Lake Simcoe area (Liberty, 1969) is located on the southern flank of the Algonquin Arch, conditions as in that well may exist north of the arch's apex. The stratigraphic unit that showed oil saturation in the A. Breedon No. 1 well in Adjala township is known to be present and possibly under similar or better conditions west in the Bruce Peninsula. The Manitowaning field in Black River–Trenton strata (Simcoe Group) is located on Manitoulin Island to the north. Many gas shows from the Georgian Bay Formation (Dundas–Meaford strata) are known throughout its outcrop belt distribution in Ontario; some of these have been of good size although short-lived and non-commercial.

The only known accumulation that comprised several wells and produced economically was the now virtually abandoned Hepworth gas field near the village of Hepworth in Amabel township, Bruce county. Although this field is still listed, no production figures have been presented recently. The gas was used in the village for lighting and heat. By today's standards, the production would probably not be termed commercial; the field's cumulative production since 1900 is considered to have been about 25,000 MCF. Originally, five wells were drilled by the Grey and Bruce Oil and Gas Company. Subsequently this number was increased to about twenty-five; only two were producing in 1927 for about 650,000 cu. ft. (and a rock pressure of 125 lbs per sq. inch). The original rock pressure was quoted by Malcolm (1915) as 425 pounds per square inch. Pressure decreased very little after a year's drain on the wells; no initial open flow was more than 100 MCF a day. Depth of the wells varied between 1,400 and 1,650 feet with gas at 1,405, but in all the tests details are obscure as to precise notes and results. Malcolm noted that the gas stratum was in the Trenton formation about 350 feet from the top, or conversely about 200 feet up from the base of the Simcoe Group. The level of the gas producing zone(s) was unknown, and the structure was but vaguely recognized. Actually, production was from the Simcoe Group, from the Bobcaygeon Formation and possibly the Verulam Formation. Both formations could be producing horizons, as both are known as such in adjacent map-areas. Production from the underlying lithographic Gull River Formation, however, is improbable, unless either fracture porosity or dolomitized strata had been imparted. There is no indication of either, although no well-cuttings are available from any of the field's wells and there is a dearth of detail.

With respect to structure there is now a better clue to the Hepworth gas accumulation (*see* also Sanford, 1961). This field is located atop the Cape Commodore 'headland', which 'forms' the Southampton–Kincardine shore of Lake Huron. If any credence can be placed in the 'headland-role' suggestion, perhaps this occurrence might be supporting evidence. The Hepworth 'high' is not considered to be a simple positive 'monadnock-type' feature, but an anticlinal expression of a Precambrian roll, which feature might be emphasized through subsequent movements. Further, the fact that these headlands may represent rolls could easily explain the twisting of the structure contours on the north side of the Cape Commodore headland. The degree of twisting may well represent the effects of either subsequent tilting movement of the headland or slight faulting action in addition to the Cape Commodore roll feature.

Although Hume (1932) noted that the Trenton was indistinguishable from the Black River in well samples, much more is known now about the Simcoe Group formational subdivision of these strata. If well-cuttings were available for some of the wells completed in this field, much might be decipherable as to thinning (or thickening) of the various formations of the Simcoe Group over the 'Hepworth structure', or even as to the presence (or absence) of dolomitization phenomena and thus an evaluation of the Gull River Formation. Side-wall coring by means of high penetration projectiles and conceivably a gamma-ray log of one of the central wells could present some of the answers.

Petroleum Possibilities

Reservoir and Sealing Conditions

Most of the map-area is underlain by Ordovician and Silurian strata, but Devonian strata underlie the southwesternmost third.

Devonian The probability of petroleum accumulation in Devonian strata is very slim, as most of them are truncated across the map-area. With the southwesterly dip the probability of escape of the hydrocarbons is high. This is especially important with respect to the long period of time for which these conditions probably existed, i.e., late Paleozoic to Pleistocene. Post-Pleistocene movements have added an accumulation process between the bedrock surface and the Pleistocene deposits, the latter acting as the capping agent. Pockets of natural gas have been discovered at this interface; such an occurrence is the rule rather than the exception.

The porous reefal bioherms in the Detroit River Formation is an additional possibility. For the most part the 'Formosa oval' is badly dissected, which lowers the possibility of large occurrences in that area, but smaller 'ovals' with larger bioherms may exist. The nature of the surrounding medium is not such as to promote excellent sealing or capping conditions. Were the lithographic limestone (S facies of the southern area) to become dominant and surround such a bioherm the evaluation would be quite different. It is known that this lithographic texture is so fine that it is impermeable (Liberty, 1969).

Although the area underlain by the Dundee Formation is about 850 square miles, conditions are unlikely to be favourable for the accumulation of petroleum in commercial quantities.

Silurian The Silurian formations, like the Devonian, are truncated across the map-area, but are buried more deeply and have a sealing cap of evaporite sediments above the carbonate formations. The 'probability' of petroleum escape from the Niagara Escarpment face has been emphasized unduly in the past. Any reservoirs present are probably in the porosity trap class and may be detached bodies of variable size. Bioherms and fractured carbonate zones in the Guelph, Lockport, and Manitoulin Formations may well be storing moderate accumulations. This is especially important within the map-area, for bioherms are known in all the formations.

With reference to stratigraphic traps, mention must be made of the Middle and Lower Silurian stratigraphy both north and south of the Algonquin Arch platform. Although the rock sequence is slightly different on the Bruce Peninsula from that in the Niagara Peninsula, the net product is still a structural high between the two areas, with certain units being absent over this high. In the map-area the Dyer Bay and St. Edmund sediments wedge out southward before the latitude of Owen Sound. In addition, the structure in this north flank of the Algonquin Arch must infer a northerly dip and thus any accumulations in these units must be trapped in their wedge-outs. Admittedly for Dyer Bay sediments this wedge edge outcrops in Owen Sound Bay, but the principle still applies for the area under cover to the west along strike. Thus, Williams' very porous 'St. Edmund lentille' in the top of the Cabot Head Formation may offer distinct petroleum possibilities.

Ordovician The Ordovician strata are more deeply buried than the Silurian or Devonian, but the upper parts of the Georgian Bay and Queenston Formations do outcrop at the base of and below the Niagara Escarpment. Although the strata of the Georgian Bay and Whitby Formations are not considered to be good reservoir rocks the former is known throughout its Ontario bedrock distribution for gas pockets of considerable size. These have been short-lived and non-commercial, but natural gas pockets are the rule rather than the exception. Also noteworthy is the petroleum content in the strata of the Whitby's lower member of Collingwood age. This particular member could become extremely petroliferous (Liberty, 1969).

The formations of the Simcoe Group (Black River–Trenton strata) represent one of the more promising and least tested 'horizons' for the petroleum search in Ontario. The group includes the carbonate formations lying below the Nottawasaga Group shales (with some carbonate) and the basal group's clastic rocks. As a result of the lithic subdivision of the Black River–Trenton sediments many data on the rock details are available that were previously masked. Reservoir rocks are much more plentiful than has been appreciated formerly. It is herewith suggested that carbonates need not have been dolomitized to be potentially worthwhile reservoirs for petroleum. In essence then, limestones are present in the Ordovician strata whose texture and permeability are compatible with favourable reservoir characteristics.

The Lindsay Formation (Cobourg and uppermost Sherman Fall strata) has been the most sought after unit for petroleum in the Simcoe Group. The writer suggests that the uppermost dolomite unit may not be consistently present over a wide areal extent. Its genesis was most probably controlled by recrystallization of clastic dolomite and basin bottom topography i.e., the Algonquin Arch. Black shales of the Whitby Formation's lower member (Collingwood beds) underlie the entire map-area, and these impermeable shales act as a seal for the dolomite unit of the Lindsay Formation. This aspect is admirably demonstrated on Manitoulin Island. Despite their fissility on the weathered surface, these shales are believed to be effectively impervious in the subsurface.

The remainder of the Lindsay is a 'tight' limestone varying from lithographic to sublithographic, i.e., a calcareous claystone. The lowest unit is a very fine crystalline blue limestone that is hard and brittle, and whose permeability would probably be negligible. Within the formation, however, there is also alternating limestone and shale that has shown promises of gas possibilities.

In New York State a great deal of gas has been produced from the thick shale interbeds of the Verulam Formation (lower Sherman Fall–Hartnagel, 1938). Hartnagel noted the great loss of gas by drilling ahead through pockets and zones of accumulation. Subsequently it was realized that these pockets were potentially commercial if the multiple-horizon gathering technique was used, and the practice of delayed drilling was initiated and applied to the whole carbonate section of Black River–Trenton age. The result was up to twenty gas 'pays' in one well and small community fields for local use.

Similar shallow conditions are present in central Ontario and in the Bruce Peninsula. As noted in the Lake Simcoe district (Liberty, 1969), considerable quantities of gas have been indicated in pockets in the Verulam Formation. Thus in the Verulam and part of the Lindsay there is a section of about 300 feet in which accumulations of gas may be expected. The Verulam's upper member should be a moderately good producer, at least in view of its bioclastic nature and porosity-permeability data from adjacent map-areas.

The Bobcaygeon Formation (Leray, Rockland, Hull strata), as previously noted, is a lithogenetic unit lying below the Verulam Formation and above the Gull River's lithographic limestone. It is not wholly a calcarenitic limestone unit, but presents a fourfold subdivision. The second and fourth, from the bottom, are the calcarenites and the potentially important units. The first is an argillaceous limestone; the third is sublithographic and may effectively act as a seal for the second unit. At some localities outside the map-area the permeability of the two calcarenite units is lowered by argillaceous content; others indicate a clean, porous calcarenite (Liberty, 1969). Conceivably the second and fourth units may 'clean up' in certain areas, i.e., over Precambrian highs, where their argillaceous content may be lower. The Bobcaygeon is an important formation, as production is obtained from it in southwestern Ontario.

The Gull River Formation comprises the lithographic limestone section for the most part. Although some dolomitic limestone is present in its lower member, porosity has been achieved mainly by dolomitization and/or fracture porosity. Porosity by dolomitization is believed to be present in the Acton field on the south side of the Algonquin Arch and outside the map-area; fracture porosity is considered 'probable' in the flank areas of the Algonquin Arch because of the mid-Silurian and Pleistocene movements of the arch. The dolomite section in the stratigraphic position of the Gull River in the Proton well near Flesherton may also be the result of dolomitization. Thus there is a potential unit at this stratigraphic position, for Liberty has corroborated Carozzi's (1960) note that lithographic limestone is most susceptible to dolomitizing solutions.

Perhaps of equal importance is the fact that this lithographic section may produce excellent sealing conditions for accumulations in the basal group formations. This aphanitic-cryptocrystalline texture is equally impervious to shales.

Although the Shadow Lake Formation belongs to the basal group, its shales and arkoses are not considered a probable unit for petroleum accumulation. The only possibility would be in the arkoses, where these thin against Precambrian 'highs' from thicker developments in depressions. Stratigraphic traps could occur in such overlap.

Cambrian The Cambrian formations belong to the basal group and are overlapped by the Ordovician formations. Reasonably good porosity and permeability is expected of the Mount Simon strata in contrast with the finer textured Jacobsville.

Three items make these Cambrian units particularly noteworthy as possible petroleum sources. First, natural gas and oil shows are known, and there is production in these strata in southwestern Ontario at present (1965). Second, with reference to the Ordovician overlap, the impervious Gull River strata may act as a seal for accumulations, provided fracture porosity has not been imparted to that formation in a given area. Third, and of equal importance is the relief of the Precambrian surface on the west side of the Bruce Peninsula. Not only are the Precambrian formations limited by this relief, but lowest stratigraphic units may well truncate against rather than drape over it. Should transition occur and sealing conditions be good, then the probability of petroleum accumulation will depend solely on its occurrence in those Cambrian strata and will increase proportionately.

Summary

The writer considers the value of the units in order of importance to be: 1) Lindsay dolomite; 2) Bobcaygeon calcarenites; 3) basal beds in a westerly strip; 4) Gull River; and 5) Manitoulin Formation where it has sufficient cover in the southwestern part of the map-area. In that same area there may well be possibilities for the Guelph as well as for the Detroit River reefal phase.

Finally, any of these carbonate units can be dolomitized by the entry of hydrothermal solutions, due to faulting, etc. This is believed to have occurred in the Proton well where the Gull River appears to be almost wholly dolomite. As there was no master section for comparison, other occurrences may have been misinterpreted. Further, the arc lining up the

Scipio trend in Michigan, Dover field on Lake St. Clair, the Proton well and the Hepworth field just might not be fortuitous in that it may possibly flank the Algonquin Arch.

Techniques

The use of electric logs is becoming increasingly important in industry and may well add to the further subdivision of the Simcoe Group. Gamma-ray logging may well permit this as well as identification of dolomite in the Hepworth field.

If any credence can be placed in the writer's structural concept of the 'cross-rolls' and its correlation with the Hepworth gas accumulation, resultant hydrocarbon increase in the soil can be detected and the concept verified by geochemical testing over the apices. Such an increase should occur over the apex of a structure in which petroleum has accumulated. Possibility of radioactive haloes could also be investigated as a second method. Briefly, a petroleum accumulation acts as an insulator and attenuates the radioactive emanations from the earth's surface. Areas in which haloes (minima) appear can thus be considered as potential sites of accumulation. Should there be a correlation of a few occurrences with the 'cross-rolls', then there might be a quicker, easier method of evaluating petroleum possibilities. Further, areas underlain by recently (i.e., Pleistocene) migrated petroleum will show up as readily as others, whereas they might escape notice by the geochemical technique.

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APPENDIX A – STRATIGRAPHIC SECTIONS 1–32

ORDOVICIAN SECTIONS 1–8

Section 1. On middle branch of Sucker Creek, lot 33, con. 10, St. Vincent tp., Grey co.

	Thickness Feet	Inches
Queenston Formation		
Limestone: grey, crystalline, irregularly bedded; *Columnaria alveolata*, Bryozoa	1	0
Concealed interval: probably grey shale	5	0
Limestone: grey, finely crystalline, in beds 2 to 3 inches thick; *Columnaria alveolata, Zygospira meafordensis, Z. cincinnatiensis, Byssonychia meafordensis, Tetradium huronense, Hebertella occidentalis, Leperditia caecigena, L. manitoulinensis*	1	6
Shale: greenish grey, occasional interbeds of grey limestone	4	6
Limestone: grey, crystalline, in beds 6 to 8 inches thick with intercalated greenish grey shale; Bryozoa	2	0
Shale: greenish grey, soft	2	0
Shale: red, mottled with green	3	6
Shale: greenish grey, soft	1	6
Limestone: grey, finely crystalline	1	0
Shale: greenish grey, soft	1	0
Limestone: grey with green 'clay' pellets	0	6
Shale: olive-green, soft	3	0
Shale: red, mottled	3	8
Limestone: grey, argillaceous, in thin irregular beds; *Zygospira meafordensis, Byssonychia* sp., *Leperditia manitoulinensis*	5	0
Shale: greenish grey, soft	2	0
Shale: red	36	7
Shale: red, numerous hard greenish grey limestone beds averaging 1 inch thick	18	6
Shale: red and green mottled	15	5
Georgian Bay Formation		
Limestone: bluish grey, ripple-marked	0	4
Shale: bluish grey, soft	1	0

Section 2. On west shore of Owen Sound, half a mile north of Sutton Point

	Feet	Inches
Queenston Formation		
Shale: blue, soft	2	0
Limestone: grey, crystalline, impure, weathered into irregular beds 2 inches to 1 foot thick; *Byssonychia* sp., Bryozoa	4	0
Shale: greenish grey	2	0
Limestone: grey, crystalline, impure, ripple-marked, in regular beds 4 inches to 1 foot thick	3	0
Shale: red	2	0

Section 2. (*cont.*)

	Thickness Feet	Inches
Concealed interval	5	0
Shale: red	10	0
Concealed interval to lake level	4	0

Section 3. On shore at Montressor Point, Cape Croker

Queenston Formation

	Feet	Inches
Limestone: grey, crystalline, fossiliferous in beds 2 to 6 inches with grey shale partings	4	0
Shale: greenish grey with occasional thin limestone bands	6	0
Interbedded grey limestone and soft grey shale in equal amounts	8	0
Shale: grey, greenish grey, and bluish grey, soft, with occasional thin crystalline limestone bands	15	0
Limestone: grey, crystalline, fossiliferous, in thin even beds with grey shale partings	2	0
Shale: greenish grey	12	0
Shale: red	25	0
Concealed interval to lake level	10	0

About ¼ mile south of Montressor Point, grey, thin-bedded limestone with greenish grey shale partings forms a pavement-like outcrop at water level and is herein called the Montressor Point Reef. This rock lies below the foregoing section and contains a profusion of reef-forming fossils (Appendix B, Queenston Formation).

Section 4. On shore at Prairie Point, west side of Cape Croker on Sydney Bay—herein known as the Prairie Point Reef

Queenston Formation

	Feet	Inches
Limestone: grey, crystalline, in beds 2 to 8 inches thick, reef-like at the base, many fossils (Appendix B, Queenston Formation)	5	0

Section 5. At North Point on White Cloud Island, Colpoys Bay

Queenston Formation

	Feet	Inches
Limestone: grey, finely crystalline, in even beds ½ inch to 4 inches thick, with thin greenish grey shale partings	2	0
Shale: greenish grey	6	0

On the shore immediately south of this section many reef-forming fossils indicating the same horizon as that seen on the shore ¼ mile south of Montressor Point (Appendix B, Queenston Formation).

Section 6. Composite section of outcrops along north shore of Griffin Island at Cornet Point, Colpoys Bay

Queenston Formation

	Feet	Inches
Limestone: grey, crystalline, in thin irregular beds; Bryozoa indet., *Zygospira meafordensis*, ostracods, pelecypods	2	0

	Thickness	
	Feet	Inches

Section 7. On a small creek, con. IV, Mulmur tp., Dufferin co., 2 miles west of Randwick

Queenston Formation		
Shale: red	330	0
Georgian Bay Formation		
Limestone: grey to bluish grey, fine, ripple-marked in bed about 2 inches thick with thin interbeds of olive-green shale	5	0
Limestone: grey, fine, ripple-marked, in beds 4 to 6 inches thick with interbeds of greenish grey shale	10	0
Shale: bluish grey and olive-green with frequent 2- to 8-inch beds of grey, fine, ripple-marked limestone	11	0

Section 8. In a small gully traversing the Blue Mountains, lot 10 con. II, St. Vincent tp., 3 miles east of Meaford

Queenston Formation		
Shale: red, occasional thin beds of grey to bluish grey, ripple-marked limestone in the lower few feet	15+	0
Georgian Bay Formation		
Shale: green, soft, with occasional ½- to 2-inch beds of bluish grey, ripple-marked limestone in the upper 6 feet	12	0
Limestone: grey, fine, in beds 2 to 8 inches thick; many Bryozoa	4	0
Limestone: grey, fine, in thin even beds interbedded with equal amounts of soft bluish grey shale	14	0
Concealed interval of steep wooded slope on surface of which are loose slabs of crystalline limestone containing Bryozoa and *Byssonychia* sp	128	0
Shale: greenish grey, soft, with frequent thin, grey limestone bands	25	0
Limestone: grey and greenish mottled, crystalline, brownish weathered, in even beds 4 to 10 inches thick, with shale partings; many fossils (Appendix B, Georgian Bay Formation)	4	0
Concealed interval	2	0
Shale: bluish grey, soft, at water level		

SILURIAN SECTIONS 9–28

Section 9. On road between lots 30 and 31, con. I, Mulmur tp., Dufferin co.

Whirlpool Formation		
Sandstone: grey, rusty weathering, medium grained, in thin irregular beds	4	0
Soft weathered, rotten, rusty coloured sand	0	2.6
Queenston Formation		
Shale: bluish grey, soft, plastic	5	0
Shale: red, plastic	4+	0

Section 10. In lot 30, on road between cons. I and IIE, Mulmur tp., Dufferin co.

Manitoulin Formation		
Dolomite: grey, fine, in thin beds a few inches thick	3	0
Soft bluish grey calcareous and argillaceous 'mud'	0	4

	Thickness	
	Feet	Inches
Section 10. (*cont.*)		
Whirlpool Formation		
Sandstone: grey, fine to medium grained, in irregular and lensy beds from a few inches to a foot thick with gently undulating lower surface	10	0
Queenston Formation		
Shale: bluish grey and bluish green, soft, plastic	4	0

Section 11. In a gully just below highway 24, 2 miles east of Singhampton

Manitoulin Formation		
Dolomite: grey, hard, fine, in thin irregular beds	2	6
Bluish grey argillaceous mud rock	0	0.4
Whirlpool Formation		
Sandstone: grey, fine grained, in beds 2 to 4 inches thick	2	6
Sandstone: bluish grey, fine grained, in a single bed	1	0
Sandy shale: bluish grey, compact, in thin beds	1	4
Queenston Formation		
Shale: blue, soft, plastic	5	0
Concealed interval	10	0
Shale: red	100+	

Section 12. On small creek just north of road between lots 26 and 27, con. XI, Nottawasaga tp., Simcoe co., 2¼ miles northwest of Duntroon

Manitoulin Formation		
Dolomite: grey, fine, thin, unevenly bedded	3	0
Whirlpool Formation		
Mass of soft ,'weathered' limy rock with thin 1-inch sandy layers	2	6
Shaly sandstone: bluish grey, soft, in thin layers	1	0
Sandstone: grey, fine grained, in beds about 10 inches thick	3	6
Queenston Formation		
Shale: blue, compact, in part sandy	1	6

Section 13. On the east side of the Sound in the city of Owen Sound

Manitoulin Formation		
Dolomite: grey to brownish grey, finely crystalline, buff weathered, in thin uneven beds 1 inch to 5 inches thick with small white weathered chert nodules along some bedding planes	19	2
Queenston Formation		
Shale: blue and bluish grey, plastic when wet	4	0
Shale: red	5+	

Section 14. On small stream at Duncan in con. XII, Collingwood tp., Grey co.

	Thickness Feet	Thickness Inches
Manitoulin Formation		
Dolomite: grey, finely crystalline, in beds 6 to 12 inches thick	10	0
Shaly limestone and shale: bluish grey, compact, thin bedded	4	0
Queenston Formation		
Shale: greenish grey, compact, sandy	2	0
Shale: bluish and greenish grey, compact	8	0
Shale: red	20+	

Section 15. At falls a mile east of Fairmount in Euphrasia tp.

	Feet	Inches
Manitoulin Formation		
Dolomite: grey to brownish grey, finely crystalline, in thin irregular beds 4 to 6 inches thick in upper part, beds as thick as 2 feet near base	20	0
Queenston Formation		
Shale: greenish and bluish grey, soft, in places compact and calcareous forming ½- to 1-inch hard layers	6	0
Shale: greenish grey, compact	6	0
Shale: brick red	8+	

Section 16. On small creek entering Beaver River, ½ mile north of Vandeleur

	Feet	Inches
Manitoulin Formation		
Dolomite: grey, crystalline, impure, in thin uneven beds, 1½ to 6 inches thick	5	6
Dolomite: grey, crystalline, grey weathered, in beds 8 inches to 1 foot thick	23	0
Dolomite: grey, finely crystalline, appears to be in single bed	4	0
Limestone: impure, grey to bluish grey, dense, ripple-marked	0	2
Queenston Formation		
Shale: soft, bluish grey, sticky when wet	1	0

Section 17. At Cape Chin

	Feet	Inches
Cabot Head Formation, Dyer Bay member		
Dolomite: grey, greenish grey, and bluish grey, crystalline, in thin beds 2 to 10 inches thick with greenish grey argillaceous partings and, in places, green argillaceous 'pellets'; *Homoeospira* cf. *immatura*, cf. *Enterolasma geometricum*, *Virgiana decussata*	12	0
Cabot Head Formation, Cabot Head member [restricted]		
Shale: green, soft, plastic when wet	3	0
Shale: red, 2-inch bed of hard, greenish grey, impure limestone at the base	12	0

	Thickness	
	Feet	Inches
Section 18. At 'Clay Cliffs' (Rocky Bay), 3 miles west of Cabot Head		
Lockport Formation, member 2		
Dolomite: brown, fine crystalline, porous, vuggy, thinly bedded; fossiliferous: pentameroids and *Favosites* spp. (Fossil Hill Formation)	9	0
Lockport Formation, member 1		
Dolomite: grey, lithographic, sublithographic and very fine crystalline, thinly bedded and laminated, irregularly vuggy	3	0
Cabot Head Formation, St. Edmund member		
Shale: green	3	0
Dolomite: brown, fine crystalline, mottled light and dark brown dolomite, weathers brownish grey, massive, well jointed; *Favosites cristatus*	8	0
Cabot Head Formation, Wingfield member		
Dolomite with thin alternating layers of shale (ribbon dolomite): shale is green and plastic; dolomite is brownish and greenish grey, fine crystalline, weathering greenish, beds 1 inch to 5 inches thick; dolomite encloses green argillaceous pellets; shale contains ostracods	36 (*after* Caley)	
Cabot Head Formation, Dyer Bay member		
Dolomite: bluish mottled with green, fine crystalline; minor sublithographic and lithographic brown and dark brown dolomite; weathers into thin and medium beds, well jointed	15	0
Cabot Head Formation, Cabot Head member [restricted]		
Shale: predominantly red, with occasional patches of green; 3 feet of green clay shale at top; occasional bed (3½ to 4½ inches) of buff, fine crystalline, dolomite with grey dolomite in mid-section; minor gypsum and mineral moulds; *Helopora fragilis*	51	0
Manitoulin Formation		
Dolomite: below water level		

	Feet	Inches
Section 19. Exposed at the base of the escarpment at Hope Bay		
Lockport Formation, member 2		
Dolomite: grey weathered, grey to cream coloured, fine to medium textured, in beds 18 inches thick, though in places weathered into 4-inch layers; many *Pentamerus oblongus* (Fossil Hill Formation)	20	0
Concealed interval	2	8
Cabot Head Formation, Wingfield member		
Dolomite: grey to brownish grey, fine to medium, in thin even beds ¼ inch to 2 inches thick with green shaly partings and green argillaceous "pellets"; many ostracods	2	0
Concealed interval	3	4
Dolomite: grey, fine grained, in thin even beds ½ to 1 inch thick	2	0
Covered interval	4	4
Shale: bluish grey, soft	0	6

Section 19. (*cont.*)

	Thickness	
	Feet	Inches
Cabot Head Formation, Dyer Bay member		
Dolomite: shaly, grey weathered, grey, medium, in thin irregular beds 1 inch to 6 inches thick with green shaly partings; *Helopora fragilis, Rhynchonella* sp., *Virgiana* sp., *Buthotrephis* sp.	12	6
Dolomite: grey, dense, in even beds 8 to 12 inches thick that break conchoidally.	2	0

Section 20. In road-cut at Inglis Falls, Owen Sound

	Feet	Inches
Lockport Formation, member 3a		
Dolomite: grey, medium to finely crystalline in even, grey weathered beds 18 inches to 2 feet thick with chert nodules ½ inch to 2 inches in diameter (Lions Head Member, Amabel Formation)	9+	
Lockport Formation, member 2		
Dolomite: massive to roughly bedded, grey, medium textured, basal foot argillaceous; lower and upper contacts sharp; *Pentamerus oblongus, Favosites* sp., *Halysites* sp., *Syringopora* sp., stromatoporoids (Fossil Hill Formation)	7	6
Cabot Head Formation		
Shale: bluish green, compact, plastic when wet	5+	

Section 21. On shore of Isthmus Bay about ⅓ mile north of Lions Head dock

	Feet	Inches
Lockport Formation, member 1		
Dolomite: grey to cream coloured, finely crystalline, in thin irregular beds a few inches to a foot thick; *Pentamerus oblongus, Favosites* sp., stromatoporoids (Fossil Hill Formation)	17	6
Cabot Head Formation, Wingfield member		
Shale: greenish grey, soft	4	0
Dolomite: grey, dense	1/4	
Shale: dark greenish grey, compact	2	6
Dolomite: brownish grey, fine, argillaceous, in thin platy layers	1	0
Dolomite: grey, dense, with pyrite	1	0
Shale: greenish grey, compact	1	0

Section 22. Exposed in the road-cut at Sky Lake

	Feet	Inches
Guelph Formation		
Dolomite: brown, finely crystalline, rough weathered in beds as thick as 3 feet; *Eospirifer radic tus*	3	0
Lockport Formation, member 3c		
Dolomite: bituminous, dark brown, fine to dense, in thin even beds 2 to 4 inches thick with black bituminous streaks and laminae. Numerous chert nodules and white, spherical and lens shaped concretionary masses 1 inch to 1½ inches across; *Stromatopora* sp., *Pycnostylus* cf. *elegans, Favosites niagarensis, F. hispidus, Eospirifer radiatus, E. eudorc.,* cf. *Cyrtia meta, Discosorus* sp., *Geisonocerina* sp.	21	6

	Thickness	
	Feet	Inches
Section 22. (*cont.*)		
Dolomite: buff to brown, dense, in a single reef-like bed; *Favosites* sp.	1	0
Dolomite: bituminous, dark brown, in even beds 1 inch to 4 inches thick	1	6
Dolomite: brown, dense, in a single bed with many *Favosites* sp.	1	0
Dolomite: bituminous, brown, dense, in thin even beds with black bituminous streaks	2	0
Dolomite: dark brown, dense, in a single bed with irregular surfaces; *Favosites* sp.	1	0
Dolomite: bituminous, dark brown, dense, in thin even beds 8 to 10 inches thick but weathering thinner	2	0

Section 23. A composite section made from the several outcropping sections located on South Saugeen River between Neustadt and Calderwood

Salina Formation

Shale: calcareous, red, compact	1	0
Shale: green and greenish grey, calcareous, compact, in thin hackly breaking beds	29	0
Dolomite: grey, fine, in even beds 4 to 8 inches thick with greenish grey shaly partings	5	0
Shale: greenish grey, limy, with compact hard zones	10	0
Dolomite: grey to buff, fine to dense, in thin beds 2 to 10 inches thick with small needle-like cavities	5	0
Dolomite: buff, dense, with thin dark bituminous streaks and weathered into platy slabs averaging 2 inches thick	9	0
Concealed interval	5	0
Dolomite: light buff, dense, grey weathered, in even beds 2 to 10 inches thick	10	0
Shale: greenish grey	2	0
Dolomite: brown, fine, in beds 2 to 7 inches thick with rough uneven surfaces	6	0
Shale: calcareous, greenish grey, compact	1	0
Dolomite: grey, fine, in 8-inch beds	2	0
Dolomite: buff, fine, in irregular layers 2 to 4 inches thick	1	0
Dolomite: brown, hard, finely porous, in a single concretionary bed	2	0
Shale: calcareous, brown, in thin wavy layers	1	0
Dolomite: grey to brownish grey, dense, in irregular beds 2 to 14 inches thick, the thicker beds somewhat lensy, with black bituminous streaks	9	0
Dolomite: brown, porous, in very rough uneven beds from a few inches to 1½ feet thick; thick beds concretionary	6	0
Concealed interval	33	0
Dolomite: light brown, finely crystalline and granular, in irregular beds 4 inches to 2 feet thick with black bituminous streaks	4	0
Dolomite: argillaceous, brownish grey, dense, bluish weathered, in layers ½ inch to 3 inches thick	4	0
Limestone: shaly, bluish grey, in beds ¾ inch to 1½ inches thick	2	0
Shale: dark green, soft, in uneven beds 1½ to 2 inches	0	4
Shale: green, soft, rotten	0	2
Dolomite: brown, dense, lensy	0	4
Dolomite: brown, dense, in thin obscure beds	1	3
Dolomite: brown, dense, in 2- to 4-inch beds with small needle-like cavities	1	0
Shale: drab, greenish grey, soft	6	0
Shale: calcareous, greenish grey, compact	2	0
Shale: greenish grey and brown, soft, with compact lensy zones	3	0
Dolomite: grey, dense	0	8
Shale: bluish grey, laminated	2	0
Shale: dark bluish grey, compact, laminated	4	0

	Thickness	
	Feet	Inches

Section 24. On the right side of Saugeen River, east of big bend, south of Walkerton, lot 36, con. IIIS, Brant tp.

Salina Formation

Dolomite: brown, fine	0	8
Shale: bluish grey, soft, thin bedded	10	0
Dolomite: brown, fine	0	8
Shale: bluish grey, soft	10	0
Shale: red and green mottled, compact	3	0
Shale: grey and bluish grey	3	0

Section 25. On left side of Teeswater River 1¼ miles above its mouth

Salina Formation

Shale: calcareous, grey, compact, mottled with red shale at the top	4	0

Section 26. On an intermittent stream entering Saugeen River from the west in lot 3, con. VII, Brant tp., 4½ miles north of Walkerton

Bois Blanc Formation (Devonian)

Limestone: grey, medium grained, with much grey chert; corals	3	0
Limestone: shaly, weathered soft, with sand grains and glauconite	1+	

— Disconformity —

Bass Island Formation (Silurian)

Dolomite: buff and brown, finely crystalline and dense, in vertically jointed beds from a few inches to a foot thick	12	0
Concealed interval	5	0
Dolomite: light buff, finely crystalline, with dark bituminous streaks imparting a 'ribbon' appearance, and in uneven beds 6 to 12 inches thick	5	0
Concealed interval	9	0
Dolomite: light grey to buff, fine, vertically jointed, with dark streaks imparting a 'ribbon' appearance, and weathered to a light cream colour	5	0
Dolomite: buff, finely crystalline, even bedded and concretionary, vertically jointed	33	0
Dolomite: light buff, concretionary at the top	7	0
Dolomite: oölitic	1	0
Dolomite: buff, finely crystalline, in thin even beds 2 to 10 inches thick and with needle-like cavities	25	0
Shale: limy, bluish and greenish grey	3	0
Dolomite: buff, porous, fine, in even beds 2 to 12 inches thick	12	0
Dolomite: brown and buff, fine to dense, with some dark bituminous streaks and in rough uneven beds 8 inches to 2 feet thick; ostracods, *Whitfieldella* sp.	16	0
Dolomite: buff, fine, in thin even beds	1	0

Salina Formation

Shale: calcareous, greenish grey, compact and hackly breaking	8	0
Shale: calcareous, red and green mottled	2	0

	Thickness	
	Feet	Inches

Section 27. Exposed on creek crossed by Canadian Pacific Railway ½ mile south of highway 4 at Walkerton

Bass Island Formation

	Feet	Inches
Dolomite: light buff, dense, in even beds 2 to 8 inches thick with needle-like cavities	5	0
Shale: bluish grey, soft, calcareous	1	6
Dolomite: buff, dense, in vertically jointed beds as thick as 12 inches with needle-like cavities	8	0
Dolomite: very shaly, brown, in thin layers	1	0
Concealed interval	4	0
Dolomite: buff and brown, fine, in heavy buff weathered beds 10 inches to 2 feet thick; ostracods, *Whitfieldella* sp	5	0
Concealed interval	8	0

Salina Formation

	Feet	Inches
Shale: red and green mottled, trace of anhydrite	4	0

Section 28. Composite section from exposures on west side of Saugeen River valley 1.8 miles north of Dunkeld

Bass Island Formation

	Feet	Inches
Dolomite: cream coloured and buff, hard, dense, buff weathered, in even beds 4 to 15 inches thick with vertical joints and needle-like cavities	11	0
Shale: calcareous, soft, rusty weathered	1±	
Dolomite: oölitic, brownish grey, hard	3	0
Dolomite: cream coloured, dense, vertically jointed, in beds 2 to 8 inches thick, concretionary near the top	10	0
Dolomite: light buff, dense, in even beds 2 to 10 inches thick, concretionary in the upper part	16	0
Dolomite: brown, finely crystalline, massive	5	0
Dolomite: drab, dense, in even beds 1 inch to 4 inches thick	4	0
Dolomite: oölitic, buff	1	0
Dolomite: cream coloured, dense, in even beds 6 to 12 inches thick	5	0
Dolomite: cream coloured, dense, in even beds 2 to 7 inches thick with needle-like cavities and vertical joints	15	0
Dolomite: brown, fine to dense, in even beds 1 inch to 3 inches thick	6	0
Shale: limy, bluish grey, compact and hackly breaking	2	0
Dolomite: brown, fine, in beds ½ inch to 3 inches thick	3	0
Dolomite: cream coloured, dense, in thin vertically jointed beds 4 to 8 inches thick with needle-like cavities	5	0
Dolomite: very shaly, brown, soft, in thin layers	3	0
Dolomite: brown, fine, with dark streaks, in beds 8 to 18 inches thick; ostracods, *Whitfieldella* sp	2+	

DEVONIAN SECTIONS 29–32

Section 29. Along the banks and in the bottom of the Teeswater River at Chepstow (*after* Best, 1953 MS., p. 129)

Detroit River Formation

	Feet	Inches
Limestone: grey, very fine grained, dense; fossiliferous (many *Stromatopora*): heavy beds; biohermal (B facies)	1	2
Dolomite: medium brown, fine grained, granular, uniform; in 2-inch beds; normal N facies	4	0

Section 29. (*cont.*)

	Thickness Feet	Inches
Dolomite: chocolate-brown, fine grained, heavy massive beds; many bituminous laminae	2	8
Dolomite: medium brown, fine grained, crystalline, dense; many fossils and fossil fragments of calcite	0	6
Limestone: light brown, fine grained, few vugs, filled with calcite; fossiliferous	0	6
Dolomite: light brown, fine grained; few fossils	0	3
Limestone: medium brown, fine grained, dense; very fossiliferous	1	9
Dolomite: medium brown, fine grained; earthy; bituminous laminae; calcite fossils	0	8
Limestone: light brown, fine grained, crystalline dense	0	6
Dolomite: medium brown, fine grained, earthy; numerous bituminous laminae	0	6
Dolomite: light brown, fine grained, crystalline; few bituminous laminae; many calcite fossils and fossil fragments	0	3
Dolomite: as above with no bituminous laminae	0	9
Limestone: medium brown, fine grained; many bituminous laminae	0	3

Section 30. Composite section along the Maitland River at Goderich (*after* Best, 1953 MS., p. 135)

Dundee Formation

	Feet	Inches
Conglomerate: pebbles of the Detroit River Formation in a matrix of coarse-grained sandy limestone	2	0±

Detroit River Formation

	Feet	Inches
Limestone: medium brown, very fine grained, dense, many carbonaceous laminae, thinly bedded	3	3
Limestone: medium brown, fine grained, splintery and breaks into blocky mass, carbonaceous laminae in places may be an intraformational breccia	4	6
Limestone: light brown, fine grained, granular, streaks of dark brown granular limestone	0	3
Limestone: light grey, fine grained, faintly laminated; in 2- to 3-inch beds	0	9
Limestone: as above with many carbonaceous laminae and stylolites	0	8
Limestone: light brown, fine grained, few faint laminations, few crystal impressions (length 1 mm)	0	9
Limestone: very fine grained, dense; grades into bed above; contains many gypsum crystal impressions as long as $1\frac{1}{2}$ cm in all orientations to give bed brecciated appearance	1	3
Dolomite: light brown, fine grained, granular, minute intergranular porosity, numerous bituminous laminae which are wavy; whole bed is hummocky and irregular; at top and bottom of bed may have local breccias composed of material derived from this algal biostrome	2	3
Dolomite: breaks down into soft, shale-like mass	0	8
Limestone: breccia, light brown, fine grained, crystalline limestone matrix with angular small flat ($\frac{1}{8}$ by $\frac{1}{2}$ inch) fragments of algal dolomite	0	5
Dolomite: medium brown, fine grained, granular, soft; in wavy 3-inch beds	1	3
Limestone: breccia as one above	0	2
Dolomite: light grey, fine grained, dense, faintly laminated, thinly bedded; laterally may be a vuggy reefy type limestone	1	5
Dolomite: light brown, fine grained, granular, many bituminous wavy laminae; bed is massive, hummocky, irregular (likely an algal biostrome)	6	10
Dolomite: calcareous, medium brown, fine grained, dense hard, thinly bedded; alternating dark and light colour	0	3
Limestone: medium greyish brown, sublithographic, many stylolites	0	5
Limestone: fine grained, alternating light and medium brown, dense, carbonaceous and bituminous laminae	1	5
Dolomite: dark brown, fine grained, granular, many bituminous laminae	4	0−

Section 31. Southeast side of Maitland River at the east edge of Goderich (*after* Best, 1953 MS., p. 181)

	Thickness Feet	Inches
Upper member, Dundee Formation		
Limestone: light brown, fine grained, heavy massive uniform beds with many stylolites, evenly bedded; crinoidal debris scattered through beds; fossils not abundant	7	0
Limestone: dark purplish grey, very fine grained, dense	1	6
Limestone: as above only hard and splintery	1	3
Limestone: dark purplish grey, very fine grained, dense brittle, uniform; breaks into two beds with the upper one extremely fossiliferous	1	3
Lower member, Dundee Formation		
Limestone: light brown, fine grained, crystalline, carbonaceous laminae common; areas of mascerated fossil material common; really one massive bed but tendency to break down into 1-foot beds	7	0
Limestone: light brown, fine grained, crystalline, granular; fossil fragments common; small intergranular porosity and small vugs	1	2
Limestone: light brown, fine grained, few carbonaceous laminae and stylolites; areas of fossil fragments, fossils not abundant; really one bed which breaks into irregular blocks	9	8
Limestone: medium greyish brown, fine grained, rather crystalline, few carbonaceous laminae; few corals; section not exceedingly fossiliferous, scattered brachiopods and the more abundant corals; breaks into irregular 8-inch beds	6	3
Limestone: medium brown, fine grained, carbonaceous laminae and few stylolites; 1-foot areas of crinoidal and fossil fragments; whole fossils scattered through beds; breaks down into irregular beds	3	8
Conglomerate: composed of rounded pebbles (as much as 2-inch diameter) of Detroit River limestone and dolomite in a light brown, fine grained, slightly sandy limestone matrix; conglomerate grades into overlying limestone; lower contact irregular with local relief of 1 foot	0	3
Detroit River Formation		
Dolomites and limestones: great variety of lithologies	10	0

Section 32. On left bank of Maitland River, lot 4, Maitland concession, Colborne township, 1½ miles above highway bridge at Goderich

	Feet	Inches
Dundee Formation		
Limestone: crystalline, grey, weathered grey to buff; in massive and thinner irregular beds; fossiliferous: *Cyathophyllum* sp., *Crania crenistriata*, *Rhipidomella* cf. *semele*, *Stropheodonta perplana*, *S. demissa*, *Spirifer* sp., *Atrypa reticularis*	18	0
Limestone: fine grained, buff weathered, brownish; dark bituminous streaks; jointed	66	0
Limestone: brownish, rough, impure; vuggy; irregularly bedded	2	0
Limestone: brown, fine grained, thin even beds 4 inches thick, vertically jointed; lower 6 inches with calcite stringers; upper 2 inches soft and ochreous	2	6
Limestone: medium grained, buff weathered, grey to cream coloured; dark brown to black bituminous streaks; traced laterally this interval becomes a single 6-foot bed with *Favosites* sp.; encloses conglomerate of Detroit River limestone and dolomite	6	0
Detroit River Formation		
Limestone: fine grained to dense, buff and brown, in beds 2 to 8 inches thick; upper few inches are soft, yellowish, and rotten, and contact with overlying rocks is undulating (normal N facies)	5	0

APPENDIX B – FAUNAL LISTS

ORDOVICIAN

These lists include only fossils identified by A. E. Wilson from localities within the map-area (for illustrations of some of the Ordovician fossils *see* Liberty, 1964, pp. 50-53).

1. GEORGIAN BAY FORMATION

(Dundas–Meaford beds)

GRAPTOZOA

Diplograptus cf. *peosta* Hall var.

ANTHOZOA

Columnaria alveolata Goldfuss

BRYOZOA

Bryozoa indet.

BRACHIOPODA

Catazyga sp.
cf. *Glyptorthis insculpta* var. *manitoulinensis* Foerste
Hebertella cf. *occidentalis* (Hall)
H. sinuata (Hall)
Plectorthis fissicosta (Hall)
Rafinesquina alternata subcircularis Dyer
Strophomena cf. *huronensis* Foerste
Zygospira meafordensis Foerste

PELECYPODA

Byssonychia sp.
Cuneamya cf. *scapha* Hall and Whitfield
Modiolopsis meafordensis Foerste
Pterinea demissa (Conrad)

GASTROPODA

cf. *Clathrospira subconica* (Hall)
Liospira sp.

QUEENSTON FORMATION

(limestone reefs)

Genera and Species	Localities: White Cloud Island	Hay Island	Presqu'ile Point	Pyette Point	Cameron Point (1 mile West)	Cameron Point (1 mile East)	Prairie Point	Cape Croker (1 mile South)	Montressor Point	Sucker Creek	Gravelly Point
ANTHOZOA											
Calapoecia canadensis Billings	x								x		
Columnaria alveolata Goldfuss									x		
Columnaria alveolata rigida (Billings)							x			x	
Streptelasma rusticum (Billings)	x	x							x		
Tetradium huronense Foord	x						x			x	
BRYOZOA											
Constellaria polystomella Nicholson									x		
Rhombotrypa quadrata (Rominger)									x		
BRACHIOPODA											
Hebertella alveata richmondensis Foerste	x										
H. occidentalis (Hall)								x	x	x	x
H. cf. *subjugata* (Hall)				x							
Platystrophia clarkesvillensis Foerste	x								x		x
Sowerbyella rugosus manitoulinensis (Foerste)				x							
Strophomena planumbona (Hall)								x	x		
Zygospira cincinnatiensis Meek										x	
Z. kentuckiensis James						x	x		x	x	x
Z. meafordensis Foerste			x			x	x		x	x	x
Z. modesta (Hall)									x		
PELECYPODA											
Byssonychia grandis Ulrich							x				
B. borealis Foerste	x	x									
B. cf. *meafordensis* Foerste										x	
B. praecursa Ulrich var									x		
B. radiata (Hall)							x	x			
Ischyrodonta (?) *manitoulinensis* Foerste							x				
Modiolopsis meafordensis Foerste								x			
M. modiolare (Conrad)								x			

Genera and Species	Localities										
	White Cloud Island	Hay Island	Presqu'ile Point	Pyette Point	Cameron Point (1 mile West)	Cameron Point (1 mile East)	Prairie Point	Cape Croker (1 mile South)	Montressor Point	Sucker Creek	Gravelly Point
PELECYPODA (cont'd)											
Modiodesma cf. *ovata* (Conrad)								x			
Pterinea cf. *demissa* (Conrad)				x							
Pterinea sp.						x			x	x	
Rhytimya kagawongensis Foerste										x	
R. cf. *kagawongensis* Foerste					x						
GASTROPODA											
Bellerophon parksi Foerste									x		
Clathrospira cf. *subconica* (Hall)									x		
Cyclonema bilix var. *conica* Miller									x		
Eotomaria sp.									x		
Hormotoma gracilis (Hall) var.								x			
Liospira micula (Hall)									x		
Lophospira cf. *beatrice* Foerste									x		
L. bowdeni (Safford)									x		
Salpingostoma sp.									x		
CEPHALOPODA											
cf. *Actinoceras crebriseptum* (Hall)							x				
Ormoceras sp.									x		
Sactoceras cf. *manitoulinense* Foerste				x			x				
TRILOBITA											
Proetus sp.						x					
OSTRACODA											
Drepanella richardsoni canadensis Ulrich			x								
Leperditia caecigena Miller											x
L. manitoulinensis Foerste							x		x		
Primitia sp. aff. *impressa* Ulrich					x						
Primitia sp.									x		

SILURIAN

1. MANITOULIN FORMATION

This list includes those forms reported by Williams (1919, p. 30) and Bolton (1957) from localities within the present area (for illustrations of Silurian faunas of Ontario *see* Bolton, T. E., 1966, *Geol. Surv. Can.*, Paper 66-5).

STROMATOPOROIDEA

Clathrodictyon vesiculosum Nicholson and Murie

ANTHOZOA

Enterolasma cf. *geometricum* (Foerste)
Favosites cf. *forbesi* (Edwards and Haime)
Kionelasma cf. *spongiaxis* (Rominger)
Palaeofavosites asper (d'Orbigny)
Streptelasma cf. *hoskinsoni* Foerste
Syringopora retiformis Billings

CYSTOIDEA

Brockocystis tecumseth (Billings)

BRYOZOA

Hallopora cf. *magnopora* (Foerste)
Subretepora angulata (Hall)
Helopora fragilis Hall
Phaenopora ensiformis Hall
P. expansa Hall and Whitfield
Pachydictya crassa (Hall)
P. turgida Foerste
Rhinopora verrucosa Hall

BRACHIOPODA

Dolerorthis flabellites (Foerste)
Glyptorthis fausta (Foerste)
Platystrophia biforata (Schlotheim)
P. daytonensis Savage
Stegerhynchus neglectum (Hall)
'*Atrypa*' *parksi* Williams
Coelospira planoconvexa (Hall)
Whitfieldella cataractensis Williams
W. nitida (Hall)
Plectodonta transversalis (Wahlenberg)
Strophonella striata (Hall)
Leptaena rhomboidalis (Wilckens)
Parmorthis eugeniensis (Williams)
P. eugeniensis palaeoelegantula (Williams)
Rhipidomella cf. *hybrida* (Sowerby)

GASTROPODA

Lophospira pulchra Williams
Hormotoma subulata (Conrad)
Platyostoma cornutum (Kindle and Breger)

ANNELIDA

Cornulites distans Hall

TRILOBITA

Liocalymene clintoni (Vanuxem)
Encrinurus ornatus (Hall)

In addition to the foregoing species, Ellers (1944, p. 748) reported the following diagnostic scolecodonts from the Manitoulin Formation of this area: *Lumbriconereites hibbardi* Eller, *L. scrobiculus* Eller, *Nereidavus invisibilis* Eller, *Oenonites exactus* Eller, *O. kopfi* Eller, *O. marginatus* Eller, *Ildraites peramplus* Eller, *I. geminus* Eller, *Leodicites varidentatus* Eller, *Arabellites rectidens* Eller, *Staurocephalites pyramis* Eller, *S. externus* Eller.

2. DYER BAY MEMBER, CABOT HEAD FORMATION

(*Williams, 1919, p. 37; Bolton, 1957 and GSC fossil report S1-B, 54/55*)

Genera and Species	Localities			
	Oxenden–Colpoys Village	Barrow Bay	Dyer Bay	Rocky Bay
PLANTS				
Buthotrephis gracilis Hall				x
ANTHOZOA				
Aulopora sp.	x		x	
Enterolasma cf. *geometricum* (Foerste)			x	
Favosites cristatus Edwards and Haime		x	x	x
F. obliquus Rominger			x	x
Streptelasma cf. *hoskinsoni* Foerste			x	x
Syringopora retiformis Billings				x
BRYOZOA				
Helopora fragilis Hall	x		x	x
Hallopora magnopora (Foerste)	x			
Ptilodictya cf. *expansa emarcescens* Foerste	x		x	
BRACHIOPODA				
cf. *Virgiana decussata* (Whiteaves)	x			
Rhynchonella (?) *bidens* Hall		x		
R. (?) *janea* Billings	x	x	x	x
Rhynchotreta cabotensis Williams	x		x	x
R. lepida Savage	x		x	
'*Atrypa*' cf. *parksi* Williams	x			
Strophonella striata (Hall)				x
PELECYPODA				
Pterinea cf. *undata* (Hall)	x		x	x
GASTROPODA				
Hormotoma subulata (Conrad)	x		x	
Platyostoma sp.	x			
TRILOBITA				
Liocalymene clintoni (Vanuxem)	x	x	x	
OSTRACODA				
Leperditia cabotensis Ulrich and Bassler	x		x	x
Chilobolbina punctata Ulrich and Bassler	x		x	x
Zygobolba williamsi Ulrich and Bassler	x		x	x

LOCKPORT FORMATION

The following lists are compiled from Williams (1919, p. 64) and include forms reported by Parks, Grabau, Lambe, and in Bassler's *Bibliographic Index*, as well as those collected by the writers from the Lockport of the Bruce Peninsula (Bolton, 1957, and fossil report S1-B, 54/55).

3. LOCKPORT MEMBER 2 (Fossil Hill Formation)

STROMATOPOROIDEA

Clathrodictyon striatellum (d'Orbigny)
C. vesiculosum Nicholson and Murie
C. vesiculosum minutum (Rominger)

ANTHOZOA

Alveolites sp.
Amplexus shumardi (Edwards and Haime)
Arachnophyllum diffluens (Edwards and Haime)
A. mamillare (Owen)
A. pentagonum (Goldfuss)
Cladopora laqueata (Rominger)
Coenites laminatus (Hall)
'*Cyathophyllum*' *thoroldense* Lambe
Cystiphyllum niagarense (Hall)
Diplophyllum caespitosum (Hall)
Favosites favosus (Goldfuss)
F. hisingeri (Edwards and Haime)
F. hispidus Rominger
Halysites catenularia (Linnaeus)
Catenipora microporus (Whitfield)
Heliolites elegans Hall
H. interstinctus (Linnaeus)
H. megastomus McCoy
H. subtubulatus (McCoy)
Lyellia americana Edwards and Haime
L. superba (Billings)
Plasmopora follis Edwards and Haime
Ptychophyllum major (Rominger)
P. stokesi Edwards and Haime
Syringopora fibrata Rominger
S. retiformis Billings
Zaphrentis stokesi Edwards and Haime

BRACHIOPODA

Dolerorthis flabellites (Foerste)
Pentamerus oblongus Sowerby
Atrypa reticularis (Linnaeus)
Eospirifer eudora (Hall)
Howellella crispa (Hisinger)
Leptaena rhomboidalis (Wilckens)

PELECYPODA

Amphicoelia leidyi Hall

4. LOCKPORT MEMBER 3B (Wiarton Member, Amabel Formation)

STROMATOPOROIDEA

Clathrodictyon striatellum (d'Orbigny)
C. vesiculosum Nicholson and Murie

ANTHOZOA

Alveolites labechei Edwards and Haime
Arachnophyllum eximius (Billings)
Cystostylus infundibulus (Whitfield)
Favosites hisingeri (Edwards and Haime)
F. hispidus Rominger
Halysites agglomerata Hall
Pycnostylus elegans Whiteaves

CYSTOIDEA

Caryocrinites ornatus Say
Gomphocystites glans Hall

CRINOIDEA

Lecanocrinus cf. *pisiformis* (Roemer)
Siphonocrinus pentagonus Wachsmuth and Springer
Eucalyptocrinites crassus Hall

BRYOZOA

Fenestrellina elegans (Hall)
Pachydictya crassa (Hall)
Rhinopora verrucosa Hall

BRACHIOPODA

Dolerorthis flabellites (Foerste)
Platystrophia daytonensis laurelensis McEwan
Barrandella fornicata Hall
Rhynchotreta americana Hall

Stegerhynchus neglectum (Hall)
S. whitii (Hall)
Plectatrypa nodostriata (Hall)
Atrypa reticularis (Linnaeus)
Eospirifer eudora (Hall)
E. radiatus (Sowerby)
Howellella crispa (Hisinger)
H. crispa simplex (Hall)
Nucleospira pisiformis (Hall)
Strophonella striata (Hall)
Fardenia subplana (Conrad)
Parmorthis elegantula (Dalman)

PELECYPODA

Pterinea brisa Hall
Cornellites emaceratus (Conrad)
Amphicoelia leidyi Hall
Mytilaraca acutirostra (Hall)
Cypricardinia arata Hall
Concocardium elegantulum Billings
Streptomytilus aphaea (Hall)
Goniophora speciosa Hall

GASTROPODA

Phanerotrema occidens (Hall)
Eotomaria durhamensis (Whiteaves)
'*Straparollus*' *mopsus* Hall
Holopea guelphensis Billings
Platyostoma cornutum (Kindle and Breger)
Strophostylus (?) *elevatus* (Hall)
Subulites terebreviformis Hall and Whitfield
Cyrtospira ventricosa Hall

CEPHALOPODA

Michelinoceras sp.
Kionoceras cf. *scammoni* (McChesney)
Protokionoceras trusitum (Clarke and Ruedemann)
Anaspyroceras varro (Billings)
Cyrtorizoceras byronense Foerste
Amphicyrtoceras laterale (Hall)
A. orcas (Hall)
A. pettiti (Billings)
A. williamsi Foerste
Phragmoceras ontarioense Foerste
Lechritrochoceras desplainense (McChesney)

TRILOBITA

Bumastus ioxus (Hall)
Scutellum acamus (Hall)
Sphaerexochus romingeri Hall

5. LOCKPORT MEMBER 3C (Eramosa Member, Amabel Formation)

Genera and Species	Localities				
	Stokes Bay	Sky Lake	Red Bay	Wiarton	Shallow Lake
ANTHOZOA					
Diphyphyllum sp.			X		
Favosites hispidus Rominger		X			
F. niagarensis Hall		X		X	
Halysites catenularia (Linneaus)	S				
Pycnostylus cf. *elegans* Whiteaves		X			
BRACHIOPODA					
Rhynchotreta americana Hall					X
Stegerhynchus neglectum (Hall)	S			S	
S. (?) *pisa* (Hall and Whitfield)					X
S. whitii (Hall)					X
Eospirifer eudora (Hall)		X			
E. radiatus (Sowerby)		X	X	S	
Howellella crispa (Hisinger)		X		X	X
Cyrtia sp.			X		
cf. *Cyrtia meta* (Hall)		X			
Whitfieldella intermedia (Hall)				X	X
Homoeospira evax (Hall)					X
CEPHALOPODA					
Discosorus sp.		X			
Geisonocerina sp.		X		X	
OSTRACODA					
Leperditia sp.					X
EURYPTERIDA					
Eusarcus logani Williams		X		X	
Eurypterus sp.				X	

S Shaw, E. W.: Royal Canadian Institute, vol. 21, Pt. 2, No. 46, p. 341, 1937.
X Collected by the writers (Bolton, 1957, and fossil report S1-B, 54/55).

DEVONIAN

1. BOIS BLANC FORMATION

(composite)

PLANTAE

Tasminites? sp.

PORIFERA

Hindia fibrosa Duncan

GRAPTOZOA

Dictyonema sp.

STROMATOPOROIDAE

Clathrodictyon sp.
Idiostroma sp.

ANTHOZOA

Acrophyllum oneidaense (Billings)
Alveolites squamosus Billings
Billingsastraea verneulli (Edwards and Haime)
Breviphrentis mirablis (Billings)
Cladopora aff. *C. billingsi* (Nicholson)
Cladopora aff. *C. labiosa* (Billings)
Compressiphyllum sp.
Cyathophyllum robustum Hall
Cystiphylloides americanus (Edwards and Haime)
Emmonsia emmonsi (Rominger)
E. ramosa (Rominger)
E. tuberosa (Rominger)
Favosites baculus Davis
Favosites aff. *F. goldfussi* d'Orbigny
F. heliolitiformis (Rominger)
F. intermedius Stewart
F. aff. *F. ramulosus* Davis
F. turbinatus Billings
F. winchelli (Rominger)
Heliophyllum aff. *H. halli* Edwards and Haime
H. aff. *H. sciotense* Stewart
Heliophylloides sp.
Kionelasma mammifera (Hall)
Metriophyllum sp.
Pleurodictyum convexum (d'Orbigny)
P. favosoideeum (Billings)
Scenophyllum conigerum (Rominger)
Siphonophrentis gigantea (Lesueur)
Stereolasma sp.
Synaptophyllum arundinaceum (Billings)
S. aff. *S. simcoense* (Billings)
Syringopora hisingeri Billings
S. perelegans Billings
Temnophyllum sp.
Thamnopora limitaris (Rominger)
Thamnophyllum sp.

BRYOZOA

Fenestrellina sp.
Semicosinium sp.
Thamniscus sp.

BRACHIOPODA

Amphigenia elongata (Vanuxem)
Atrypa impressa Hall
Atrypa sp.
Athyris sp.
Brevispirifer aff. *B. gregarius* (Clapp)
Camarotoechia billingsi (Hall)
C. tethys (Billings)
Centronella glansfagea (Hall)
Chonetes hemisphericus Hall
Cryptonella aff. *C. rectirosta* (Hall)
Fimbrispirifer divaricatus (Hall)
Leiorhynchus sp.
Leptaena "rhomboidalis" (Wilckens)
Leptocoelia camilla (Hall)
Megastrophia hemisphaerica (Hall)
Meristella nasuta (Conrad)
Pentamerella arata (Conrad)
Rhipidomella cleobis (Hall)
R. livia (Billings)
"*Spirifer*" *duodenarius* (Hall)
"*Spirifer*" *macrothyris* Hall
"*Spirifer*" *varicosus* Hall
Stropheodonta sp.
Strophonella ampla (Hall)

GASTROPODA

Euryzone aff. *E. arata* (Hall)
Loxonema sp.
Murchisonia maia Hall
Platyceras aff. *P. carinatum* Hall
P. aff. *P. erectum* (Hall)
P. aff. *P. lineata* Conrad
Pleuronotus sp.

PELECYPODA

Conocardium cuneus (Conrad)
C. ohioense Meek
C. aff. *C. subtrigonale* d'Orbigny
Plethomytilus aff. *P. ponderosus* Hall

TRILOBITA

Anchiopsis anchiops (Green)
Calymene platya Green
Phacops cristata Hall
P. cristata var. *pipa* Hall and Clarke
Proetus crassimarginatus Hall

OSTRACODA

Bythocypris sp.

2. DETROIT RIVER FORMATION (N Facies)

(*from E. W. Best, 1953 MS.*)

STROMATOPOROIDAE

Clathrodictyon sp.
Idiostroma nattressi Grabau

ANTHOZOA

Aulopora sp.? (reef flank)
Cladopora sp.? (and reef flank)
Favosites sp. (and reef flank)
Heliophyllum sp.
Siphonophrentis sp.
Synaptophyllum sp.?
Temnophyllum integumentum (Barrett)

BRACHIOPODA

Chonetes sp. (and reef flank)
Cryptonella sp.? (reef flank)
Cymostrophia sp.?
Prosserella lucasi Grabau
P. planisinosus Grabau
Rhipidomella sp.? (reef flank)
Schuchertella interstriata (Hall) (and reef flank)
"*Spirifer*" sp. "*S.*" *duodenarius* (Hall) (reef flank)
"*Spirifer*" aff. "*S.*" *raricosta* (Conrad) (reef flank)
"*Spirifer*" likely "*S.*" *sulcata submersus* Grabau (reef flank)
"*Spirifer*" *sulcata submersus* Grabau
Stropheodonta vasculosa? Grabau (reef flank)

PELECYPODA

Concocardium monroicum Grabau
C. monroicum? Grabau (reef flank)

GASTROPODA

Acanthonema sp. (reef flank)
Euryzone sp. (and reef flank)
Murchisonia sp.? (and reef flank)
P. (*Platyceras*) sp. (and reef flank)

TRILOBITA

Proetus crassimarginatus Hall (and reef flank)

3. DETROIT RIVER FORMATION (B (bioherm) Facies)

(*from E. W. Best, 1953 MS.*)

STROMATOPOROIDAE

Actinostroma sp.
Clathrodictyon spp.
Idiostroma sp.
Stromatoporella sp.

ANTHOZOA

Breviphrentis sp.?
Cladopora labiosa (Billings)
Cyathophyllum sp.
Cystiphylloides aff. *C. vesiculosum* (Goldfuss)
Emmonsia emmonsi (Rominger)
E. ramosa (Rominger)
Favosites arbor Davis
F. baculus Davis
F. basalticus (Goldfuss)
F. frutex Davis
F. goldfussi d'Orbigny
F. heliolitiformis (Rominger)
F. intermedius Stewart
F. ramulosus Davis
Heliophyllum halli Edwards and Haime
H. sciotense Stewart
Scenophyllum sp.?
Siphonophrentis gigantea (Lesueur)
Synaptophyllum arundinaceum (Billings)
S. simcoense (Billings)
Syringopora hisingeri Billings
Thamnopora limitaris (Rominger)

BRYOZOA

abundant fenestellate type

BRACHIOPODA

Ambocoelia aff. *A. umbonata* (Conrad)
Atrypa spp.
Athyris cora Hall
Brevispirifer sp.

Camarotoechia billingsi (Hall)
C. aff. *C. sappho* (Hall)
C. tethys (Billings)
Chonostrophia sp.
Cranaena lincklaeni (Hall)
Cryptonella aff. *C. planirostra* (Hall)
Cryptonella aff. *C. reimanni* Cloud
Cymostrophia inequiradiata (Hall)
C. patersoni (Hall)
Emanuella sp.
Fimbrispirifer divaricatus (Hall)
Gypidula sp.
Leiorhynchus aff. *L. kelloggi* Hall
Megastrophia sp.
Meristella aff. *M. doria* Hall
M. nasuta (Conrad)
Nucleospira sp.
Pentamerella arata (Conrad)
P. thusnelda Nettelroth
Pholidostrophia sp.
Productella sp.
Protoleptostrophia sp.
Rhipidomella aff. *R. livia* (Billings)
Rhytistrophia beckii (Hall)
Schizophoria propinqua (Hall)
"*Spirifer*" aff. "*S.*" *duodenarius* (Hall)
"*Spirifer*" aff. "*S.*" *raricosta* (Conrad)
"*Spirifer*" aff. "*S.*" *segmentus* Hall
"*Spirifer*" aff. "*S.*" *sulcata submersus* Grabau
"*Spirifer*" *varicosus* Hall
Stropheodonta sp.

PELECYPODA

Actinopteria sp.
Conocardium cuneus (Conrad)
C. monroicum Grabau
C. ohioense Meek
Mytilarca sp.
Plethomytilus ponderosus Hall
Pterinopecten insons Hall

GASTROPODA

Bellerophon aff. *B. pelops* Hall
Elasmonema bellatulum (Hall)
E. cona (Kindle)
Loxonema aff. *L. laeviusculum* Hall
L. aff. *L. parvula* Whitfield
L. solida Hall
Mourlonia filitexta (Foerste)
Murchisonia sp.
Naticopsis aff. *N. levis* Meek
Platyceras aff. *P.* (*Orthonychia*) *subrectum* Hall
P. (*Platyceras*) *carinatum* Hall
P. aff. *P.* (*Platyceras*) *dumosum* Conrad
P. (*Platyceras*) *erectum* (Hall)
P. (*Platyostoma*) *lineatum* Conrad
P. (*Platyostoma*) *turbinatum* (Hall)
Procrucibulum sp.?
Straparollus sp.
Strobeus sp.

CEPHALOPODA

Acleistoceras sp.
Michelinoceras sp.
Ryticeras sp.
Spyroceras sp.

SCAPHOPODA

Dentalium (*Laevidentalium*) sp.

TRILOBITA

Cyphaspis sp.
Echinolichas aff. *E. eriopis* (Hall)
Proetus conradi Hall
P. crassimarginatus Hall
P. ovifrons Hall
P. verneuili Hall

4. DUNDEE FORMATION (lower member)

(*after E. W. Best, 1953 MS.—Delaware, lower member*)

PLANTAE

Protosalvinia sp.

STROMATOPOROIDAE

Clathrodictyon sp.

ANTHOZOA

Aulacophyllum dundeense (Grabau)
A. aff. *A. dundeense* (Grabau)
Cladopora sp.
Cyathophyllum aff. *C. robustum* Hall
Cystiphylloides sp.
Cystiphyllum sp.
Favosites rotundituba Davis
F. turbinatus Billings
Emmonsia sp.
Heliophyllum aff. *H. halli* Edwards and Haime
Platyaxum sp.

BRACHIOPODA

Atrypa costata Bassett
A. aff. *A. costata* Bassett
A. elegans (Grabau)

A. aff. *A. elegans* (Grabau)
Atrypa spp.
Brevispirifer lucasensis (Stauffer)
Camarotoechia carolina (Hall)
C. aff. *C. medea* (Billings)
C. prolifica (Hall)
Chonetes deflectus Hall
C. aff. *C. deflectus* Hall
Cranaena sp.?
Craniops hamiltonae (Hall)
C. neali (Bassett)
C. oblatus (Hall)
Cryptonella aff. *C. planirostra* (Hall)
Cymostrophia spp.
Crytina aff. *C. hamiltonensis recta* Hall
Douvillina sp.?
Fimbrispirifer sp.
Leptaena "*rhomboidalis*" (Wilckens)
Longospina? *maconensis* (Bassett)
L. mucronata (Hall)
Megastrophia concava (Hall)
M. aff. *M. concava* (Hall)
Meristella aff. *M. barrisi* Hall
Mucrospirifer aff. *M. consobrinus* (d'Orbigny)
Nucleospira aff. *N. concinna* (Hall)
Orbiculoidea sp.
Pholidostrophia nacrea (Hall)
Productella spinulicosta Hall
Protoleptostrophia perplana (Conrad)
Pustulina sp.
Rhipidomella vanuxemi (Hall)
R. variabilis Grabau
Rhytistrophia sp.
Schizophoria foleyi Bassett
"*Spirifer*" *manni* Hall
Stropheodonta spp.

PELECYPODA

Actinopterella sp.
Conocardium normale Hall
Cypricardinia identa Conrad
Paracyclas proavia (Goldfuss)

GASTROPODA

Loxonema sp.
Lucina sp.?
Mourlonia lucina (Hall)
Pleuronotus sp.?
Platyceras (*Platyostoma*) *lineatum* Conrad
P. (*Platyceras*) sp.
Straparollus sp.

ANNELIDA

Tentaculites sp.

TRILOBITA

Coronura aspectans (Conrad)
C. aff. *C. myrmecophorus* (Green)
Phacops sp.
Proetus crassimarginatus Hall
P. aff. *P. macrocephalus* Hall
P. planimarginatus Meek
P. rowi (Green)

5. DUNDEE FORMATION (upper member)

(*after E. W. Best, 1953 MS.—Delaware, upper member*)

GRAPTOZOA

Dictyonema hamiltonae Hall

ANTHOZOA

Aulacophyllum dundeense (Grabau)
A. aff. *A. dundeense* (Grabau)
Breviphyllum sp.
Chaetetes sp.
Cladopora sp.
Cyathophyllum aff. *C. robustum* Hall
Cystiphylloides sp.
Disphyllum sp.
Eridophyllum sp.
Fasciphyllum sp.?
Favosites aff. *F. goldfussi* d'Orbigny
F. turbinatus Billings
Hallia sp.?
Heliophyllum aff. *H. halli* Edwards and Haime
Heterophrentis sp.
Syringopora aff. *S. intermedia* Nicholson
Thamnophyllum sp.
Trachypora "*osculata*" (Davis)

ECHINODERMATA

Arachnocrinus ignotus Stauffer

BRACHIOPODA

Ambocoelia aff. *A. praeumbona* (Hall)
A. umbonata (Conrad)
A. aff. *A. umbonata* (Conrad)
Athyris vittata Hall
Atrypa costata Bassett
A. aff. *A. costata* Bassett

A. ehlersi Bassett
A. aff. *A. ehlersi* Bassett
A. elegans (Grabau)
A. aff. *A. elegans* (Grabau)
Brevispirifer lucasensis (Stauffer)
Callipleura aff. *C. nobilis* (Hall)
Camarotoechia aff. *C. carolina* (Hall)
C. aff. *C. medea* (Billings)
C. nitida Kindle
C. prolifica (Hall)
C. aff. *C. prolifica* (Hall)
C. aff. *C. sappho* (Hall)
Chonetes deflectus Hall
Cranaena aff. *C. lincklaeni* (Hall)
C. aff. *C. romingeri* (Hall)
Craniops sp.
Cryptonella aff. *C. planirosta* (Hall)
C. aff. *C. reimanni* Cloud
Cryptonella spp.
Cymostrophia inequiradiata (Hall)
C. patersoni (Hall)
Cyrtina aff. *C. hamiltonensis recta* Hall
Douvillina sp.?
Etheridgina ? *spinosa* Bassett
Fimbrispirifer aff. *F. grieri* (Hall)
F. aff. *F. venustus* (Hall)
Gypidula sp.
Leiorhynchus aff. *L. laura* (Billings)
L. mysia Hall
L. aff. *L. mysia* Hall
Leptaena "*rhomboidalis*" (Wilckens)
Longospina? *maconensis* (Bassett)
L. mucronata (Hall)
"*Martinopsis*" *maia* (Billings)
Megastrophia concava (Hall)
Meristella barrisi Hall
M. aff. *M. barrisi* Hall
Mucrospirifer aff. *M. consobrinus* (d'Orbigny)
M. aff. *M. macrus* (Hall)
M. aff. *M. mucronatus* (Conrad)
Nucleospira aff. *N. concinna* (Hall)
Orbiculoidea doria (Hall)
Pentagonia unisulcata (Conrad)
Pentamerella spp.
Pholidostrophia nacrea (Hall)
Productella spinulicosta Hall
Protoleptostrophia perplana (Conrad)
Pustulina sp.
Rhipidomella penelope (Hall)
R. vanuxemi (Hall)
R. variabilis Grabau
Rhytistrophia sp.
Schizophoria foleyi Bassett
"*Spirifer*" aff. "*S.*" *byrnesi* Nettelroth
"*Spirifer*" *raricosta* (Conrad)
"*Spirifer*" *varicosus* Hall
Stropheodonta spp.
Stropholasia sp.?

PELECYPODA

Actinopterella sp.
Actinopteria subdecussata (Hall)
Conocardium sp.
Cypricardella sp.
Cypricardinia identa Conrad
Modiomorpha sp.?
Paracyclas lirata (Conrad)
P. proavia (Goldfuss)
Phenacocyclas pholi La Rocque
Plethomytilus sp.
Pterinea sp.?
Solemya sp.

GASTROPODA

Elasmonema aff. *E. bellatulum* (Hall)
Loxonema sp.
Murchisonia sp.
Platyceras (*Orthonychia*) *attenuatum* ? Hall
P. (*O.*) *conicum* (Hall)
P. (*Platyceras*) *bucculentum* Hall
P. (*P.*) *carinatum* Hall
P. (*P.*) *dumosum rarispinosum* Hall
P. (*P.*) *erectum* (Hall)
P. aff. *P.* (*P.*) *rictum* Hall
P. (*P.*) *symmetricum* Hall
P. (*P.*) *thetis* ? Hall
P. keoughi Bassett
Pleuronotus aff. *P. decewi* (Billings)
Straparollus aff. *S.* (*Straparollus*) *rudis* (Hall)

CEPHALOPODA

Agoniatites vanuxemia (Hall)
Centroceras sp.?
Gigantoceras inelegans (Meek)
Michelinoceras sp.
Spyroceras sp.

ANNELIDA

Coleolus sp.
Styliolina fissurella (Hall)
Tentaculites gracillistriatus Hall

TRILOBITA

Calymene sp.?
Coronura myrmecophorus (Green)
Odontocephalus aegeria Hall
O. selenurus (Eaton)
Phacops aff. *P. rana* Green
Proetus crassimarginatus Hall
P. macrocephalus Hall
P. aff. *P. macrocephalus* Hall
P. planimarginatus Meek

APPENDIX C — WELL LOGS

(*Logged by officers of the Geological Survey of Canada*)

1. The following partial logs show the lithology of the Cabot Head, Manitoulin, and Queenston Formations.
   Well: Bruce Oil and Gas Company—Dept. of Lands and Forests No. 1
   Location: Lot 20, con. 2W, Lindsay tp., Bruce co.
   Elevation: 667 feet
   Year completed: 1951

Formation	Depth (feet)	Thickness (feet)	Lithology
Cabot Head	275–280	5	Dolomite: olive-green to dark brown, finely crystalline, argillaceous (St. Edmund? member)
	280–285	5	Shale: olive-green, dolomitic with 40 per cent greyish green, finely crystalline, argillaceous dolomite (Wingfield member)
	285–295	10	Dolomite: buff, very finely crystalline; equal amount greyish green, finely crystalline, argillaceous dolomite
	295–305	10	Dolomite: dark brown, finely crystalline; green shale
	305–320	15	Dolomite: dark greyish brown, finely crystalline, argillaceous; Bryozoa (Dyer Bay member)
	320–325	5	Dolomite: grey to grey-buff, finely crystalline, argillaceous
	325–330	5	Dolomite: buff, finely crystalline; olive-green to grey shale
	330–340	10	Shale: brick red; olive-green, fissile shale fragments (Cabot Head member [restricted])
	340–345	5	Shale: red and green; equal amounts of red and green, argillaceous dolomite
	345–350	5	Dolomite: buff, very finely crystalline; red and green shale fragments
	350–385	35	Shale: brick red; minor amount green shale
	385–390	5	Shale: brick red; 40 per cent green shale
	390–410	20	Shale: green, fissile
Manitoulin	410–465	55	Dolomite: grey, finely crystalline, argillaceous; white chert lower 15 feet; fossiliferous
Queenston	465–475	10	Shale: red and green; minor dolomite interbedded with green shale
	475–495	20	Shale: red and green in equal amounts

Well: W. McKillop—J. Hughes No. 2
Location: Lot 14, con. 10, Amabel tp., Bruce co.
Elevation: 603 feet
Year completed: 1919

Formation	Depth (feet)	Thickness (feet)	Lithology
Cabot Head	225–235	10	Dolomite: grey, finely crystalline, minor amount of green shale; trace of pyrite (Dyer Bay member)
	235–310	75	Shale: red; green shale at 310 feet (Cabot Head member [restricted])
	310–340	30	Shale: grey and green; equal amount of grey crystalline limestone; trace of red shale
Manitoulin	340–390	50	Limestone: dolomitic, grey, crystalline; trace of green and red shale
	390–435	45	Limestone: dolomitic, dark grey, finely crystalline; minor amount of grey shale
Queenston	435–465	30	Shale: red

2. The following partial logs show the Salina lithology in detail.
Well: Dominion Natural Gas Co.—G. B. Armstrong No. 1
Location: Lot 5, con. 8, Culross tp., Bruce co.
Elevation: 1,044 feet
Year completed: 1941

Formation	Depth (feet)	Thickness (feet)	Lithology
Bass Island	305–333	28	Dolomite: cream coloured, finely crystalline
	333–375	42	Dolomite: light buff, finely crystalline
	375–393	18	Dolomite: buff, finely crystalline; some oölitic dolomite
	393–438	45	Dolomite: buff, finely crystalline
Salina	438–442	4	Dolomite: grey, fine crystalline
	442–466	24	Shale, limy: red and green; trace of gypsum
	466–525	59	Shale: green; minor amount of red shale
	525–530	5	Dolomite: grey, finely crystalline
	530–541	11	Shale, limy: greenish grey; little red shale
	541–546	5	Dolomite: brownish grey, finely crystalline; trace of gypsum
	546–562	16	Dolomite, shaly: grey; trace of gypsum
	562–587	25	Dolomite: brownish grey, dense; some grey shaly dolomite; trace of gypsum
	587–605	18	Dolomite: shaly: grey, dense; trace of gypsum
	605–617	12	Shale, limy: greenish grey; trace of red shale
	617–629	12	Dolomite, shaly: grey
	629–683	54	Dolomite: grey, dense; trace of gypsum
	683–701	18	Shale: green; few embedded sand grains; little red shale
	701–713	12	Shale: red and green; trace of gypsum

Well: Dominion Natural Gas Co.—G. B. Armstrong No. 1 (*cont.*)

Formation	Depth (feet)	Thickness (feet)	Lithology
Salina (*cont.*)	713–725	12	Shale: green; some red shale and brown dolomite
	725–755	30	Shale: greenish grey; little brown dolomite; trace of gypsum
	755–777	22	Dolomite: brownish grey, finely crystalline; 5 per cent gypsum
	777–783	6	Shale: grey; 25 per cent gypsum
	783–823	40	Dolomite: brownish grey, finely crystalline; trace of gypsum
	823–850	27	Dolomite: grey, finely crystalline; trace of gypsum
	850–873	23	Dolomite: dark brownish grey, finely crystalline
	873–915	42	Dolomite: brownish grey, finely crystalline; 25 per cent gypsum in lower 10 feet
	915–1,017	102	Limestone: dark brownish grey, finely crystalline; trace gypsum in lower 15 feet
	1,017–1,029	12	Dolomite: grey, finely crystalline; much gypsum
	1,029–1,041	12	Gypsum: little grey dolomite
	1,041–1,047	6	Dolomite: brownish grey, finely crystalline; little gypsum
Guelph	1,047–1,059	12	Dolomite: buff, finely granular; trace of selenite

Well: Kincardine Salt Co.
Location: Village of Kincardine, Bruce co.
Elevation: 586 feet
Year completed: 1929

Formation	Depth (feet)	Thickness (feet)	Lithology
Salina	555–590	35	Dolomite: brownish grey, finely crystalline; minor amount of grey shaly dolomite; trace gypsum at 560 feet
	590–650	60	Shale: green; minor amount of reddish brown shale; trace gypsum at 630 feet
	650–790	140	Dolomite: brownish grey, finely crystalline; trace of green and red shale at 650 to 680 feet; trace of gypsum at 730 to 750 feet
	790–850	60	Shale: greenish grey; little red shale
	850–860	10	Shale: reddish brown and green; trace of gypsum
	860–880	20	Shale: greenish grey; trace of gypsum
	880–900	20	Dolomite: brownish grey, finely crystalline; little gypsum
	900–920	20	Salt
	920–930	10	Gypsum: little greenish grey shale
	930–940	10	Shale: greenish grey
	940–950	10	Gypsum: little greenish grey shale
	950–1,115	165	Salt
	1,115–1,125	10	Dolomite: brown, fossiliferous; trace of gypsum

3. Complete well records

Well: W. Forrest—F. McNeill No. 2
Location: Lot 28, con. 1, Sarawak tp., Grey co.
Elevation: 730 feet
Year completed: 1939

Formation	Depth (feet)	Thickness (feet)	Lithology
	0–6	6	No samples
Manitoulin	6–17	11	Dolomite: grey, crystalline; trace of pyrite at base
Queenston	17–24	7	Shale: red and green
	24–36	12	Limestone: grey, crystalline; some greenish grey shale; Bryozoa
	36–41	5	Shale: red and green
	41–47	6	Mixture grey limestone and red and green shale
	47–56	9	Samples missing
	56–194	138	Shale: red; minor amount of green shale in most samples
	194–200	6	Limestone: grey, finely crystalline; some grey shaly limestone and limy shale
	200–208	8	Shale: greenish grey; equal amount of grey crystalline limestone
	208–234	26	Limestone: grey, finely crystalline; little red and grey shale near the base
	234–245	11	Shale: red; minor amount of green shale
	245–251	6	Limestone: grey, crystalline; fossiliferous
	251–268	17	Shale: red; minor amount of green shale
	268–285	17	Shale: greenish grey; minor amount of red shale
	285–296	11	Shale: red and greenish grey; trace of pink gypsum
	296–302	6	Limestone: grey, crystalline; much grey shale
	302–308	6	Shale: red and greenish grey; trace of grey limestone
Georgian Bay	308–319	11	Limestone: shaly, grey, crystalline; minor amount of greenish grey shale; trace of red shale
	319–351	32	Shale: greenish grey; minor amount of grey limestone; trace of red shale at 336 feet
	351–410	59	Shale: grey and greenish grey; trace of grey limestone throughout
	410–536	126	Shale: grey with greenish cast; trace of grey limestone throughout, trace of pyrite at 426, 438, and 456 feet
	536–619	83	Shale: grey; little grey limestone at 547 to 552 feet
Whitby	619–733	114	Shale: grey
	733–752	19	Shale: dark grey to black
Simcoe Group	752–771	19	Limestone: grey, finely crystalline; trace of grey shale; trace of pyrite
	771–777	6	Shale: black
	777–794	17	Limestone: grey, finely crystalline; Bryozoa
	794–802	8	Shale: black
	802–826	24	Limestone: grey to brownish grey, finely crystalline; little grey and greenish shale
	826–928	102	Limestone: grey, finely crystalline; little dark grey shale in most samples

Weel: W. Forrest—F. McNeill No. 2 (*cont.*)

Formation	Depth (feet)	Thickness (feet)	Lithology
Simcoe Group (*cont.*)	928–975	47	Limestone: grey, finely crystalline; much grey shaly limestone and limy shale
	975–980	5	Shale: dark grey
	980–1,080	100	Limestone: grey, finely crystalline
	1,080–1,250	170	Limestone: brownish grey, finely crystalline; little cream coloured dense limestone at 1,200 to 1,211 feet (Gull River Formation)
	1,250–1,266	16	Dolomite: buff, crystalline
	1,266–1,334	68	Limestone: shaly, brownish grey and grey
Shadow Lake	1,334–1,342	8	Mixture of grey limestone, green shale, frosted sand grains; trace of pyrite
	1,342–1,350	8	Shale: green and red; equal amount of subangular and rounded sand
	1,350–1,362	12	Sand: rounded and subangular; minor amount of red and green shale
Precambrian	1,362–1,364	2	Angular quartz: some biotite
	1,364–1,366	2	Angular quartz: some biotite, feldspar, and green chloritic shale

Well: Mulberry Creek Oil Company—J. Fowlie No. 1
Location: Lot 17, con. 4W, Eastnor tp., Bruce co.
Elevation: 607 feet
Year completed: 1924

Formation	Depth (feet)	Thickness (feet)	Lithology
	0–2	2	Surface drift
Guelph–Lockport	2–20	18	Dolomite: light grey, crystalline, porous
	20–80	60	Dolomite: buff, crystalline, finely porous at 20 to 60 feet
	80–120	40	Dolomite: buff, finely crystalline; trace of white chert
	120–190	70	Dolomite: light grey, crystalline
	190–250	60	Dolomite: light buff, crystalline; trace of chert
Cabot Head	250–260	10	Shale: pale green (Wingfield member)
	260–270	10	Shale: greenish grey; equal amount grey crystalline dolomite
	270–280	10	Dolomite: grey, crystalline; minor amount of greenish grey shale (Dyer Bay member)
	280–290	10	Shale: greenish grey; equal amount of buff dolomite (Cabot Head member [restricted])
	290–320	30	Shale: red; little green shale and grey dolomite
	320–340	20	Shale: greenish grey; trace of red shale

Well: Mulberry Creek Oil Company—J. Fowlie No. 1 (*cont.*)

Formation	Depth (feet)	Thickness (feet)	Lithology
Manitoulin	340–360	20	Limestone, dolomitic: grey, crystalline; Bryozoa
	360–390	30	Limestone, dolomitic: grey, crystalline; some shaly dolomite and greenish grey shale
Queenston	390–400	10	Shale: greenish grey; little red shale and grey dolomite
	400–450	50	Shale: red; trace of green shale and grey dolomite; trace of gypsum at 450 feet
	450–480	30	Shale: greenish grey; minor amount of red shale; Bryozoa at 480 feet
	480–540	60	Limestone: grey, crystalline; minor amount of green shale throughout; Bryozoa
	540–550	10	Shale: grey; little grey limestone
	550–570	20	Limestone: grey, crystalline; minor amount of grey shale
	570–600	30	Shale: greenish grey; minor amount of red shale
Georgian Bay	600–650	50	Shale: greenish grey; minor amount of grey limestone
	650–720	70	Shale: grey with green cast
	720–840	120	Shale: grey to greenish grey; little grey crystalline limestone throughout; trace of pyrite at 840 feet
Whitby (upper member)	840–950	110	Shale: grey
	950–1,010	60	Shale: dark grey
Whitby (lower member)	1,010–1,030	20	Shale: black; some brownish grey limestone
Simcoe Group	1,030–1,080	50	Limestone: brownish grey, finely crystalline
	1,080–1,130	50	Limestone: shaly, grey, crystalline; little grey shale
	1,130–1,140	10	Dolomite: grey, coarsely crystalline
	1,140–1,200	60	Limestone: grey, crystalline; little greenish grey shale; Bryozoa
	1,200–1,277	77	Limestone: grey, finely crystalline; little grey shale, Bryozoa
	1,277–1,288	11	Limestone: buff, fossiliferous
	1,288–1,367	79	Limestone: grey, finely crystalline; metabentonite? at 1,299 feet
	1,367–1,407	40	Limestone: light buff, finely crystalline to dense
	1,407–1,437	30	Limestone: brownish grey, finely crystalline
	1,437–1,447	10	Limestone: grey, oölitic
	1,447–1,537	90	Limestone: grey and buff; finely crystalline
	1,537–1,557	20	Limestone: dolomitic, grey, dense
Shadow Lake	1,557–1,567	10	Sandstone: calcareous, fine grained, light grey; much pyrite; trace of glauconite
	1,567–1,577	10	Shale: green; embedded sand grains
	1,577–1,587	10	Mixture of fine grained sandstone, green sandy shale, and grey limestone
Precambrian	1,587–1,597	10	Angular quartz, pink feldspar, biotite, green shale

Well: Dominion Natural Gas Co.—J. B. McKenzie No. 1
Location: Lot 18, con. 5, Culross tp., Bruce co.
Elevation: 1,039 feet
Year completed: 1942

Formation	Depth (feet)	Thickness (feet)	Lithology
Detroit River	0–39	39	No samples
	39–143	104	Dolomitic limestone: buff, finely crystalline
	143–158	15	Dolomitic limestone: brown, finely crystalline
	158–247	89	Dolomitic limestone: light buff, finely crystalline
	247–265	18	Dolomitic limestone: brown, finely granular
Bois Blanc	265–348	83	Dolomitic limestone: brownish grey, finely crystalline; minor amount of chert throughout
	348–450	102	Dolomitic limestone: brownish grey, finely crystalline; equal amount of chert throughout
Bass Island	450–525	75	Dolomite: buff, finely crystalline
	525–543	18	Dolomite: buff, finely crystalline with black bituminous streaks
	543–583	40	Dolomite: buff, finely crystalline
Salina	583–602	19	Dolomite: grey, finely crystalline; little grey shale; trace of gypsum
	602–669	67	Shale: red and greenish grey; trace of gypsum
	669–675	6	Dolomite: grey, finely crystalline
	675–693	18	Shale: greenish grey; little red shale and grey dolomite; trace of gypsum
	693–823	130	Dolomite: brownish grey and grey, finely crystalline; trace of gypsum
	823–869	46	Shale: greenish grey and red; little grey dolomite; trace of gypsum
	869–887	18	Dolomite: brownish grey, finely crystalline
	887–898	11	Shale, limy: greenish grey; little brown dolomite; trace of gypsum
	898–904	6	Dolomite: brownish grey; trace of gypsum
	904–909	5	Gypsum: trace of brown dolomite
	909–925	16	Dolomite: grey, finely crystalline, trace of gypsum
	925–931	6	Shale, limy: greenish grey; little gypsum
	931–971	40	Dolomite: brownish grey, finely crystalline; 10 per cent gypsum at 960 feet
	971–1,012	41	Dolomite: dark grey, finely crystalline; trace of pyrite at 989 feet
	1,012–1,034	22	Dolomite: brownish grey; some dark grey dolomitic shale
	1,034–1,041	7	Gypsum
	1,041–1,052	11	Dolomite: brownish grey, finely crystalline; trace of gypsum
	1,052–1,149	97	Limestone: dark brownish grey, bituminous, finely crystalline; trace of pyrite at 1,082, 1,098, and 1,126 feet; trace of gypsum at 1,072, 1,108, and 1,126 feet
	1,149–1,167	18	Dolomite: dark brownish grey, finely crystalline; trace of gypsum
	1,167–1,182	15	Dolomite: grey, finely crystalline; little gypsum
Guelph–Lockport	1,182–1,219	37	Dolomite: buff, finely granular; trace of selenite at 1,219 feet

Well: Dominion Natural Gas Co.—J. B. McKenzie No. 1 (*cont.*)

Formation	Depth (feet)	Thickness (feet)	Lithology
Guelph–Lockport (*cont.*)	1,219–1,265	46	Dolomite: buff, finely crystalline
	1,265–1,319	54	Limestone: light buff, finely crystalline; trace of pyrite at 1,280 to 1,292 feet
Cabot Head	1,319–1,324	5	Shale: red and green; little buff dolomite
	1,324–1,329	5	Shale: greenish grey
	1,329–1,337	8	Dolomite: grey, finely crystalline
	1,337–1,340	3	Shale: green and red; some grey dolomite
	1,340–1,343	3	Limestone: grey, finely crystalline
	1,343–1,356	13	Shale: greenish grey; little grey limestone; Bryozoa
Manitoulin	1,356–1,380	24	Limestone, dolomitic: grey, crystalline; little greenish grey shale
	1,380–1,409	29	Limestone, dolomitic: grey, crystalline
Queenston	1,409–1,555	146	Shale: red; little green shale throughout
	1,555–1,609	54	Shale: red; minor amount of green shale; trace of grey limestone throughout
	1,609–1,654	45	Shale: red; minor amount of green shale
Georgian Bay	1,654–1,725	71	Limestone: grey, crystalline; minor amount of greenish grey shale
	1,725–1,871	146	Shale: grey with green cast; little grey crystalline limestone throughout
	1,871–1,944	73	Shale: dark grey; trace of grey limestone
Whitby (upper member)	1,944–2,002	58	Shale: grey
	2,002–2,097	95	Shale: dark grey; trace of pyrite at 2,031 and 2,059 feet
	2,097–2,142	45	Shale: dark grey
Whitby (lower member)	2,142–2,169	27	Shale: black; little brownish grey limestone throughout
Simcoe Group	2,169–2,300	131	Limestone: brownish grey, finely crystalline
	2,300–2,324	24	Dolomite: grey, crystalline; trace of pyrite at 2,306 feet
	2,324–2,340	16	Limestone: brownish grey, finely crystalline; little grey limy shale
	2,340–2,372	32	Limestone: grey, finely crystalline; some grey and green limy shale
	2,372–2,458	86	Limestone: grey and brownish grey, finely crystalline; some grey shaly limestone
	2,458–2,534	76	Samples missing
	2,534–2,593	59	Limestone: grey, finely crystalline; some grey shaly limestone throughout
	2,593–2,657	64	Limestone: brownish grey, dense
	2,657–2,827	170	Limestone: dark brownish grey, finely crystalline and dense
Shadow Lake	2,827–2,833	6	Sandy limestone: grey; some green sandy shale; some sand grains
	2,833–2,843	10	Dolomite: light buff; some green shale with embedded sand

Well: Dominion Natural Gas Co.—J. B. McKenzie No. 1 (*cont.*)

Formation	Depth (feet)	Thickness (feet)	Lithology
Shadow Lake (*cont.*)	2,843–2,849	6	Shale: red and green; embedded and loose sand
Precambrian	2,849–2,855	6	Quartz, biotite, feldspar, and green shale.

Well: Union Gas Company of Canada Ltd.—J. Semple No. 1
Location: Lot 60, con. A, Kincardine tp., Bruce co.
Elevation: 596 feet
Year completed: 1941

Formation	Depth (feet)	Thickness (feet)	Lithology
	0–15	15	Samples missing
Detroit River	15–24	9	Dolomite: buff, finely crystalline, some black bituminous streaks
	24–38	14	Dolomitic limestone: buff and brownish grey, finely crystalline
	38–53	15	Limestone: brownish grey, finely crystalline; bituminous
	53–66	13	Limestone: brownish grey, finely crystalline; black bituminous streaks
	66–93	27	Limestone: brownish grey, finely crystalline
Bois Blanc	93–165	72	Dolomitic limestone: brown, finely crystalline; trace of chert throughout
	165–328	163	Dolomitic limestone: brownish grey, finely crystalline; minor amount of chert throughout
Bass Island	328–340	12	Dolomite: buff, finely crystalline; much pyrite
	340–386	46	Dolomite: brownish grey, finely crystalline
	386–453	67	Dolomite: light brown, finely crystalline; few quartz crystals at 418, 433, and 453 feet
	453–478	25	Dolomite: light brown, finely crystalline; trace grey shale at 473 feet
	478–490	12	Dolomite: dark brownish grey, finely crystalline
Salina	490–494	4	Dolomite: dark brownish grey; equal amount of dark grey shaly dolomite
	494–500	6	Dolomite, shaly: dark grey
	500–515	15	Dolomite: buff; minor amount of grey limy shale
	515–530	15	Dolomite, shaly: greenish grey and red; trace of gypsum
	530–535	5	Dolomite: buff; much green limy shale
	535–549	14	Shale: greenish grey and red; limy; trace of buff dolomite; trace of gypsum
	549–570	21	Dolomite, shaly: grey; trace of gypsum
	570–591	21	Dolomite, shaly: greenish grey; trace of buff dolomite; trace of gypsum

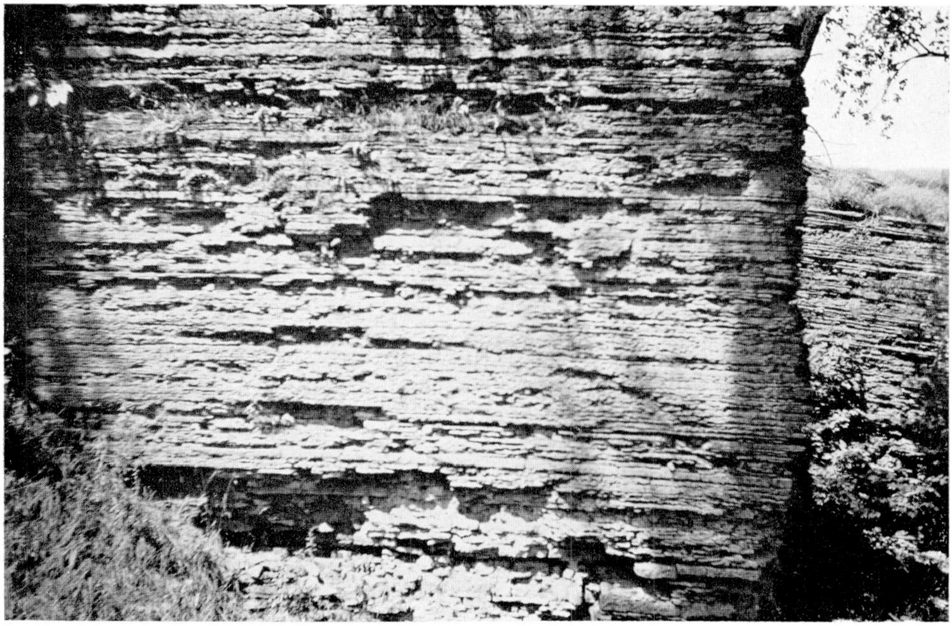
Well: Union Gas Company of Canada Ltd.—J. Semple No. 1 (*cont.*)

Formation	Depth (feet)	Thickness (feet)	Lithology
Salina (*cont.*)	591–595	4	Dolomite: brownish grey, finely crystalline; trace of gypsum
	595–614	19	Dolomite: grey, finely crystalline; trace of gypsum
	614–631	17	Dolomite: buff, finely crystalline
	631–683	52	Dolomite: buff and grey, finely crystalline; trace of gypsum in lower 10 feet
	683–730	47	Dolomite, shaly: grey; trace of gypsum
	730–736	6	Shale: reddish brown and green; little buff dolomite
	736–742	6	Dolomite, shaly: grey, little reddish brown shale; trace of gypsum
	742–751	9	Dolomite: brownish grey and grey; trace of gypsum
	751–760	9	Shale: limy, greenish grey; trace of gypsum
	760–778	18	Dolomite: brownish grey, finely crystalline; trace of gypsum
	778–790	12	Dolomite, shaly: greenish grey; little gypsum
	790–813	23	Dolomite: brownish grey, finely crystalline; trace of pyrite
	813–831	18	Dolomite, shaly: grey, finely crystalline
	831–836	5	Limestone: grey, crystalline; trace of pyrite
	836–842	6	Dolomite: brownish grey, finely crystalline; trace of gypsum
	842–848	6	Gypsum
	848–860	12	Dolomite: brownish grey, finely crystalline; trace of gypsum
Salina and/or Guelph–Lockport(?)	860–878	18	Dolomite: brown, finely crystalline to granular; much selenite at 878 feet
	878–901	23	Limestone: brownish grey, finely crystalline; trace of selenite in upper 10 feet
	901–924	23	Limestone: brown, finely crystalline, porous
	924–930	6	Unreliable sample
	930–981	51	Limestone: brownish grey, finely crystalline
	981–1,107	126	Limestone: light grey, finely crystalline
	1,107–1,204	97	Limestone: medium grey, finely crystalline
	1,204–1,366	162	Limestone: light grey, crystalline
	1,366–1,425	59	Limestone: light grey, finely crystalline
Guelph–Lockport	1,425–1,436	11	Limestone, dolomitic: grey, finely crystalline
	1,436–1,447	11	Limestone: grey, finely crystalline
	1,447–1,453	6	Dolomite: buff, finely crystalline
	1,453–1,470	17	Limestone: light buff, finely crystalline
	1,470–1,486	16	Dolomite: buff, finely crystalline, porous
	1,486–1,495	9	Limestone, dolomitic: brownish grey, finely crystalline
Cabot Head	1,495–1,501	6	Shale: green; trace of reddish brown shale
	1,501–1,522	21	Shale: red
	1,522–1,527	5	Shale: red and green
	1,527–1,562	35	Shale: greenish grey; minor amount of grey limestone
Manitoulin	1,562–1,579	17	Limestone: grey, crystalline; little greenish grey shale; Bryozoa

Well: Union Gas Company of Canada Ltd.—J. Semple No. 1 (*cont.*)

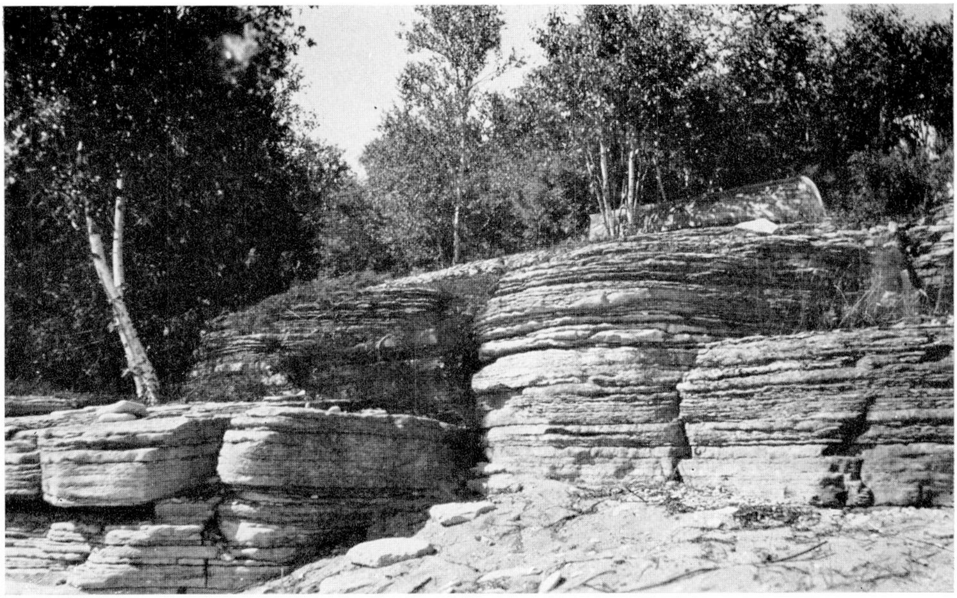
Formation	Depth (feet)	Thickness (feet)	Lithology
Manitoulin (*cont.*)	1,579–1,594	15	Limestone: grey to brownish grey, crystalline
Queenston	1,594–1,599	5	Shale: green; minor amount of red shale
	1,599–1,676	77	Shale: red; minor amount of green shale
	1,676–1,719	43	Shale: red; trace of green shale; trace of pink gypsum throughout
	1,719–1,725	6	Shale: greenish grey; trace of grey crystalline limestone; Bryozoa
	1,725–1,734	9	Shale: red; minor amount of green shale
	1,734–1,760	26	Shale: greenish grey; trace of grey limestone; Bryozoa, brachiopods
	1,760–1,800	40	Shale: greenish grey; trace grey limestone in most samples
	1,800–1,832	32	Shale: red; little greenish grey shale; trace of pink gypsum
Georgian Bay	1,832-1,880	48	Shale: grey with greenish cast; little grey crystalline limestone
	1,880–2,018	138	Shale: grey; little grey crystalline limestone in many samples; trace of pyrite at the base
Whitby (upper member)	2,018–2,202	184	Shale: dark grey; Bryozoa from 2,137 to 2,148 feet
	2,202–2,255	53	Shale: dark grey to black
Whitby (lower member)	2,255–2,261	6	Shale: dark grey to black; some grey limestone
	2,261–2,271	10	Limestone: brownish grey, finely crystalline; much black shale
Simcoe Group	2,271–2,282	11	Limestone: dark brownish grey, finely crystalline; little black shale
	2,282–2,351	69	Limestone: brownish grey, finely crystalline; fossiliferous
	2,351–2,388	37	Limestone: shaly, grey, crystalline
	2,388–2,432	44	Limestone: grey, crystalline; some greenish grey shale and grey shaly limestone
	2,432–2,488	56	Limestone: grey, crystalline; little grey shale in most samples
	2,488–2,504	16	Limestone: brownish grey, finely crystalline; some grey shaly limestone
	2,504–2,629	125	Limestone: grey, crystalline; little grey shaly limestone and limy shale in most samples
	2,629–2,664	35	Limestone: brownish grey, finely crystalline; trace of "bentonite"? at 2,649 feet
	2,664–2,669	5	Limestone: light buff, dense; trace pyrite; trace of metabentonite
	2,669–2,713	44	Limestone: dark brownish grey, dense
	2,713–2,725	12	Limestone: brownish grey, finely crystalline; some oölitic limestone
	2,725–2,763	38	Limestone: brownish grey, finely crystalline
	2,763–2,794	31	Limestone: dark brownish grey, finely crystalline to dense
	2,794–2,809	15	Limestone: buff, finely crystalline
	2,809–2,829	20	Limestone: brownish grey, finely crystalline
	2,829–2,841	12	Dolomitic limestone: buff, finely crystalline

Formation	Depth (feet)	Thickness (feet)	Lithology
Simcoe Group (*cont.*)	2,841–2,867	26	Limestone: dark brownish grey, finely crystalline; trace of pyrite
	2,867–2,872	5	Limestone: brownish grey; trace of green shale with embedded sand grains; trace of pyrite
	2,872–2,880	8	Limestone: grey, much light grey calcareous sandstone and free sand; trace of pyrite
	2,880–2,885	5	Shale: limy, dark grey; much light grey calcareous sandstone
	2,885–2,898	13	Dolomite: light grey, crystalline; little sand; trace pyrite
	2,898–2,916	18	Dolomite: light grey, crystalline; trace of pyrite
	2,916–2,921	5	Shale: dark grey; much grey dolomite
	2,921–2,923	2	Limestone: light grey, crystalline; trace glauconite



TEB, 1–5–50

PLATE II A. Manitoulin Formation, escarpment section east side of road 1.6 miles south of Kemble.



TEB, 4–2–50

PLATE II B. Dyer Bay member, Cabot Head Formation, shore section a mile north of village of Dyer Bay.

B. A. Liberty

PLATE III A. Member 2, Lockport Formation (Fossil Hill Formation), $2\frac{1}{2}$ miles north of village of Lions Head on Isthmus Bay.

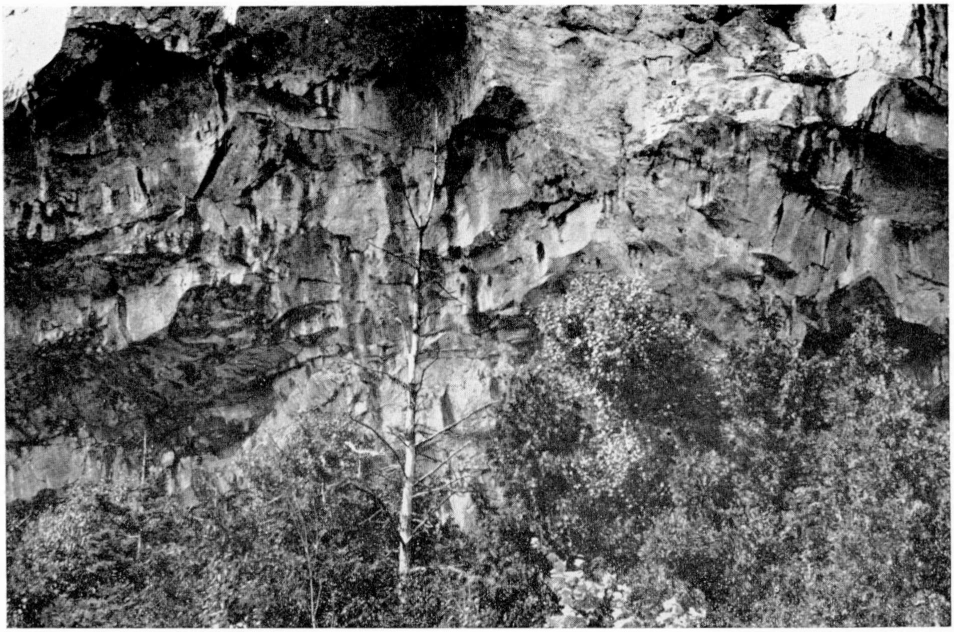


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PLATE III B. Member 3b, Lockport Formation (Amabel Formation), half a mile north of village of Dyer Bay.

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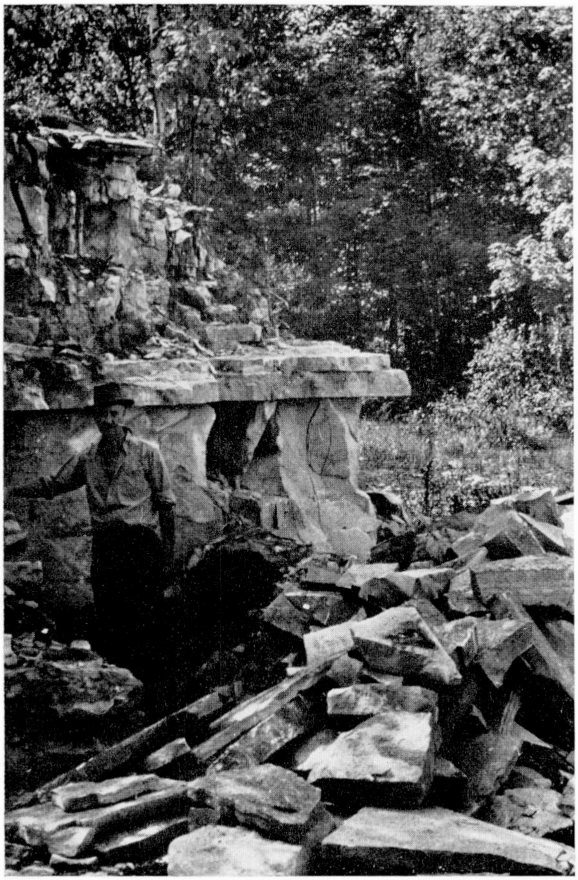
PLATE IV A. Member 3c, Lockport Formation (Eramosa Member, Amabel Formation), Cook quarry 2 miles west of Wiarton.

87671

PLATE IV B. Glacial grooving on Guelph Formation, Berford Lake, 4½ miles northwest of Wiarton.



B. A. Liberty

PLATE V A

Guelph Formation, massive basal beds, quarry east side of Brinkman Corners road, $\frac{7}{8}$ mile northwest of church, village of Cape Chin.

BAL, 2-3-65

PLATE V B. Guelph Formation showing reef-interreef relationship, Halfway Rock Point 7 miles east of Tobermory, north shore Bruce Peninsula.

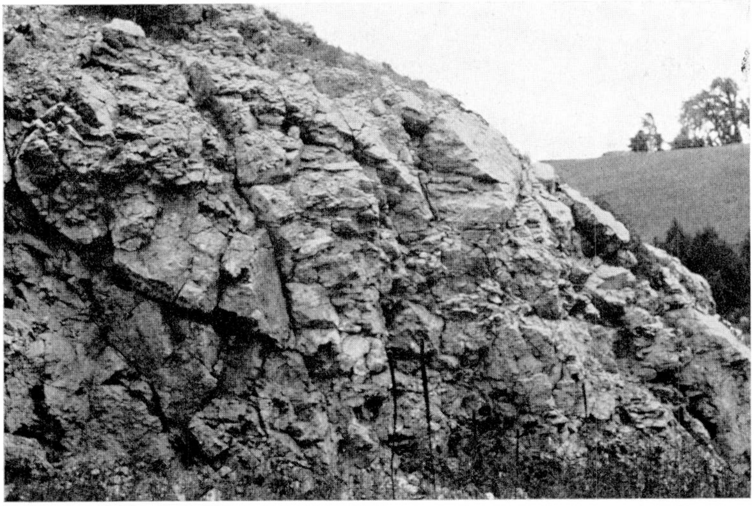
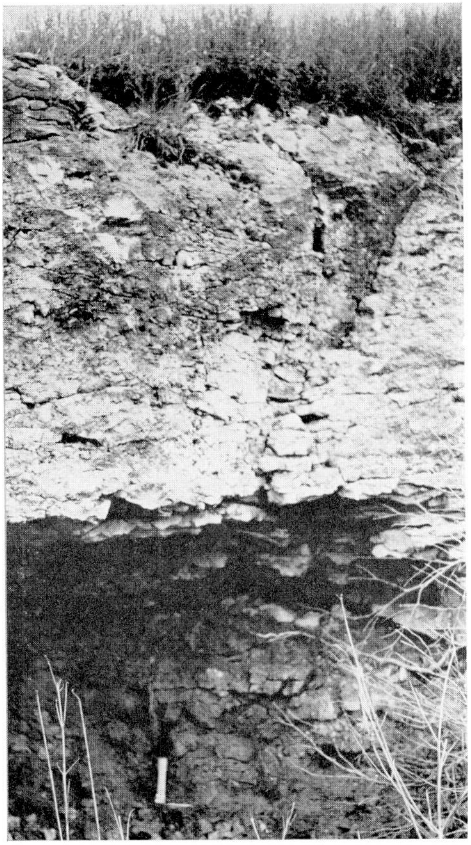


PLATE VI A

Bioherm (B facies) within Detroit River Formation, roadcut $2\frac{1}{2}$ miles north of Formosa.

B. A. Liberty



87661

PLATE VI B. N facies overlain by bioherm (B facies) within Detroit River Formation, same locality as A.

EWB, 1953

PLATE VI C. Bioherm (B facies) limestone showing abundant laminar type Stromatoporoidea, same locality as A.

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