HYDROCARBON CONTENT
of the
MANITOULIN DOLOMITE
on
MANITOULIN ISLAND

by

JOHN A. CAMERON

A Thesis
Submitted to the Department of Geology
in Partial Fulfilment of the Requirements
for the Degree
Bachelor of Science

McMaster University
May 1975

TABLE OF CONTENTS

ABSTRACT

The Manitoulin Formation on Manitoulin Island consists of a lower biostrome extending across the island and an upper biohermal accumulation just south of Manitowaning.

Viscible hydrocarbon accumulations occur in the bioherm, mostly contained in the more porous framework corals Paleofavosites and Palaeophyllum. Hydrocarbons found in other sample sites across the island show a very low bulk weight per cent and are of no economic significance.

The bulk of the hydrocarbon was likely formed in lower carbonates near the centre of the Michigan Basin. Petroleum is also thought to have been introduced with solutions which formed calcite deposits.

ACKNOWLEDGEMENTS

Financial assistance for this thesis was provided in the form of a grant by the Ontario Petroleum Institute. Consumers Gas Company was responsible for the funding of several field trips to Manitoulin Island.

Core Laboratories in Calgary was very helpful in analysing the Manitoulin Dolomites for their hydrocarbon content.

Sincere gratitude is due to Dr. Michael J. Risk, who suggested the topic and supervised the project. Without his guidance, the completion of the thesis would have been impossible.

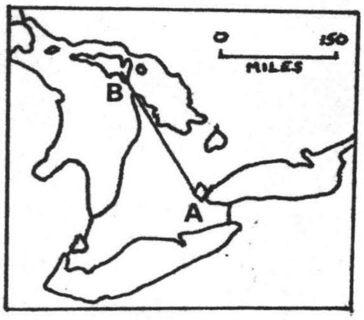
Many thanks to my fiancé Allison Holmes, for her encouragement in times of despair and who gave freely of her time in typing this manuscript.

INTRODUCTION

The Manitoulin Formation on Manitoulin Island is a member of the Lower Silurian Cataract Group (Bolton, 1953). Lower Silurian carbonate deposition in North America represents sedimentation in shallow, warm, marine waters. Thick uniform platform rocks also indicate rapid subsidence. The sediment source was the newly formed Taconic Mountains and the Adirondack Dome in the east, and the Canadian Shield in the north-west. A lateral facies shift can be traced from the pure Whirlpool sandstones in the east to the even-bedded dolomites on Manitoulin Island. Overlying the Manitoulin dolomites is the Cabot Head, the marine equivalent of the Grimsby Shales (Figure 1) indicating a transgressive sequence.

The term Manitoulin Formation was first proposed by Williams in 1913 for the 44 foot thickness of calcareous rock on Manitoulin Island. The fresh colour of these dolomites is usually a grey to bluish grey, weathering to a typical buff colour. They are fine grained with partings of a bluish shale.

Faunal diversity and density increase from the base of the Manitoulin Formation to the top, where a series of pinnacle reefs reach up another twenty feet. These reefs are highly fossiliferous. Siliceous or dolomitic replacement of fossils is common, but no group of organisms seems to be preferentially



Correlation of the Manitoulin Formation

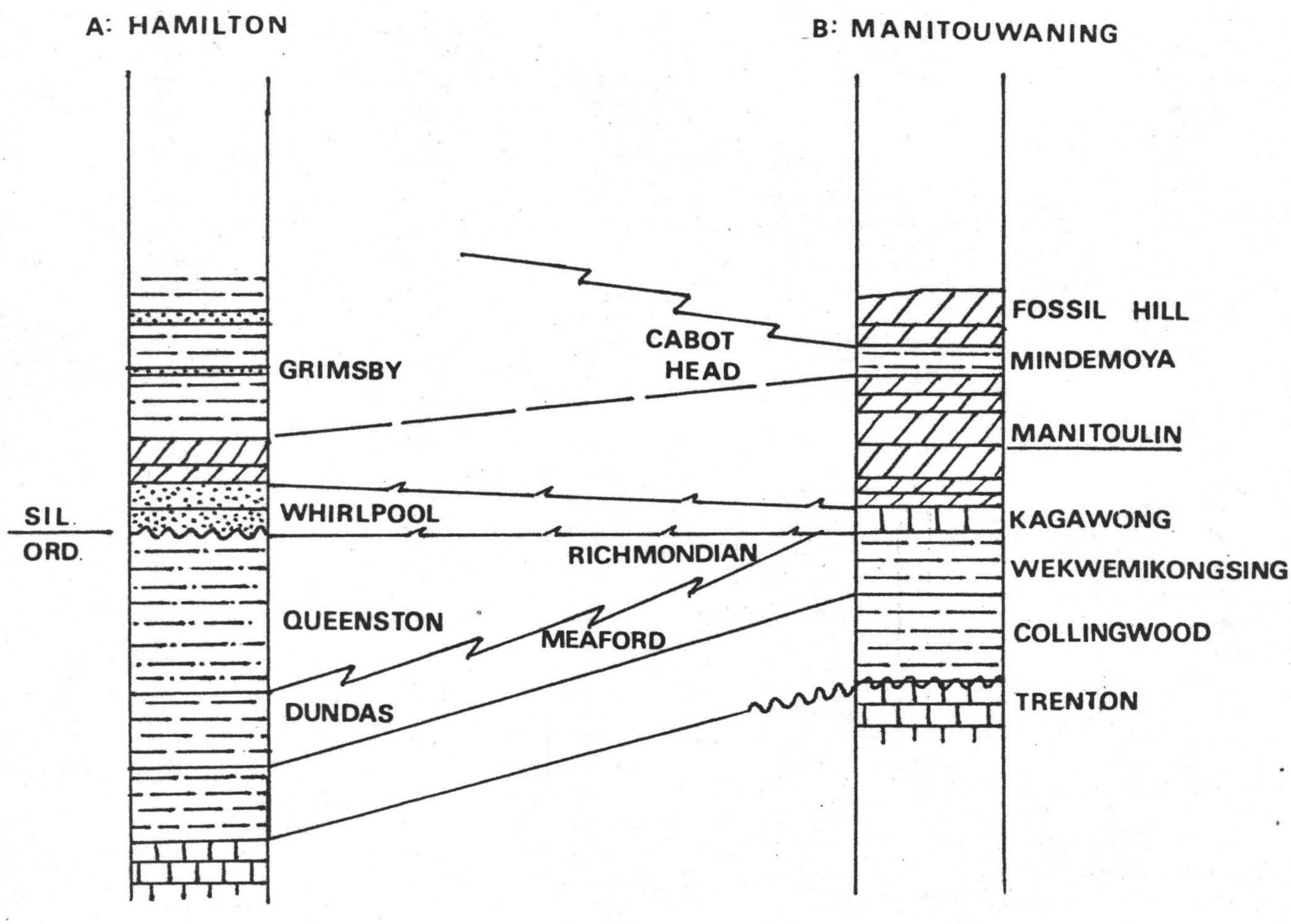
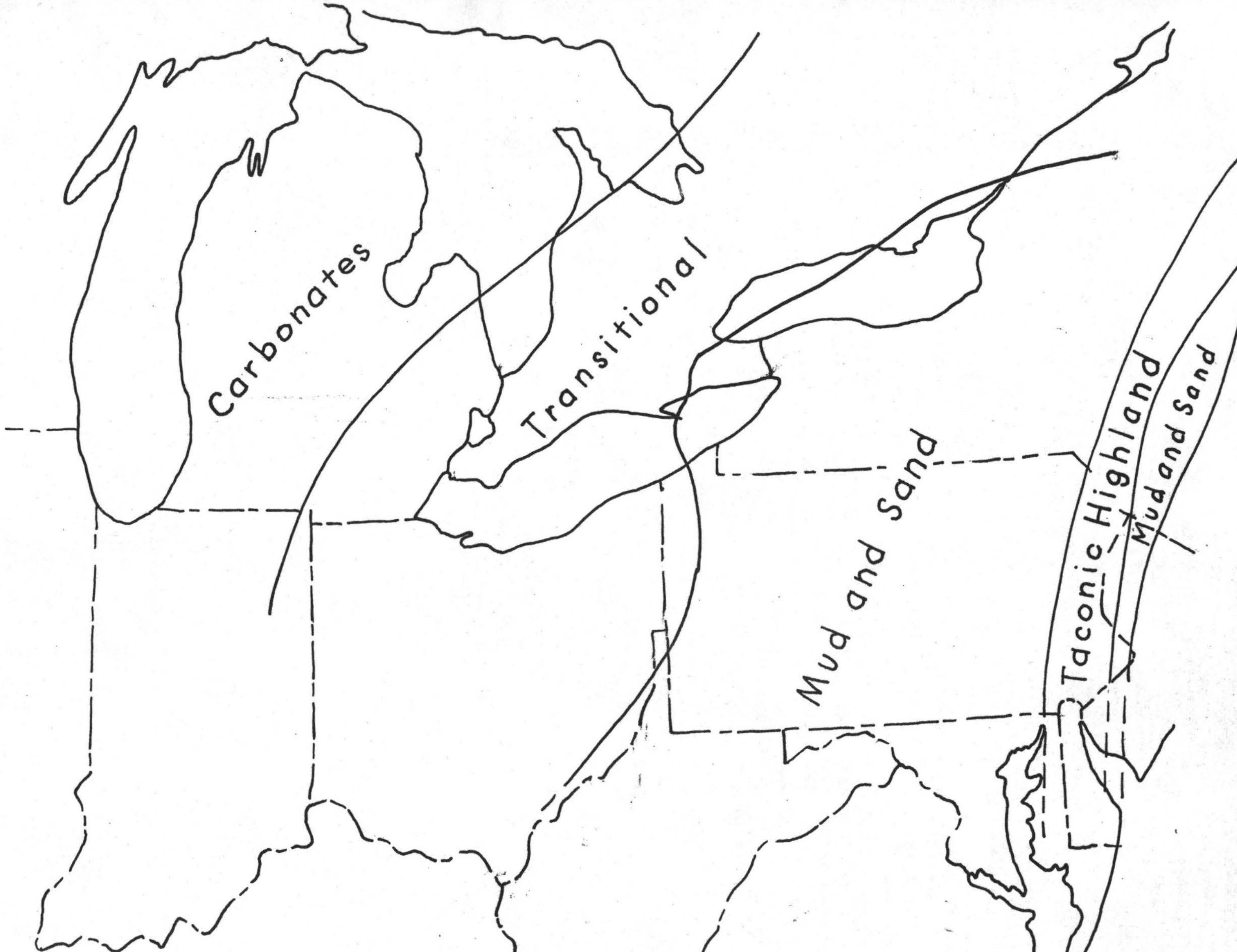


FIG. 1

MAP 1



Depositional facies of Lower Silurian, subsequent to the Taconic Orogeny replaced. Hydrocarbons are most noticeable in this upper reef complex.

OBJECTIVES

The original objective was an intensive study of the pinnacle reef complex south of Manitowaning. Field observations prompted an expansion, to include the geology of the Manitoulin Formation on the whole island in order to further decipher its relation to the Michigan Basin.

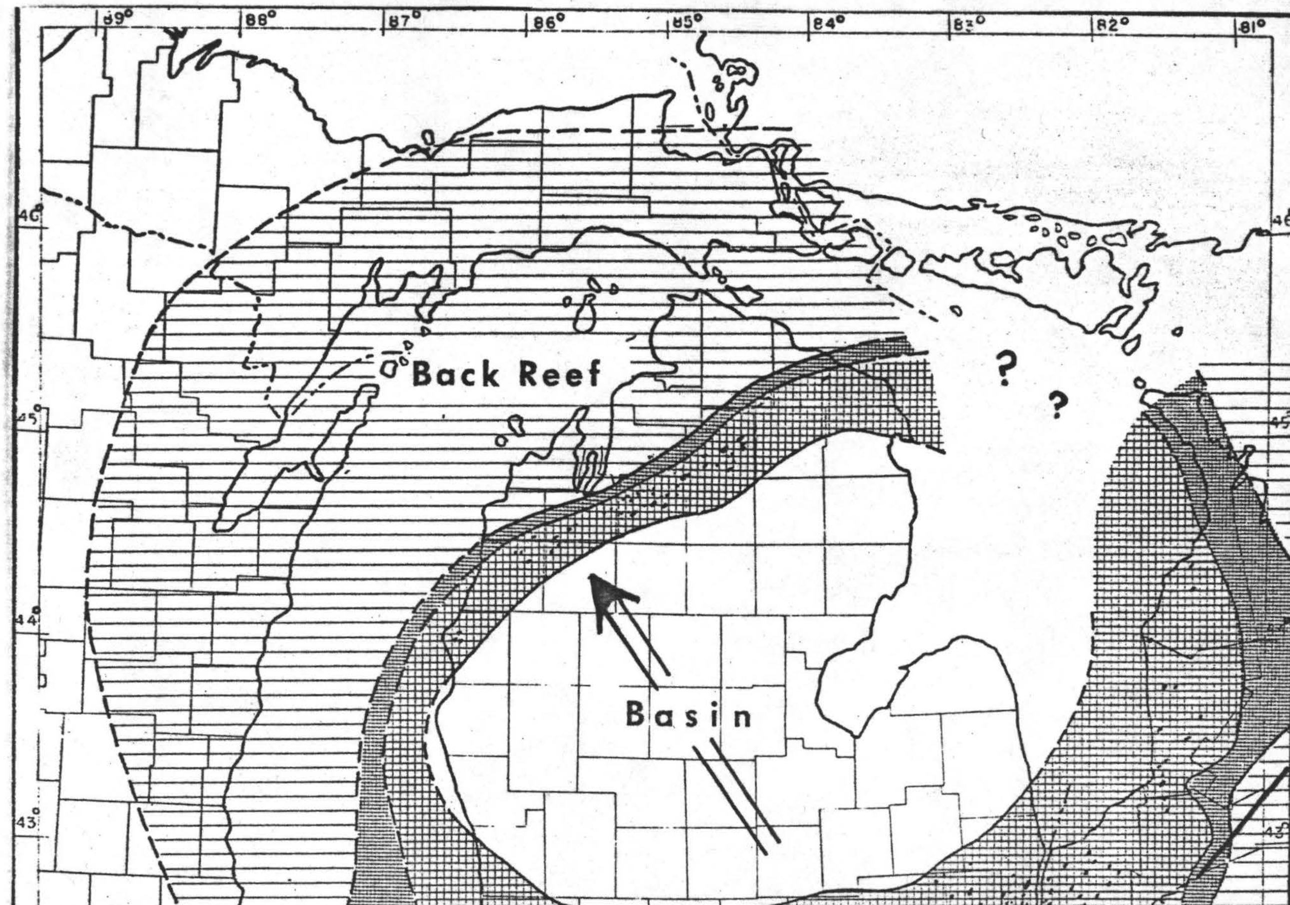
An effort to correlate structural and paleontological data has been made to explain the presence of hydrocarbons in this formation.

REGIONAL GEOLOGY

Mid-Silurian hydrocarbon-bearing reefs have been known in the south-east Michigan Basin for many years. These pinnacle reefs have been successfully drilled for oil. In 1969 a similar series of reefs was found trending in a north-east direction across the northern tip of Michigan. This lead to the belief that a rim of carbonates made up of barrier and patch reefs extended around the entire Michigan Basisn. Cores taken across northern Michigan indicate that there are three general categories of reef complexes: 1) non-reef; 2) barrier reef; and 3) pinnacle reefs (Mesolella et al, pg. 39). The reef bank and back reef deposits comprise the carbonate bank environments, the pinnacle reefs are located along the shelf zone and the basin environments are the deeper water areas. Barrier and pinnacle reefs are separated by inter-reef deposits of dense argillaceous, micritic dolomite. The barrier reef is a massive stromatoperoid coral facies which represents the environment of highest energy. Pinnacle reef complexes are dominated by framework corals.

On Manitoulin Island, the Manitoulin Formation can be divided into a lower massive carbonate biostrome and an upper biohermal development which appears just south of Manitowaning. The evidence in this study suggests that this bioherm represents the northern limit of reef bank development in the Michigan Basin. If this be the case, then it would indicate that pinnacle reefs were fully developed during the early Silurian.

The carbonate banks west of Manitowaning represent the building of a stromatoporoid reef that extends the full breadth of the island.


Back Reef
Basin
Shelf
Reef Bank
Basin
Basin
?
?
?
NIAGARA
SALINA
ENVIRONMENTS

MAP 2

AREA OF STUDY

The Manitoulin Formation outcrops the whole sixty-four mile length of Manitoulin Island. The strata dip slightly to the south-west toward the centre of the Michigan Basin at 5^0 to 15^0 (Liberty and Bolton, 1956) The thickness of the formation varies between 20 feet and 30 feet reaching its maximum development of 50 feet at the Manitowaning bioherm. Although the beds are relatively undeformed, a fault was observed in the main bioherm south of Manitowaning. The strike of this fault is almost due north and is slightly concave upwards. Close examination showed that none of the abundant fauna had been intersected by this fault.

Topography of the island has been greatly modified by Pleistocene glaciation. Ice-gouged striae are seen on many rock surfaces, The Manitoulin dolomites are more resistant than the conformable overlying and underlying beds and form prominant scarp features. The Manitowaning bioherm stands out as a long low hill. No inferences about the original shape can be made because the extent of erosion is not known.

METHODS OF STUDY

Three field trips were made to Manitoulin Island. The first, late in September 1974, was a preliminary reconnaissance.

PHOTO I

Site 3 - Shows the resistance of the Manitoulin Formation to glaciation by standing 35 feet above the landscape

The next was made in late October, 1974, for the purpose of taking exact measurements of faunal distributions in the bioherm and to collect samples at various sites across the island for hydrocarbon analysis. In the bioherm, the diameter of the five largest corals (of Paleofavosites and Paleophyllum) were taken at 10 foot intervals to see if there was a size distribution. Faunal distribution was also recorded. Samples were also taken every 10 feet for hydrocarbon content and porosity studies. Many samples were collected in the vicinity of the bioherm in an attempt to determine its extent.

The final trip was made in April 1975, to photograph several of the outstanding features and to review the collection sites.

PREVIOUS WORK

As early as 1821, Bigsby (Caley, 1940) classified the rocks of Manitoulin Island as the "limestones of the Manitoulin Range." In 1852 the Silurian strata were divided into the Clinton, Niagara and Onondaga Salt groups. Schuchert (1913) suggested the term Cataract to apply to the sediments between the Ordivician Queenston and the Lower Silurian Grimsby. The Whirlpool, Manitoulin and Cabot Head were considered by Johnson (1934) to be members of the Cataract. Bolton (1953) raised the Cataract to group status by including the Whirlpool, Manitoulin, Cabot Head and Grimsby formations. The Grimsby formation is not seen in the section on Manitoulin Island.

As a result of Ellers (1944) comparison of distribution and environment of modern polycheats to conodont fragments, the Manitoulin sea is thought to have been a shallow, warm, well aerated body of water with a relatively low salinity. B.A. Liberty published the Geologic Survey of Canada Maps of Manitoulin Island from 1954 to 1957. Recent work by Bolton and Liberty (1971) has acknowledged or accepted the principle of a rim of reef structures in the Lower Silurian but warns "... the basin is not merely indicative of a perimeter ring only. Too much is left unexplained."

PETROGRAPHY

a) Acetate Peels

A series of acetate peels was made from sections measured every 10 feet across the bioherm. The samples were first cut and then carefully polished by hand. The polished surface of each section was dipped into 4% hydrochloric acid for thirty to forty seconds. When removed, the surface was washed in distilled water and sprinkled with acetone to allow it to dry faster. The section was then placed on a lump of plasticene to secure it. A section of acetate was then cut slightly larger than the polished surface. The etched surface was again covered in acetone and the acetate was carefully placed on the wet surface. The sections were allowed to dry for twenty-four hours. When removed, they were placed between two glass plates, heated to 85^{0}C and allowed to cool.

From the study of the peels, it was possible to identify several major taxa and discern many of the internal features. Hydrocarbon stains were left on the acetate when it was separated from the rock. It became obvious that most of the petroleum was to be found in the more porous framework corals. Petroleum concentration was also found along the boundaries where reworking of carbonate sediments had taken place. From a complete examination of the peels, it appeared that hydrocarbons were concentrated towards the centre of the bioherm and were scarce at either end.

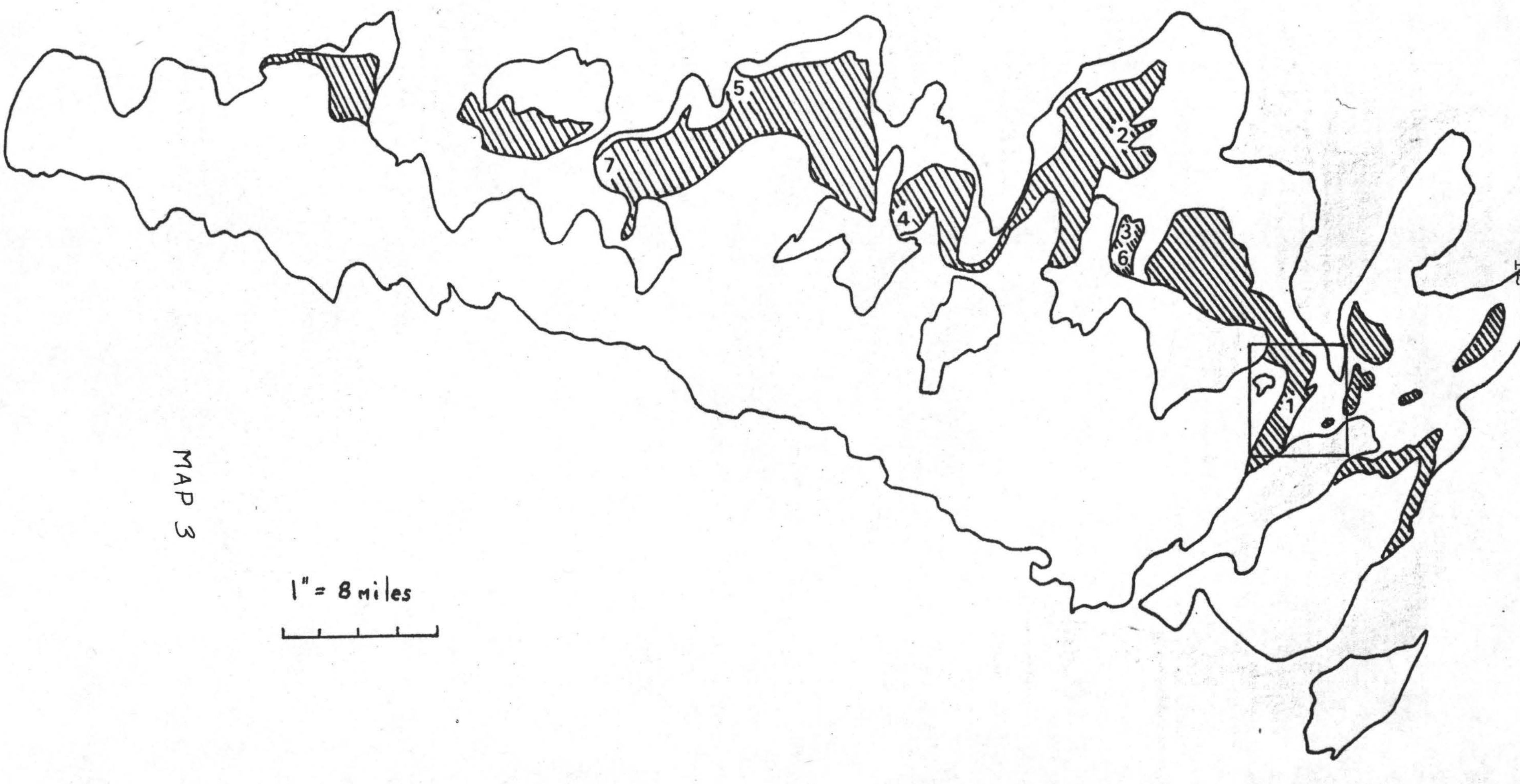
The acetate peels were of limited use in petrographic studies and were used mainly for more generalized observations.

b) Thin Sections

Twelve thin sections were cut from samples collected across the island. (See Map 3)

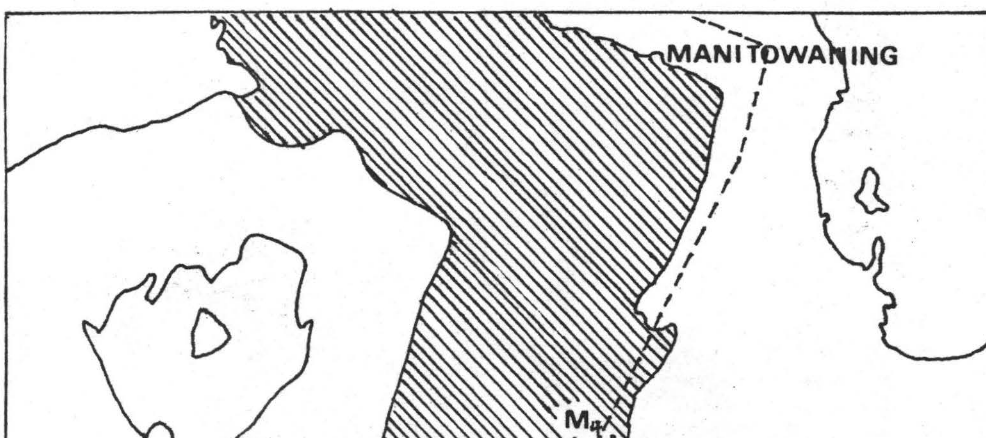
MANITOULIN ISLAND

SAMPLE SITES



MAP 3

BIOHERM REGION



MAP 4

i) Dolomite

Analysis of the thin sections revealed that over 80% of the Manitoulin Formation is dolomite. It consists of masses of closely packed cryptocrystalline grains. The relative size of the individual grains was fairly constant across the island. Variations in grain size do occur in the replacement of the shells of organisms. In comparing a dolomitized stromatoporoid with the surrounding sediment, the stromatoporoid was much finer grained. (.2mm vs .5mm) Similarly, in other fauna where the shell had been replaced, the grains were much finer.

Several theories exist for the origin of dolomites. These are summarized in Bathurst (1971) and Blatt, Middleton and Murray (1972). Modern theories have tried to explain the growth of dolomites by 1) primary precipitates, 2) penecontemporaneous alteration products, and 3) late diagenetic products.

Laboratory tests have shown that it is difficult or nearly impossible to synthesize dolomite at low temperatures. Sea water is saturated with respect to dolomite. Recent studies show that dolomite is presently forming on Deep Springs Lake in California (Paterson et al, 1966). Sophisticated geochemical techniques have measured the growth rates as ranging from 0.05 to 0.09 per thousand years. It is generally accepted that crystallization of highly ordered structures at low temperatures must occur very slowly.

PHOTO 2

Highly bioturbated sediments:
Stromatolite mats.

PHOTO 3

Site 2 - Thin flat-lying
dolomites.

PHOTO 4

Fore-slope sediments: There
is a distinct lack of fauna
and the layers are thick
and even.

When competing in a calcium saturated solution, dolomitization is prevented.

The theory that dolomite had its origin in the alteration of limestone has been held by geologists for many years. Dana (1843) was the first to suggest that the magnesium necessary for the alteration of $CaCO_3$ was supplied directly by the sea. It is necessary that an excess of magnesium with respect to calcium be present in the water. This is done by removing calcium ions from solution, for example precipitated as gypsum. It should also be noted that the dolomitization of limestones is accompanied by a 13% reduction in the volume of the rock. Because of this, permeability and porosity are enhanced. This makes it extremely accessable to hydrocarbons. Fifty percent of the worlds petroleum resources are found in dolomites. (Levorsen, 1958)

Adams and Rhodes (1960) and later, Deffeyes (1965) postulated a reverse process of dolomitization which they called "seepage refluction". The hypersaline reflux mechanism combines a source of high force to move the water through the sediments. Evaporation of lagoonal waters is sufficient to supersaturate the water. With precipitation of gypsum, the Mg:Ca ratio increases, raising the density of the water. This denser water sinks to the lower lake levels. Deffeyes (1965) calculated that a Mg:Ca ratio of about 30:1 would be sufficient to carry these dense waters seaward, dolomitizing the sediments through which it passes.

On Bonaire, Netherlands Antilles, secondary replacement of limestones are thought to be forming dolomites by the downward flow of hypersaline waters.

Hsu and Siegenthaler (1969) proposed an alternative method of dolomitization called "Evaporative Pumping". Experimenting with saline interstitial waters under an arid coastal plain, they were albe to show that "fluid flow through a porous medium could be induced by an upward decrease in hydrodynamic potential during evaporation." (Hsu and Siegenthaler, 1969) They showed that movement of salt water under an arid coastal plain could be caused by evaporation and evaporative loss could be replaced by seepage flow from the sea. They also showed that the rate of flow is not governed by the permeability of the medium, but rather by the rates of evaporation. The Persian Gulf provides a good example of dolomitization by evaporative pumping in an arid area. Salt flats surrounding the lagoon are permeated and occasionally flooded by the hypersaline water. Surface evaporation concentrated the pore fluids to a highly saline brine from which gypsum is precipitated. The resulting magnesium-rich liquid dolomitizes the aragonite sediments.

In the discussion of the formation of dolomite it is apparent that there are several main requirements for the alteration of limestones. For both the 'Reflux' model and the 'Evaporative pumping' theory, it was necessary to maintain; 1) a high Mg:Ca ratio, 2) a high activity of magnesium ions compared to calcium ions, and 3) a driving force that continually flushes the dolomitizing fluids through the rock fast enough to allow the reaction to occur.

The Manitoulin Formation was originally deposited as limestones composed of calcium carbonate shells of marine organisms. It may be that one of the above alteration mechanisms applies to the formation of the Manitoulin dolomites.

ii) Calcite

Calcite is found mainly in the voids of the larger organisms on the reef. Dog-tooth calcite may be found lining the cavities, or complete infilling may have occurred. In thin section these large, coarse euhedral crystals are easily identified by their well developed lamellae. It is thought that possibly the dolomite has been replaced by the calcite. High Ca:Mg ratios generated by meteoric waters may have caused the reverse of the dolomitization process (Blatt et al, 1972) Oxidized pyrite is often found in association with the calcite.

iii) Silica

Although many of the organisms of the bioherm have undergone replacement by dolomite, it was observed on the western section of the island that many of the larger corals and marine organisms had been completely infilled by silica.

Examination of the thin sections showed that the silica in-fillings were of interstitial quartz or chalcedony. The outer periphery was lined with chalcedony, while the central portions of the voids were filled with coarser interstitial quartz.

As fresh water may contain ten times as much silica as marine water, this increase may represent a fresh water influx from the west. An alternate source of the silica may be siliceous shallow water organisms such as sponges and diatoms.

Several small grains of detrital quartz were also found. These well rounded grains indicate long transport. Much of the silica has been corroded, probably by the dolomitizing fluids, resulting in uneven crystal outlines. In some cases, there has been even more complete replacement and large dolomite rhombs can be found completely embedded in the quartz. These larger rhombs often replace cryptocrystalline dolomite.

PALEONTOLOGY

The Manitoulin dolomites represent a reef complex that was deposited during the final stages of a transgressive Silurian sea. The total picture of reef development cannot be seen on Manitoulin Island because these reefs reflect only the immature stages of the great Niagaran and Salina complexes.

PHOTO 5

View of the pinnacle reef
in the Manitoulin Formation

PHOTO 6

Minor Fault in the Manitowaning
bioherm.

a) Basinal Sediments

The basinal sediments are represented by section M-3. The section is composed mostly of fine grained dolostones. These carbonates are massive and there is a distinct lack of faunal incidence. One large tabulate coral was found, but it was overturned and presumably it had tumbled off the fore-reef slope and was deposited in the deeper water sediments.

b) Pinnacle Reefs

Gill and Briggs (1970) in studies of Mid-Silurian reefs have recognized three major growth phases within pinnacle reefs; 1) biohermal, 2) organic reef, and 3) supratidal cover complex. Two ecological zones in the Manitowaning bioherm may be easily recognized. The lower biohermal core is thought to be an interfingering of the organic reef and the supratidal cover complex reflecting the raising and lowering of the Lower Silurian sea levels. (Diagram 2)

The lower bioherm core has been built by the combination of the framework coral Paleofavosites and tabulate stromatoporoids.

The tabulate corals have not been preserved in their growth positions. The majority have realigned themselves in an east-west orientation. There were no major size variations across the bioherm, the average size of the tabulate corals being 6.0 inches. The size was measured at the largest visible diameter and the five largest corals were measured every ten feet.

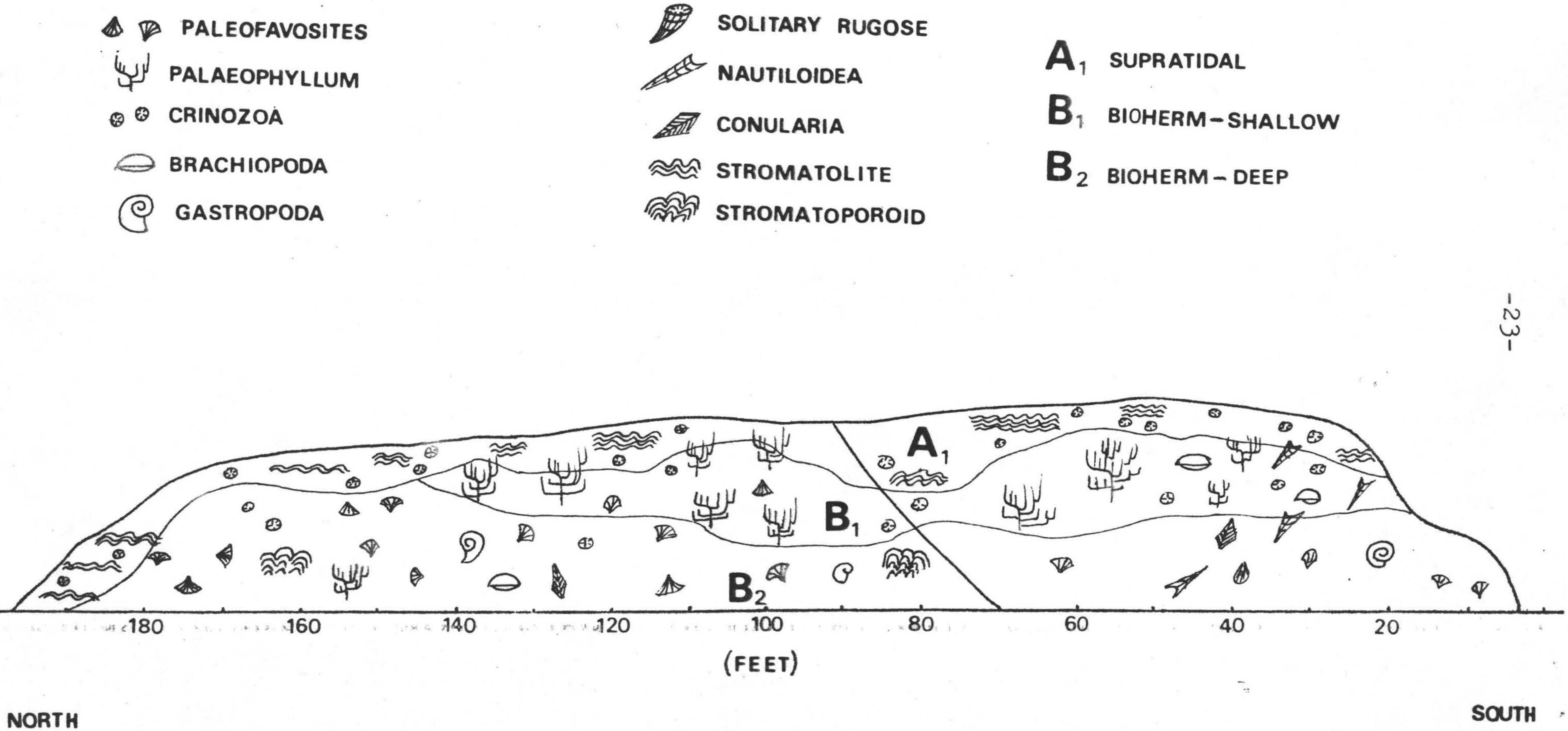
Paleofavosites were found to incorporate micritic mud, shell, and organic debris into its framework. This periodic dumping of organic debris has caused distortion of the corallites, resulting in crowded septa and in some cases, stopping vertical growth.

Tabular stromatoporoids are present as wrinkled, convoluted structures which also show the effects of sedimentation. Crinoidal debris has often caused the interruption of growth of the stromatoporoid, and debris is found wedged in cracks within the stromatoporoid.

In the lower biohermal layer, other fauna also existed as an intimate part of the reef community. The rugose corals *Enterolasms*, *Streptelasma*, and *Palaeophyllum* also made a major contribution to the buildup of this bioherm.

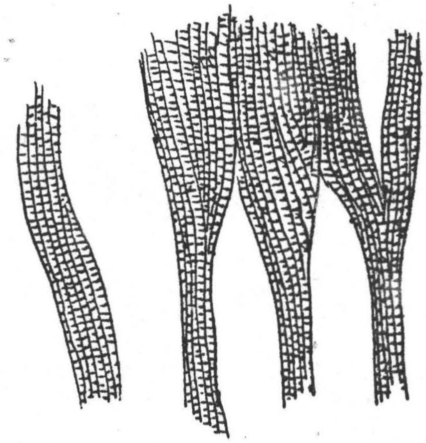
In between the larger dominant corals, other organisms survived and were protected from the waves. Samples of the conulariid *Eoconularia* were extremely well preserved, and were found in abundance. Populations of gastropods and brachiopods also survived here but they were found to be poorly preserved. It is likely that their shells were fragmented, which provided a cementing material to bind the reef together. In green shaley layers on the reef front, bryozoans (*Fenestrallina*, *Helopora*, and *Pachydictya*) and brachiopods (*Strophomena*, *Rhynchonella*, and *Leptaena*) and

MANITOWANING BIOHERM

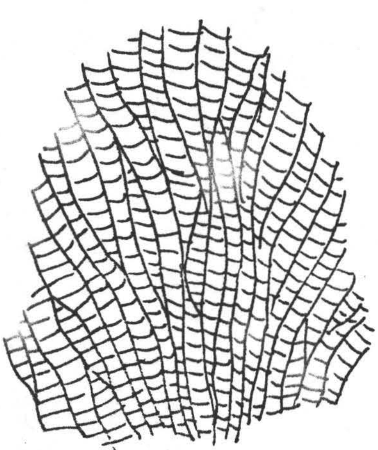


DIAG. 2

PALAEOPHYLLUM

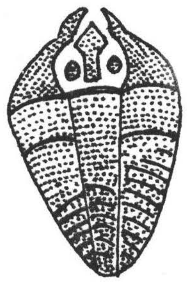


PALEOFAVOSITES

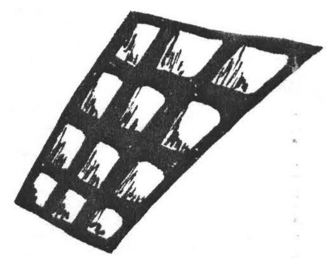


DIAG. 3

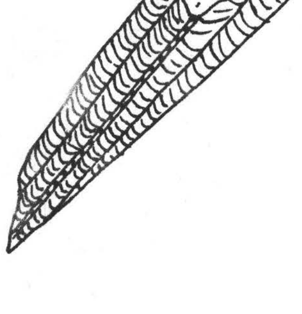
CALYMENE NIAGARENSIS



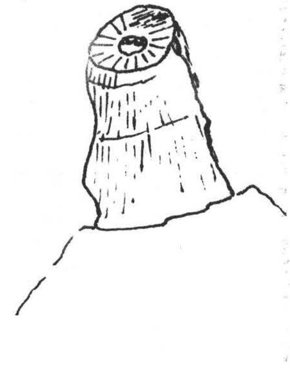
CLATHROPORA



EOCONULARIA



ENTEROLASMA



DIAG. 4

even the predatory trilobite Calymene niagarensis were found to be extremely well preserved. Within the reef structure itself, dolomitization has prevented the recognition of many of these invertebrate organisms. The rugose coral Palaeophyllum seems to have gradually replaced the tabulate coral Paleofavosites, in its role as a framework builder, towards the top of the section. The presence of this coral will be used to define Gill and Briggs' organic reef. Also associated with this section are the massive stromatoporoids found in the lower bioherm core. The structures are bound by crinoidal fragments and other skeletal debris. Much of this fine mudstone has been burrowed and bioturbated.

The upper supratidal cover complex, is as might be expected, characterized by an abundance of stratified algal stromatolites. Crinoidal debris is also abundant here. No intact 'lillies' were found, so differentiation between Crinoidea and Cystoidea was impossible.

c) Interreef Area

Shaver (1974) and Wilson(1974) have both described the presence of an interreef region which is intermediate between the organic reef buildups and the carbonate platforms. The interreef materials have a wide variety of textures which range from mudstones to grainstones. Most debris is biogenic and results from the breakdown of organisms growing on top of the pinnacle reefs. At section six, there were three distinct layers. (PHOTO 2 ~~Diagram~~) The upper layer consisted of wavy stromatoporoid layers and the coral Paleofavosites was found randomly overturned. Below this no stromatoporoids could be found; only crinoid debris mixed with micrite. Again, small overturned corals occurred. The lower layer consisted of only crinoid debris and micrite. It is suggested that the lower two layers may be the interreef sediments and the platform stromatoporoids overlie them.

d) Carbonate Platform

The carbonate platform sediments consist of extensive flat lying stromatoporoid beds. They are thick and uniform. The shallow area of deposition has allowed finely crystalline micritic dolomites to be mixed with the stromatoporoids. In areas, the beds have been highly bioturbated. Bioturbation has produced a mottled texture where stromatoporoids have completely slumped. The large tabulate Paleofavosites is often overturned. Heavy storms may have washed in the corals and deposited them in random positions. At other sites farther north, large populations of brachiopods have been discovered. (Liberty and Bolton, 1957)

A microfossil breakdown revealed the presence of siliceous sponge spicules, along with Bryozoa, Brachiopoda, and Annelida fragments. It is known that organisms of the above phyla live in warm, shallow sea environments. A calm water environment was also needed by these phyla, as agitated sands and muds tend to clog up their filters. (See Appendix I for Complete list of Fossils)

PALEOENVIRONMENT

Lithologic, paleontologic and structural evidence define the lithofacies and biofacies in the Manitoulin Formation.

The large carbonate platform represents rapid carbonate accumulation on a shallow tidal flat. This passes laterally into a high energy marine environment and finally drops off into a quiet open shelf. The faunal changes across these facies reflect variations in nutrients, turbidity and salinity, which are controlled by the water energy and water circulation (Laporte, 1969). Faunal zonation within the Manitowaning bioherm reflects the lateral facies changes. The structure probably reached a maximum height of twenty-five feet, growing in relative turbulent water. The colonial coral Paleofavosites which formed the central bioherm core, grew in slightly deeper water and Paleophyllum in shallower areas. Crinoid debris forced the corals to grow rapidly upward to maintain the polyps above the fast accumulating sediment. The carbonate accumulation may have exceeded the rate of subsisdence which caused a local regression. The reef growth stopped as the result of this shallowing, which eventually led to the deposition of the supratidal complex. The association of marine sediments and shallow water stromatoporoids on the carbonate platform and in the bioherm, show that there was a periodic shifting of the relative sea levels.

HYDROCARBONS

a) INTRODUCTION

Most petroleum is found in marine rocks. There are many biological and geological factors which control the amount of oil and gas that can be formed and subsequently trapped in sedimentary rocks.

The wealth of phytoplankton in marine basins governs the amount of hydrocarbons released to the sediments after deposition. With the high abundance of floating plants and organisms in modern tropical marine environments, it is assumed that the reef complex of the Manitoulin Formation was also rich in phytoplankton. When the organisms die, their soft bodies decay, releasing organic carbon chains to the sediments. The organic material is then captured and preserved in the rapidly accumulating carbonate sediments.

During diagenesis, the hydrocarbons are squeezed into voids or pores within the rock. These may simply be intergranular spaces left after compaction of sediments, or pores within and between fossil shells. The availability of pore space is often defined as the number of interconnecting voids. The effective porosity, or permeability of the Manitoulin dolomites was measured mainly by internal pin point vugs. The diagenetic process of dolomitization contributes to what is commonly called secondary porosity. It is because of the thirteen per cent volume reduction in the alteration of limestones to dolomites that dolomites are generally better traps.

Rapid subsidence causes the beds to dip steeply towards the centre of the basin. The hydrocarbons then migrate upwards; parallel to the beds until they become concentrated in organic reefs or accumulated under impermeable layers which prevent their escape.

b) METHODS

i) Weight Per Cent Oil and Water

One hundred grams of each sample was crushed and placed into a retort cup. The cups were then placed into a conventional retort. The oil and water contained intthe pore space was driven off and recovered in calibrated receiving tubes. The amount of oil and water recovered represents the bulk weight per cent.

ii) Porosity Measurements

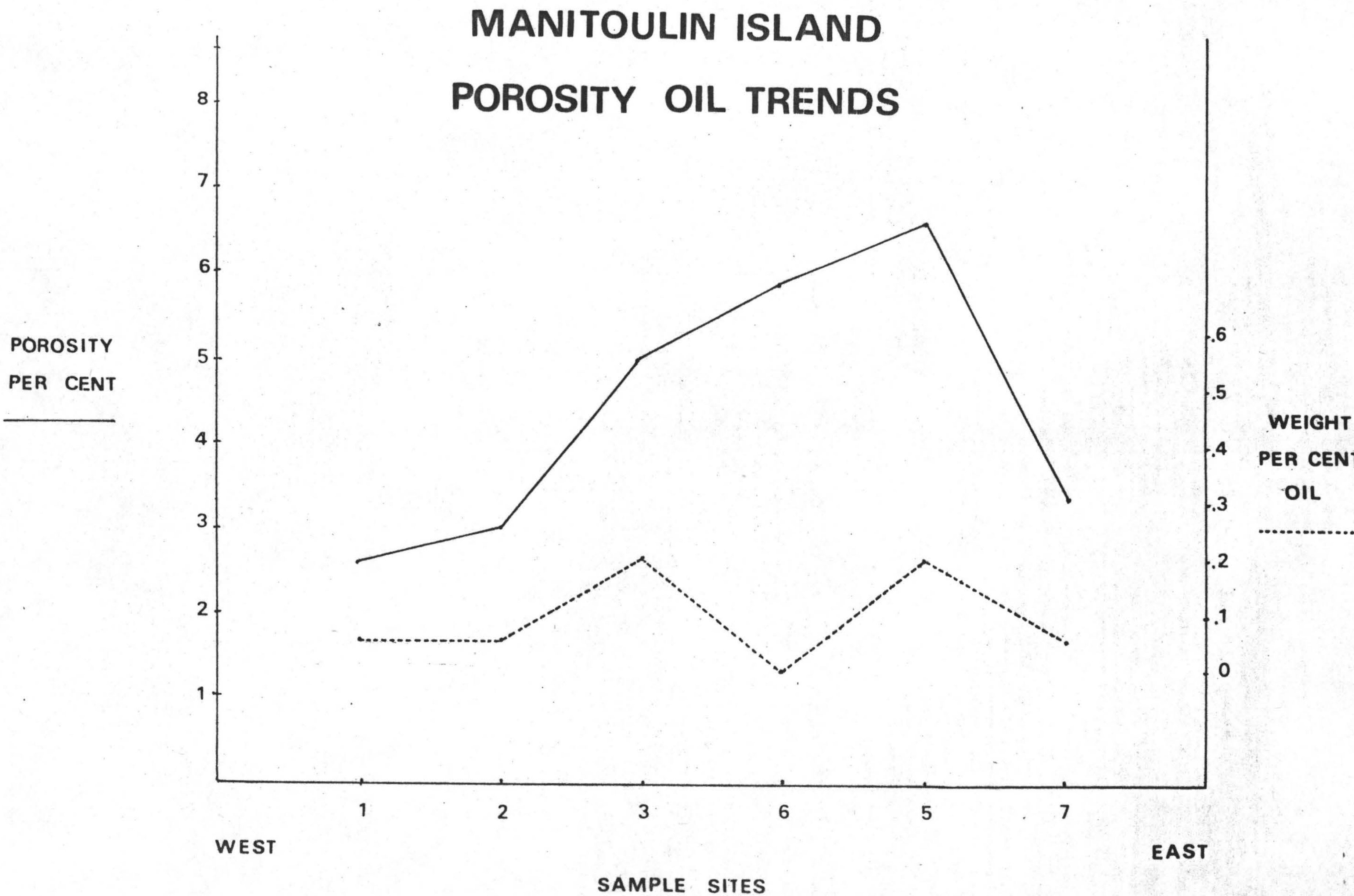
Prior to the oil - water analysis, representative pieces of approximately 10cc in volume were removed from each sample. These pieces were cleaned of all oil and then dried. The samples were then placed individually in a mercury pump and bulk volume was determined. The pore space was measured by the expansion of gases method in this same mercury pump. In this method of determining the bulk and pore volume, it is impossible to account for the external vugular porosity. Therefore, porosity values reported are measurements of the matrix of the core samples, and of any internal vugs.

c) RESULTS

The oil recovered by retorting appeared to be comparable to that of some tar sand oils with a gravity of 10 to 20 API. (As described by Core Laboratories) This assumption was not confirmed, as the high temperature used in retorting would have caused cracking of the oil.

The average porosity of dolomites from across the island was 4.4% of the total rock mass. The maximum value of 6.6% was reached in section five, but some local spots in the bioherm were higher. The average bulk weight per cent of oil across the whole island was 0.1%. Average water content across the island was, with little variation, 0.3%.

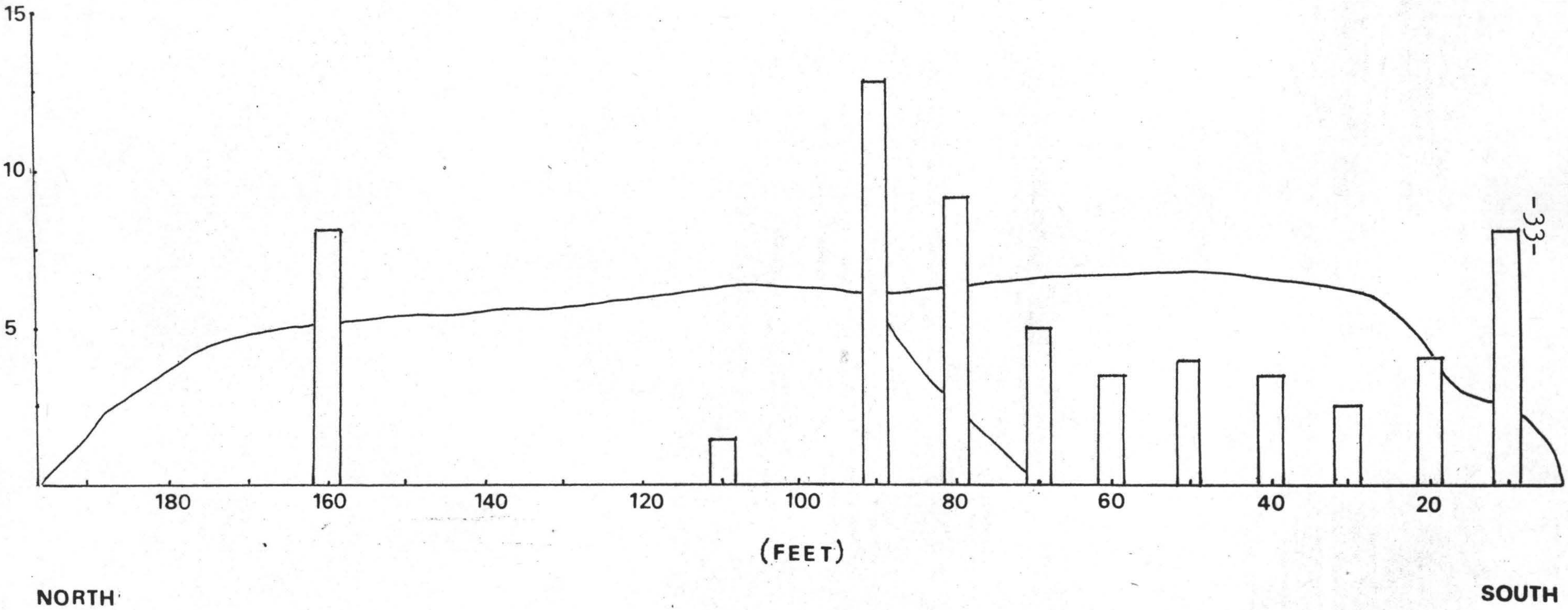
The porosity of the sediments across the Manitowaning bioherm showed a wide range. This could be accounted for,


MANITOULIN ISLAND
POROSITY OIL TRENDS
POROSITY
PER CENT
8
7
6
5
4
3
2
1
WEIGHT
PER CENT
OIL
.6
.5
.4
.3
.2
.1
0
1
2
3
6
5
7
WEST
EAST
SAMPLE SITES

GRAPH 1

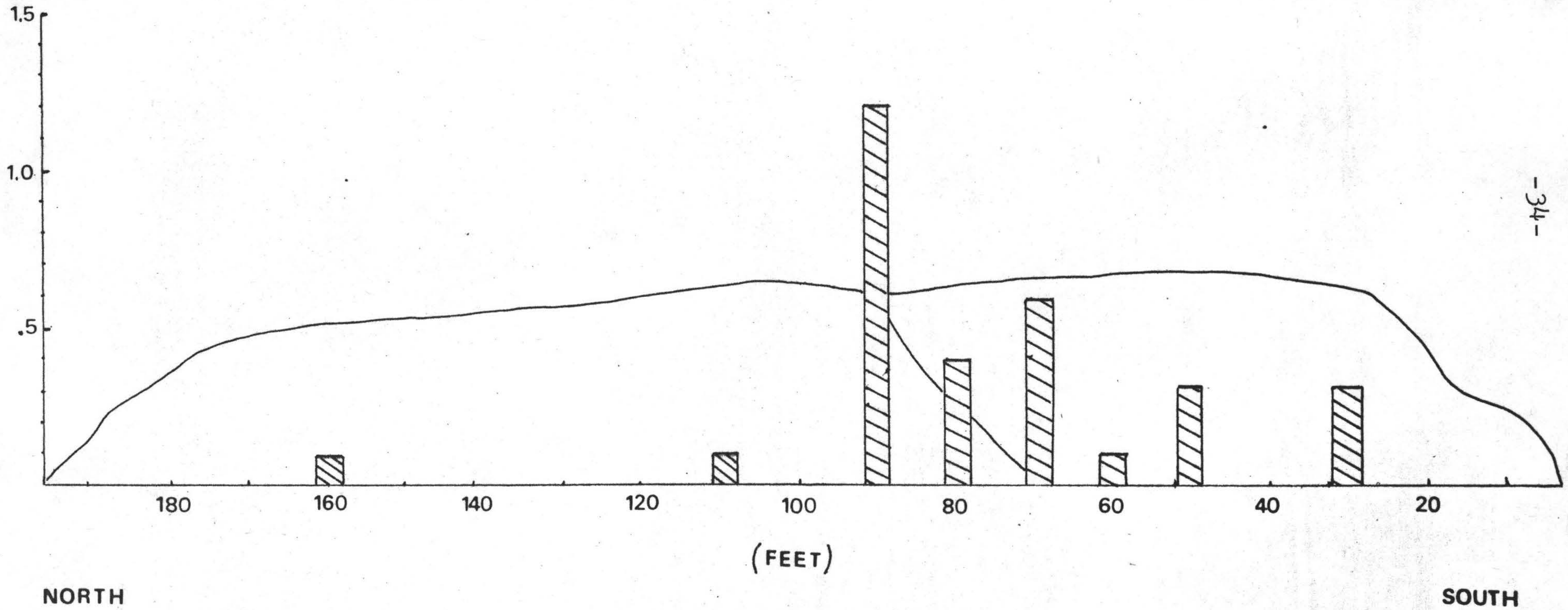
MANITOWANING BIOHERM

POROSITY



GRAPH 2

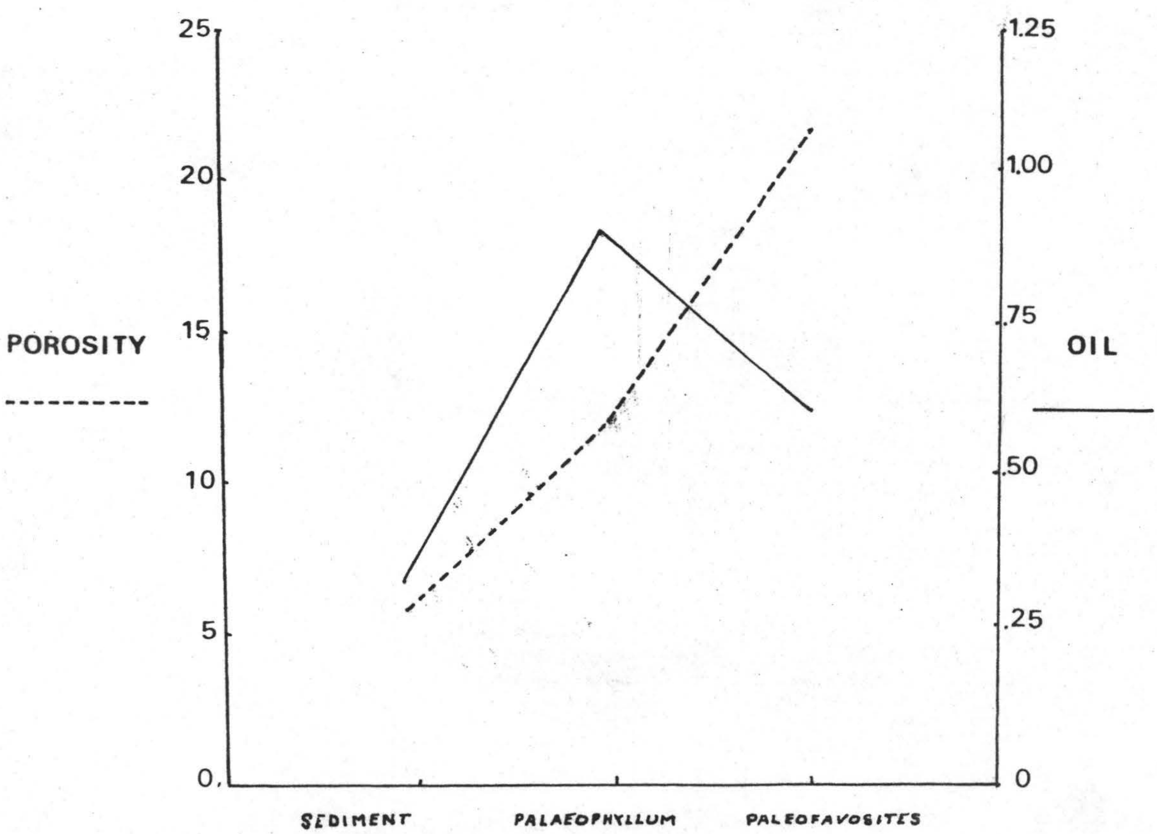
MANITOWANING BIOHERM
WT. % OIL



GRAPH 3

by considering the average grain size of the original particles used to cement the framework together/ Similarly, the greatese amount of oil corresponded to the most porous rocks. (See GRAPH 3 & 4 ~~Diagram~~)

It is interesting to note that both the porosity and the bulk weight per cent oil increase near the fracture zone in the bioherm. A comparison of the porosity and petroleum content in the bioherm binding sediments, the tabulate coral Paleofavosites, and the rugose coral Palaeophyllum showed the framework corals to be saturated with respect to the binding sediments. However, although Paleofavosites has a greater porosity than Palaeophyllum, there is less petroleum in the voids.



GRAPH 4

This might be explained by the fact that Palaeophyllum has smaller chambers then Paleofavosites, but they are more numerous in the Palaeophyllum. (See Diagram 3)
This would allow more petroleum to be contained within Palaeophyllum, giving it a greater bulk weight per cent.

A statistical count on the orientations of the tabulate coral Paleofavosites shows that the petroleum has a tendency to accumulate in corals that are positioned in an upright orientation. Those that have been overturned, seldom contain petroleum.

d) DISCUSSION

The quantities of petroleum found in the Manitoulin outcrops are the remains of the organisms that once survived in the tropical waters. The majority of the oil in the bioherm is trapped in the chambers of the larger framework corals, although smaller amounts are trapped in the sediment pore spaces. There appears to be no economic future for this particular Silurian bioherm as the petroleum contents were considerably lower than might have been expected. Because the Manitoulin Formation is part of a great basin complex, the hydrocarbons found here have probably migrated upwards from greater depths. Perhaps future sub-surface drilling will reveal greater accumulations in other similar Silurian bioherms.

It was noted that both the porosity and oil content increased near the fault zone in the bioherm. The faulting likely loosened the surrounding carbonate matrix making it more easily accessable to oil The fault zone itself may have provided an effective channel for the petroleum migration. In many cases, the oil was found closely associated with calcite. This suggests that the petroleum may have come in with the solutions that deposited the crystals. The hydrocarbon measurements taken from the Manitoulin dolomite may not be considered a true representative sample because the number of samples taken had to be limited.

APPENDIX I

FAUNAL DIVERSITY

PORIFERA
- Hyalospongia
- Demospongia

SCYPHOZOA
- Conulariidae

ANTHOZOA
- Paleofavosites
- Paleophyllum
- Enterolasma
- Streptelasma

BRYOZOA
- Helopora fragilis
- Pachydictya
- Fonestrellina
- Nemaropora
- Cheilotrypa
- Clathropa

BRACHIOPODA
- Atrypa
- Dalmanella
- Leptaena rhomboidalis
- Platystrophia
- Rhynchotreta
- Strophomena
- Rhipidomella
- Camarotoechia

MOLLUSCA
- Bucanella
- Michelinoceras
- Actinoceras

APPENDIX

II

SECTION	POROSITY PER CENT	BULK WEIGHT PER CENT OIL	BULK WEIGHT PER CENT WATER	
Man - S10	8.1	0.0	0.3	
Man - S20	3.8	0.0	0.3	
Man - S30	2.4	0.3	0.2	
Man - S40	3.2	0.0	0.4	Samples
Man - S50	4.3	0.3	0.3	Across
Man - S60	3.2	Trace	0.1	Bioherm
Man - S72	5.0	0.6	0.2	
Man - S80	9.1	0.4	0.2	See Map
Man - S90	12.7	1.2	0.2	of
Man - S110	1.7	Trace	0.2	Bioherm
Man - S164	7.6	Trace	0.2	
Man - #1	2.6	Trace	0.2	
Man - #2	3.0	Trace	0.3	Sample
Man - #3	5.0	0.2	0.3	Sites
Man - #5	6.6	0.2	0.4	Across
Man - #6	5.8	0.0	0.3	Island
Man - #7	3.3	Trace	0.3	
S - RV1	8.4	0.9	0.4	
S - RV2	12.8	1.0	0.2	Palaeophyllum
S - RV3	17.4	0.8	0.2	
S - TA1	20.2	0.9	0.2	
S - TA2	22.1	0.5	0.2	Paleofavosite
S - TA3	23.3	0.5	0.2	
Man - MA1	3.3	0.0	0.3	
Man - MA2	3.6	0.0	0.3	
Man - MA4	3.7	0.0	0.1	See insert
Man - T1	12.8	0.2	0.2	Map 4
Man - V1	4.7	Trace	0.2	

BIBLIOGRAPHY

Adams, J.E. and Rhodes, M.L. (1960) "Dolomitization by Seepage Refluction", Bulletin of American Association of Petroleum Petrologists. 44: 1912-1920

Amsden, T.W. (1955) "Lithofacies Map of Lower Silurian Deposits in Central and Eastern U.S.A. and Canada", Bull. Am. Assoc. Petrol. Geol. V. 39, No. 1, p. 60-75

Angold, D.W. (1955) Manitoulin Formation in the Hamilton Area, Ontario. Unpublished Thesis, McMaster University

Bathurst, R.G.C. (1971) Developments in Sedimentology. Elsevier Pub. Co. New York

Blatt, Middleton, and Murray, (1972) Origin of Sedimentary Rocks. Prentice - Hall Inc., Englewood Cliffs, New Jersey

Bolton, T.E. (1957) "Memoir 289", Geol. Assoc. Can.

Caley, J.F. (1940) "Paleozoic Geology of the Toronto-Hamilton Area", Geol. Assoc. Can., Memoir 224

Deffeyes, K.S., Lucia, F.J. and Weyl, P.K. (1965) "Dolomitization of Recent and Plio-Pleistocene Sediments" by Marine Evaporative Waters on Bonaire, Netherlands Antilles", Soc. Econ. Paleon. and Minerologists, Spec. Pub. # 13

Fisher, D.W. (1954) "Stratigraphy of Medinan Group, New York and Ontario", Bull. Am. Assoc. Petrol. Geol. Vol. 39, No. 9, p. 1979-1996

Folk, R.L. and Land, L.S. (1975) "Mg:Ca Ratio and Salinity", Two Controls over Crystallization of Dolomites", Bull. Am. Assoc. Petrol. Geol. Vol. 59: 60-68

Gill and Briggs, (1970) "Silurian Reefs in the Michigan Basin", Bull. Am. Assoc. Petrol. Geol. Vol 54, No. 5, p. 848-849

Gill, D., Mesolella, K.J., Robinson, W.D., McCormic, L.M. and Ormiston, A.R. (1975) "Cyclic Deposition of Silurian Carvonates and Evaporates in the Michigan Basin", Bull. Am. Assoc. Petrol. Geol. 59: 535-541

Heckel. P.H. (1974) "Carbonate Buildings in the Geologic Record: A Review", edited by Leo F. LaParte, Reefs in Time and Space. Soc. of Econ. Paleont. and Mineraol. Spec. Pub. # 18

Hsu, K.J. and Segenthaler, C. (1969) "Prelimary Experimentation on Hydrodynamic Movement Induced by Evaporation and Their Bearing on the Dolomite Problem", Sedimentology. 12: 11-25

Jodry, R.L. (1969) "Growth and Dolomitization of Silurian Reefs", Bull. Am. Assoc. Petrol. Geol. Vo. 53, P. 957-981

Kesling, R.V., Editor (1974) Michigan Basin Geological Society of Field Conference. "Silurian Reefs - Evaporative Relationships".

Lalicker, C.G. (1949) Principles of Petroleum Geology. Appleton - Century - Crofts, Inc. New York.

LaPorte, L.F. (1969) "Recognition of a Transgressive Carbonate Sequence"; Edited by G.M. Friedman, Depositional Environments in Carbonate Rocks: Soc. Econ. Paleont. and Mineral. Spec. Pub. #14

Levorsen, A.I. (1958) Geology of Petroleum. W.H. Freeman and Co., San Francisco

Liberty, B.A. (1954-1957) Ontario Division of Mines, Maps No. 2244-2249, Manitoulin District

Lowenstam, H. (1950) "Niagara Reefs of Great Lakes Area", J. Geol. 58: 430-487

Mesolella, Robinson, McCormic, and Ormiston, (1974) "Cyclic Deposition of Silurian Carbonates and Evaporites in the Michigan Basin", Bull. Am. Assoc. Petrol. Geol. Vol. 58, No. 1, p. 34-62

Moore, R.C. Editor (1959) Treastise on Invertebrate Paleontology University of Kansas Press, and Geol. Soc. Amer.

Moore, R. Lalicker, C. and Fischer, A. (1952) Invertebrate Fossils. McGraw-Hill Book Co. Inc., Toronto

Murray, R. and Pray, L.C. (1965) "Dolomitization and Limestone Diagenesis ... A Symposium", Soc. Econ. Paleon. and Mineral. Spec. Pub. # 13

Shaver, R.H. (1974) :Silurian Reefs of Northerm Indiana: Reef and Interreef Macrofaunas", Bull. Am. Assoc. Petrol. Geol. Vol. 58: 934-956

Stevens, N.P. (1956) "Origin of Petroleum", Bull. Am. Assoc. Petrol. Geol. Vol. 40, #1, p. 51-61

Williams, M.Y. (1911) "Silurian Geology of Fauna of Ontario Penninsula and Manitoulin and Adjacent Islands", Geol. Soc. Can. Memoir 111

Wilson, J.L. (1974) "Characteristics of Carbonate Platform Margins", Bull. Am. Assoc. Petrol. Geol. Vol. 58: 810-824