THE NIAGARAN ROCKS OF DRUMMOND ISLAND, MICHIGAN AND THE RELATED ROCKS OF THE MICHIGAN BASIN

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ABSTRACT

THE NIAGARAN ROCKS OF DRUMMOND ISLAND, MICHIGAN
AND THE RELATED ROCKS OF THE MICHIGAN BASIN

by Thomas R. Manley

Logging of nearly 200 diamond drill holes on Drummond Island, Michigan revealed lateral gradation in the Niagaran rocks of the island. Very light-gray, loosely cemented, goarse-grained dolomite grades laterally into medium to light-gray, dominantly medium-grained dolomite, with the latter grading into more argillaceous, light to medium-brown cherty dolomite. The cherty beds lie toward the interior of the Michigan Basin relative to the gray and very light-gray beds.

Regionally, Niagaran dolomites grade laterally into thinner limestones in the interior of the Michigan Basin. These limestones in places are pink to reddish in color, and are more argillaceous than their dolomite time equivalents.

In all observed cases, more argillaceous beds occur in the facies nearer the interior of the Basin. This suggests a "barrier reef," with the fine clastics coming through inlets and finally coming to rest in the more interior parts of the Basin. Two definite levels of reddish, more argillaceous limestones may represent two temporary drops in sea level during Niagaran time.

Thomas R. Manley

Structurally, Drummond Island lies near the edge of the Michigan Basin. Analysis of folding and joint patterns suggests that the Drummond Island area underwent a general compression which was at right angles to the rim of the sinking Basin. Changes in the angle between joint sets appear related to slight changes in composition, which occur laterally as well as vertically. Finally, inconclusive fabric analyses indicate that there may be a slight preferential fabric in these dolomites, which is parallel to the joint patterns.

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By

Thomas R. Manley

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

Chapter I

INTRODUCTION

Scope of Study

The problem regarding the interrelationships of the extremely variable lithology of the Niagaran strata of the Michigan Basin is an attractive and challenging field of endeavor in present-day research. The actual past sedimentary environments which developed the interfingering of sedimentary facies are not well understood. This is due, in part, to the lack of closely spaced drill core data within the Niagaran strata.

Genuine problems are present because of the rapid basinward changes in the facies of the Niagaran rocks. Reefs and their associated inferred environments are prevalent in the Niagaran strata. Generally, however, the small bioherms that have been referred to as reefs by most geologists are usually less than a mile across. Additionally, they are usually of minor lateral extent within the major formations.

It seems plausible that detailed information on the stragraphic thicknesses and sequence of the Niagaran strata should reveal interfingering relationships and the environmental factors present in these rocks. Also, the basic problem as to how much of the Niagaran rocks represents "layer cake" geology or lateral gradations may be answered.

It was the good fortune of the writer to be allowed to log about 200 diamond drill cores from the exploratory drilling program of Drummond Dolomite Inc. on Drummond Island, Michigan. Figure 1 is an index map showing the location of the island. In many places the drilling was done on an one-eighth to one-fourth mile grid, to determine the amount of quarryable dolomite for extended reserves. It was believed that, at least in some places, reasonably close control could be obtained in the variable Niagaran facies. Further, it was suspected that valuable information might be obtained by using nearby outcrop data in coordination with the drill core logs. Chemical analyses of these drill cores were made available by Drummond Dolomite, Inc., and were used in formulating a concept of the Engadine Formation. It was hoped that detailed information from these drill cores could answer the question as to how much of the Engadine Formation was "layer cake" and how much represented lateral gradations between facies within the Niagaran strata.

Finally, it was anticipated that a comparison of these data with published outcrop and subsurface information might resolve some of the interfingering and environmental problems of the Niagaran strata, southward into the Michigan Basin.

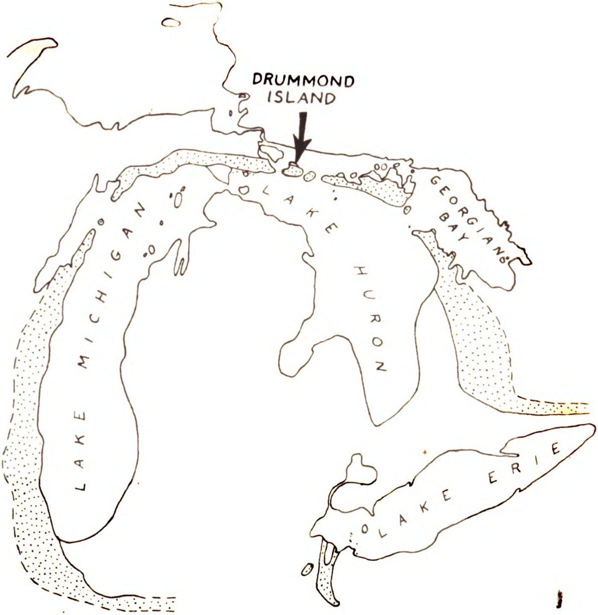


Figure 1. Index map showing the location of Drummond Island. Stipling indicates general areas of Niagaran outcrop.

Regional Setting of Silurian

The limits of the Lower and Middle Silurian of Northern Michigan as shown in Figure 2, are very close to the stratigraphic limits set down by Hall in 1843. The Salina of Late Silurian time is not included because it only appears in the subsurface. Most classifications have dealt exclusively with outcrop sections.

Figure 3 shows that the Silurian sea extended from Michigan into the Hudson Bay region and Interlake area of Manitoba. The amount of information available in the latter areas is limited due to the relatively isolated geographic locality of these places. The Silurian sea extended to the east towards New York, where the stratigraphic section becomes much more clastic. The stratigraphic section thins over the Findlay Arch, thereon thickens considerably, and becomes almost entirely clastic nearing the Appalachian mountains.

The Niagaran Group in Ontario, divided by Bolton (1957) into the Amabel and Guelph Formations as shown in Figure 3, corresponds to the Engadine Formation of Northern Michigan (Ehlers and Kesling, 1957). The Clinton Group in Ontario corresponds to the Burnt Bluff and Manistique Groups in Michigan. Particularly pertinent to this study is the fact that the blue-gray Crinoidal Amabel Dolomite of Ontario grades laterally into the Ancaster Chert to the east of the

SYSTEM	SERIES	GROUP	FORMATION
DEVONIAN	Ulsterian	Detroit River	Bois Blanc
			Garden Island
SILURIAN	Cayugan	Bass Island	
		Salina	
	Niagaran		Engadine
		Manistique	Cordell
			Schoolcraft
		Burnt Bluff	Hendricks
			Byron
			Lime Island
	Alexandrian	Cataract	Moss Lake
			Cabot Head
			Manitoulin
ORDOVICIAN	Cincinnatian		Utica

Figure 2. General stratigraphic section of the Silurian strata of Northern Michigan.

Northern Ontario Hudson Bay region	Manitoba Interlake area		Wisconsin Northeastern part		MICHIGAN Northern Peninsula			Southern Ontario Manitoulin Island and Bruce Peninsula		
					Cayugan series	Salina group	St. Ignace dolomite	Cayugan series	Bass Islands group	Akron dolomite — southwestern part of Bruce Peninsula
			Salina group	Waubakee limestone			Pte. aux Chenes shale		Salina group	Camillus shale — southwestern part of Bruce Peninsula
				Guelph dolomite	Niagaran series		*Megalomus canadensis*	Niagaran series	Albemarle group	Guelph formation
				Racine dolomite			Engadine dolomite			Amabel fm.: Eramosa member; Wiarton member; Colpoy Bay member; Lions Head member
			Manistique group	Cordell dolomite		Manistique group	Cordell dolomite		Clinton group	Fossil Hill formation
				Schoolcraft dolomite			Schoolcraft dolomite			
Attawapiskat coral reef Ekwan River limestone Severn River limestone	Interlake group	Cedar Lake formation East Arm dolomite Atikameg dolomite Moose Lake dolomite Inwood formation	Burnt Bluff group	Hendricks dolomite		Burnt Bluff group	Hendricks dolomite Fiborn limestone mb			St. Edmund formation
				Byron dolomite			Byron dolomite			Wingfield formation
Port Nelson limestone *Virgiana decussata*		Fisher Branch dolomite *Virgiana decussata*		*Virgiana decussata*			Lime Island dolomite *Virgiana decussata*			Dyer Bay formation *Virgiana decussata*
				Mayville dolomite	Alexandrian	Cataract group	Moss Lake formation			
							Cabot Head shale	Alexandrian	Cataract group	Cabot Head formation
							Manitoulin dolomite			Manitoulin formation

Figure 3. Chart showing correlation of strata in the Northern Peninsula of Michigan with those to the north, west, and east. (After Ehlers and Kesling, 1962)

Findlay Arch (Hewitt, 1960). The Findlay Arch is on the eastern rim of the Michigan Basin, which is outlined by structural arches.

Briggs (1962) has shown in detail the probable inlets of the Silurian sea into the Michigan Basin. If reefs truly ringed the Michigan Basin at this time, it would be expected that narrow inlets such as those shown by Briggs were actually present.

That the dolomites of Niagaran time grade laterally into limestones in the Basin interior appears to be an established fact. The limestones are roughly one-half the thickness of the dolomites, and have two or three distinctly more argillaceous beds within them that show the pink to reddish tints of oxidized iron, as indicated in Figure 18. This thinning has been attributed to the Mid-Michigan Ridge by Ehlers and Kessling (1962). However, this thinning toward the interior of the Basin may be due to non-deposition which is the result of "reefing" and may have been the factor that restricted the Basin during Salina time, and set the stage for evaporite deposition.

This study is mostly concerned with the Engadine Formation and the Manistique Group and their possible extension into the Michigan Basin. Since the Manistique Group has facies that are similar and probably related to the Engadine Formation, it is included in cross-sections of the Michigan Basin.

Location of Materials in Area of Study

The general area of Niagaran outcrops of the Michigan Basin is shown by the stipled area in Figure 1. Drummond Island, the focus of this study, is the most easterly extension of Northern Michigan. Figure 1 shows its location with respect to the Great Lakes region. To the west of Drummond Island is the well-traveled Detour Passage, through which freightors from all over the world pass from Lake Superior to the other Great Lakes. To the east of the island is the international boundary between Canada and the United States. First, Cockburn Island, and then Manitoulin Island lie to the east of this boundary.

Drummond Dolomite's old quarry lies directly adjacent to Detour Passage, a position convenient to shipping. Their new quarry lies about five miles to the east of this location, and approximately a mile to the north of the southern shore of Drummond Island. Stone is transported by truck to the old quarry in order to take advantage of the shipping facilities at Detour Passage. Location of the new quarry site was based on exploratory drilling from about three miles north of the southern shore, to the extreme southern portion of the island. Subsurface well cuttings of the Michigan Basin were used to see if the outcrop divisions could be followed into the subsurface.

History of the Niagaran Nomenclature of the Northern Peninsula of Michigan

Bigsby (1821) divided the limestones of northwestern Lake Huron into the Manitoulin Range (Fitzwilliams, Manitoulin, Cockburn and Drummond Islands) and that of Michilimackinac (now known as Mackinac Island). He described some of the rock on the southwestern end of Drummond Island as the "limestone of the Manitoulin Range." Bigsby (1824) described the rocks at Mable Head on the southeastern part of Drummond Island as belonging to the "Manitoulin limestone."

Houghton (1840) divided the limestones and shales of the eastern half of the Northern Peninsula into the "lower limerock and shales" and the "upper limerocks." Most of his lower and middle portions of "the upper limerocks" are of Niagaran age.

Hall (1851) divided the Silurian of the Northern Peninsula into "Clinton group" at the base, the "Niagaran group" above and the "Onondaga Salt group" at the top. These were correlated by Hall with the similarly named divisions of New York State.

Many succeeding writers adopted Hall's divisions with but little variation. Lane (1909) noted that the term "Manitoulin limestone" as used by Bigsby (1824) was more or less equivalent to the Niagaran. He also noted that the top of the Niagaran was "peculiarly white" in color and correlated it with the Guelph of Ontario. Smith (1916) also noted this upper white Niagaran as being equivalent to the Guelph, while the lower grayer Niagaran was Lockport in age.

Smith named both the upper white Niagaran and the grayer dolomite beneath it as being the Engadine Dolomite. It is best exposed in the vicinity of Czark, Mackinac County, but because this name was already preoccupied in the geologic literature, it was named from the village of Engadine, where it is exposed over a large area. In succeeding years, it was referred to as either the Engadine Dolomite or the Engadine Formation. Since it fulfills the requirements for a formation, it is referred to as the Engadine Formation in this study. Smith's original concept of the Manistique Series is obviously incorrect; hence it is referred to as the Manistique Formation, or to its relatively new elevation--the Manistique Group, (Ehlers and Kesling, 1957).

Ehlers (1930) divided the Niagaran Series of the Silurian System into the Clinton and Lockport Groups. The contact between the Engadine Formation and the Manistique Formation was taken as the division between the Clinton and Lockport Groups of the Niagaran Series. Since 1930 most of the work on the Niagaran Series of the Northern Peninsula has been done by G. M. Ehlers.

CHAPTER II

STRATIGRAPHY

General Stratigraphic Section of the Silurian of Northern Michigan

The general stratigraphic section of the Silurian strata of Northern Michigan is shown in Figure 2. This composite section of Northern Michigan has been described by Ehlers and Kesling (1962). This section has been chosen as a recent work and reference point for study. It is an exposed section with a reasonably firm paleontological basis for the divisions, but lithology is used.

The top of the "Clinton" Group is referred to as the top of the Manistique Formation (now Manistique Group), the top of the first Niagaran shale, or the top of a cherty horizon in the Basin. The typical Clinton of New York State has been correlated with the "Clinton" of Michigan with the assumption of "layer cake" correlations, a condition which may not be true within the Niagaran. Oilmen still use the term when referring to the Michigan Basin.

Figure 3 shows the correlation of the rocks of Northern Michigan with other parts of the Basin. Again, this has been chosen as a recent work and a reference point for study. The

Racine Formation of Wisconsin is the same as the Racine of Illinois, both of which correlate with the Engadine Formation of Michigan.

Surface nomenclature has been used in referring to the subsurface in the Michigan Basin. However the strong paleontological basis is difficult, if not impossible, to recognize in the subsurface. The drillers terms in the Marine City, Field of Michigan, which refer to the Niagaran- "white," "gray," and "brown," are only useful to designate the general sequence of the color of the Niagaran strata.

General Stratigraphic Section of Southern Drummond Island, Michigan

This paper is concerned primarily with the detailed facies of the upper section of the Manistique Group and the Engadine Dolomite on Drummond Island, Michigan.

Figure 4 shows the general sequence of facies that were logged from the exploratory diamond drill cores of Drummond Dolomite Inc. This general sequence may be modified in areas where abrupt lateral gradations occur. It should be noted that facies is used in reference to different rock types occurring within a stratigraphic formation of definite recognizable vertical limits. Much smaller lithologic units of lesser vertical and horizontal extent are termed micro-facies.

In this study, the special terms used in Figure 4 were adopted in order to put labels on the various types of

Formation	Facies	Thickness(feet)
ENGADINE	Upper Brown	20
	Upper Cherty	30
	Dark Gray	1-12
	Upper White	0-50
	Gray Beds	40-50
	Lower White	1-4
CORDELL	Lower Brown	20
	Lower Cherty	30

Figure 4--General sequence of facies in the Cordell and Engadine Dolomites of Drummond Island, Michigan.

lithofacies. Since all facies are of dolomite composition, it is not necessary to write the word "dolomite" after each facies designation. These labels are strictly rock types within the Niagaran series. In Appendix "A" the first letters of the rock types are used as abbreviations in the logs of the Drummond Dolomite diamond drill cores. The Niagaran satisfies the requirements for a formation, but the facies within this formation interfinger in such a way as to make member designations unrealistic.

Description of Facies

Lower Cherty

Fine-to medium-crystalline dolomite, medium-to light brown, with one to 12 inch chert bands and nodules every one-half to one foot. The top of this facies can be determined by the first appearance of a one inch chert band or nodule, a one inch shaly band, and a one inch thick stromatoporoid layer, all of which characteristically occur within a foot or two of each other.

Within this facies the following cycles repeat themselves many times, and they are characteristic of this facies. The number one unit is lower stratigraphically in all sections. These repetitions are hemicycles[1] as are all the cycles

[1]Hemicycle here refers to the incomplete development of the sequence. These are not true cycles as the reverse order of the unit does not manifest itself to complete the cycle. The term cycle is used in this sense herein.

present within the different facies on Drummond Island. The thickness of these cycles is never more than a few feet.

No. 1 type cycle. Description		Thickness
3.	Fairly closely spaced shaly partings, spasmotically increasing upward, plus or minus stromatoporoids.	1'
2.	Chert	1" - 1'
1.	Less shaly partings, with a slight increase in number upward.	3" - 1'

No. 2 type cycle. Description		
3.	Closely spaced shaly partings	1/2"
2.	Chert	1 - 2"
1.	Less closely spaced shaly partings, with slight or no increase upward.	1/2 - 3"

No. 3 type cycle. Description		
3.	Well defined shale parting (1 or 2)	--
2.	Chert	1"
1.	Very minor zone of more numerous shaly partings upward.	1"

The chert in these cycles may have a light-brown, bluish or black core, with chalky white chert generally forming an outer layer of either bands or nodules. The black core chert, however, tends to have a brownish clayey chert surrounding it, and occurs 25-30 feet stratigraphically below the top of the Lower Cherty.

Light-brown chert covered with bluish chert grading outward from the latter into a dense white variety, which in turn is covered by white chalky chert, is present in the drill cores. Relatively pure light-brown chert is also present, but a pure chalky white variety is the dominant form of chert in this facies. Some of the beaches on the southern shore of Drummond Island are almost exclusively made up of this white, ashen, chert, which is the only remnant of the former outcrop. This chert seldom crops out because it was probably eroded by the differential freezing and thawing action of ice.

Changes in crystal size within a slight distance are commonly observed above and below a chert band. Above a chert band the crystal size may be relatively coarse or fine, while below the band it generally is significantly different--either finer or coarser. However, in many cases of the No. 3 type cycle described on the previous page, there is no discernable change in the crystal size.

Since recognizable fossils are not commonly found in the chert of the drill cores, it is very difficult to do any paleontological work on the drill cores. Favositid corals and stromatoporoids were about the only recognizable fossils found in the chert.

The thickest chert is associated with the thickest shaly zones, and occurs from 10 to 20 feet below the top of the Lower Cherty.

Lower Brown

Fine-to medium-crystalline, light-brown, with minor chalky white chert and siliceous partings. Occasionally the upper five to seven feet of this facies contains several one inch chert nodules. The determination of the top of this facies is given in the description of the Lower White.

Within this facies the following cycle repeats itself up to four times:

Description	Thickness
4. Dolomite, brown, relatively numerous and narrow silicified partings associated with relatively common shaly partings plus or minus narrow mottled blackish spots, generally thicker than in No. 1 below; plus or minus pyrite crystals.	1'
3. Dolomite, very light-tan, relatively wide bluish-black spots in the upper part of the underlying subfacies.	1 - 4"
2. Dolomite, very light tan, more coarsely crystalline rock lacking impurities.	1'
1. Dolomite, brown, relatively infrequent silicified partings or chert, thicker than those in No. 4 above, associated with less shaly partings, plus or minus thin narrow bluish-black patches, plus or minus rapid changes in crystal size.	2 - 4"

This facies may have two, three, or four of these cycles that are discernable in the drill core. If there are only two cycles present, they usually occur near the top of the facies. Where the upper five to seven feet of the facies contains one inch chert nodules, the cycles are not present.

Silica has its greatest thickness in the form of chert or silicified partings at the bottom of the lowest cycle, while the bluish-black zones are thickest at the top of the upper-most cycle in the section. Silica becomes less and less common upward in the cycles, while the bluish-black mottled patches become larger upward in the cycles.

Lower White

Medium-crystalline to somewhat coarser, light-gray dolomite lacking chert and with a dense appearance.

The bottom of the Lower White is taken as the base of the Engadine Formation because of the persistent color change from brown-to light-gray and the frequent occurence of thin stringers of pyrite crystals within this thin marker zone or in the foot of light-tan to light-brown dolomite below it. Also, the crystal size of the light-gray dolomite is coarser than the light-tan to light-brown dolomite below it. Furthermore, two clay partings varying from six inches to a knife edge characteristically occur close to this contact. In fact, the floor of the Drummond Dolomite Inc. quarry is based on this. It is very easy to blast off the rock evenly along these clay partings. This is the same contact as that determined by Ehlers and Kesling (1962).

Gray Beds

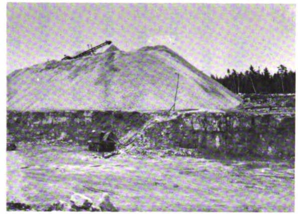
Fine-to medium-crystalline dolomite, dominantly medium-crystalline, medium-gray to lighter-gray with very little to no chert and massively bedded. Plate 1 shows the best exposures of the Gray Beds which are found in the two quarries of Drummond Dolomite, Inc.

The grayest zones usually tend to be near the middle of the Gray Beds. They are commonly only one to three feet thick, and in several cases these zones are adjacent to joints. The chalky white variety fades out away from a joint. Observation of the drill core shows that this same variety of dolomite is also found as a thin surficial layer on the outcrops of dolomite in the area.

Although some stromatolites are present, stromatoporoids are the most frequently occurring fossils that are identifiable in these beds. These can be seen quite clearly in the broken rock from the quarry blasting. In the drill core the stromatoporoids are recognized by the following "cycle":

Description	Thickness
3. Grayish zone	1/16" to 10"+
2. Very light-gray zone, nearly white	1/4" to 1/2"
1. Green organic or shaly parting	------------

The green organic or shaly parting always occurs on the bottom. It is very consistent in the quarry walls



Above: Four ten foot ledges in the old quarry.
Below: Two ten foot ledges in the new quarry.

Above: Experimental pit next to the new quarry.
Below: Small roll in the new quarry.

PLATE 1

and the surrounding outcrops. In order to see it in the outcrop, however, one must usually clear away the overlying weathered chalky white layer.

At approximately ten foot intervals within the Gray Beds, there is a clay parting that is zero to six inches thick, and which usually is not cored by the diamond drill. In the old quarry, just below these zones at 10 and 30 feet above the Engadine-Manistique contact, the number of stromatoporoids increases greatly. Although they increase in numbers at these horizons, they are thinner than the less frequent stromatoporoids below.

Several one to four foot thick beds of finer crystalline blue-mottled brown dolomite may be found within the Gray Beds. These beds have more clay and about twice the silica content of the enclosing Gray Beds. These are thin lens-like bodies which pinch out. They may be in one drill hole, and then not again for several drill holes along a section line.

Upper White

Coarsely crystalline, very light-gray, with no chert, loosely cemented, sugary dolomite, massively bedded. This facies thins and thickens within a very short distance, and grades laterally into cherty beds.

The lower beds of the Upper White have some grayer tones in them near the contact with the underlying Gray Beds.

Hence, the contact between the Gray Beds and the Upper White is transitional, but it is definite. Chemically it may be distinguished from the underlying gray beds by its extreme purity. It has less than .5% silica, while the underlying gray beds have more than .5% silica. Appendix "B" shows the silica percentage curves which correspond to the Gray Beds and the Upper White.

In places abundant brachiopods are found within the Upper White. Only the indistinct pentameroid molds are present, and the species is very difficult to determine. Outcrop and drill core information indicate that these accumulations are probably less than one-eighth of a mile across.

Dark Gray

Coarsely crystalline, dark blue-gray to dark blue-gray mottled dolomite, with little or no chert. This facies between the Upper White and the Upper Cherty is not always present.

Upper Cherty

Finely crystalline, light-brown, with one to four inch chert nodules. In most of the cases, the predominant varieties of chert have chalky white and light-blue cores, covered by the chalky white variety. Some black core chert covered with the light-brown clayey variety also has been observed. The lowest foot of these beds is dark-blue or brown-mottled.

Very few shaly partings are present in these beds. This contrasts sharply with the abundant shaly partings in the Lower Cherty. In a few drill cores a one to two inch shaly zone has been observed at the top of the Upper Cherty. Also, a few lightly developed chert cycles similar to those in the lower cherty have been recorded.

Fossils are almost non-existent in the chert found in the drill core. In outcrop, however, a fossil assemblage which seems to duplicate that of the Lower Cherty is present (Ehlers, 1930).

On the southern part of the island it can be shown that the Upper White grades laterally into the Upper Cherty. Plate 2 shows a part of this lateral relationship. A brachiopod biostrome within the Upper White lies below a marker zone, approximately one foot thick, which characteristically weathers with small quarter-inch pits, and has a denser, grayer, more weathered appearance. The surface of the marker zone is highly irregular within a short distance with a vertical relief of approximately three feet. The spaces within the joints in the latter are relatively tight, one-eighth to one-quarter inch.

On top of this one foot marker zone lies a one-half to seven foot zone of very light-gray dolomite (Upper White), which weathers with one to two inch nearly round holes. The joints in this layer characteristically show one to six inch gaps, and they may be wider. This contrasts with the

Above: Upper White overlying marker zone.
Below: Top of marker zone.

Above: Seven foot ledge of Upper White.
Below: Seven foot ledge of Upper Cherty, lateral equivalent of the Upper White shown above.

PLATE 2

much thinner gaps in the joints on top the one foot marker zone. The light-gray zone grades laterally into the Upper Cherty within the outcrop areas along the southern edge of the island.

The number of partings in the Upper White increases slightly upward in the seven feet above the small one foot marker zone. Partings are at least three times more abundant in the lateral equivalent Upper Cherty and they have a sharp increase in number upward in the seven foot ledge above the marker zone.

Upper Brown

Fine-to medium crystalline, light-brown dolomite with chert nodules less than one inch thick. These beds are similar to the Lower Brown, with the exception that they tend to be more finely crystalline. A few sedimentary cycles similar to those in the Lower Brown were recorded, but they are definitely less common in their occurrence in the Upper Brown beds.

Maximum Composite Microfacies

Table 1 is a measured composite microfacies section of the drill core logs taken from Drummond Island. The preceeding general description of the facies is shown by this composite section. In all cases, cores that indicated the maximum amount of detail were chosen to illustrate the

TABLE 1

MAXIMUM COMPOSITE MICROFACIES SECTION OF THE CORDELL AND ENDADINE FORMATIONS OF DRUMMOND ISLAND, MICHIGAN AS DETERMINED FROM DIAMOND DRILL CORES

A. Upper Brown--Medium crystalline delemite with associated mottling present only in a few drill cores.

Facies	Thickness	
7. Light-to light-medium-brown, dominantly finely crystalline dolomite, with minor siliceous partings.	27'+	
6. Dolomite, as above with blue-black mottling.		6"
5. Very light-tan, medium-to coarsely crystalline dolomite with blue-black mottling in top one inch.		8"
4. Dolomite, as unit 7 above, with top four inches mottled blue-black.	2'	
3. Dolomite, as unit 5 above, with top one inch mottled blue-black.	1'	
2. Dolomite, as unit 7 above, plus or minus 1/8 to 1/4 inch chert nodules.	11'	
1. Dolomite, as above, shaly.		2"
	42'	4"+

	Thickness
B. Upper Cherty--Fine-to fine-medium crystalline, light to light medium-brown dolomite with one to six inch chert nodules every 1/2 to 1 foot. The chert is dominantly of the white or very light-gray variety. Very rarely, a chert nodule is observed, which has more thin shaly or carbonaceous partings on top than on the bottom of the chert. The bottom one to two feet of this facies tends to be blue-black mottled.	26'
C. Dark Blue--Coarsely crystalline, dark blue-gray mottled dolomite. Only present above the Upper White beds below, and not present when the underlying Gray Beds are directly overlain by the Upper Cherty.	11'

TABLE 1--Continued

		Thickness	
D.	Upper White--Coarsely crystalline, very light-gray, loosely cemented dolomite; when missing, the underlying Gray Beds are usually in contact with the Upper Cherty. In the latter situation, it appears to pinch out as the Gray Beds retain their approximate thickness.	57'	
E.	Gray Beds--Fine-to medium, dominantly medium-crystalline, light-to medium-gray dolomite. The grayest sections usually occur near the middle of these beds. This facies grades laterally into finer-grained cherty beds and blue-black mottled, light-to medium-light-brown beds. The mottled phase occurs sporatically in the upper two thirds of the Gray Beds, and chert nodules occur near the southern shore of the island. The mottled phase locally becomes more coarsely crystalline in the Gray Beds, occuring in up to five zones, eight inches to one foot, locally four feet thick.	53'	
F.	Lower White--Medium-crystalline, light-gray dolomite, with pyrite stringers in it, and characteristically contains two prominent zero to six inch clay partings within it or just below it.		4'
G.	Lower Brown--This facies may grade laterally into strata that have none of the 'cycles' described below, particularly when the upper seven feet contains chert nodules.		
	13. Light-tan, medium-crystalline dolomite.	1'	
	12. Dominantly finely crystalline, light-brown, blue-black mottled dolomite with thin (less than 1/8 inch) siliceous partings.	1'	6"
	11. Medium-crystalline, very light-tan dolomite with the top one to two inches blue-black mottled.	1'	

TABLE 1--Continued

		Thickness	
10.	Dominantly finely crystalline, light-brown dolomite, with minor blue-black mottling in the upper foot. Contains thicker siliceous partings (1/8 inch) than in unit 12 above in the upper feet.	4'	
9.	Same as unit 12 above, but with less blue-black mottling.		8"
8.	Same as unit 11 above, with top inch blue-black mottled.	1'	
7.	Same as unit 10 above, with top six inches blue-black mottled, and silica in the form of chert about one-quarter inch thick.	5'	
6.	Same as unit 12 above.		3"
5.	Same as unit 11 above.	1'	
4.	Same as unit 10 above, but minor blue-black mottling appears only in upper two inches.	6'	7"
3.	Same as unit 12 above.		.5"
2.	Same as unit 11 above.	1'	
1.	Same as unit 10 above, except for slightly thicker half-inch chert nodules.	1'	
		24'	2.5"

H. Lower Cherty:

14. Fine-to medium-crystalline, light-brown to light-medium brown dolomite. More shaly than Upper Brown facies, and contains one inch white chert nodules every foot to half-foot. The first one inch chert nodule occurs

TABLE 1--Continued

		Thickness	
	at the top of this facies, and the first stromatoporoids appear immediately or within one foot of this level.	5'	
13.	Dolomite as in unit 14, but much more shaly with no chert nodules.	1'	6"
12.	White chert.		2"
11.	Dolomite as in unit 13, but less shaly, and with a slight increase in the number of shaly partings upward.		6"
10.	Same as unit 14 above.	3'	4"
9.	Same as unit 13 above.		8"
8.	Same as unit 12 above.		1.5"
7.	Same as unit 11 above.		6"
6.	Same as unit 14, except for slightly thicker one to two inch chert nodules.	10'	
5.	Finely crystalline, medium-brown, shaly dolomite.	2'	
4.	Dolomite as in unit 5 above, with 1/2 to one inch black core chert layers with a clayey, medium-brown coating.	2'	
3.	Same as unit 14 above, except for slightly thicker two to three inch chert nodules.	3'	
2.	Medium crystalline, very light brown dolomite with one inch white chert nodules every foot to one-half foot. These chert nodules have a small parting below them, with the spacing between		

TABLE 1--Continued

		Thickness
	the partings decreasing upward toward the chert nodule. Above the chert nodule there may occur one well defined shaly parting.*	9'
1.	Same as unit 4 above.	4'+
		41' 9.5"+
	Total	263' 4"+

*This pattern of shaly partings may be found in any of the overlying beds of the Lower Cherty. However, when it is found, the shaly partings are much more numerous both on the top and the bottom of the chert nodule.

composite section. A maximum stratigraphic section of two-hundred and sixty-three feet four inches, was measured for the Upper Cordell and Engadine Formations on the island.

The composite microfacies section is a compilation of drill cores which show the maximum amount of detail. Maximum detail in the facies is not always present due to delicate lateral gradations, which may occur only locally. Correlation between drill cores has been done by using the criteria of top determination given in the description of facies.

Lateral Distribution of Facies on Drummond Island

Figure 5 shows the area in which the Upper Cherty is present on the southern part of the island. The contact has been determined by using both outcrop and drill core data. The Engadine-Manistique contact is that described by Ehlers (1930). Figure 5 shows the smaller area that has been enlarged into Figure 6.

Figure 6 is, basically, a structural contour map of the Engadine-Manistique contact. It shows the locations and identifying letter-number designations of the well cores that were studied, and Appendix "A" shows the detailed logs of these holes, including collar elevations.

All the letter-number designations of the diamond drill cores that were logged are not shown in Figure 6. The

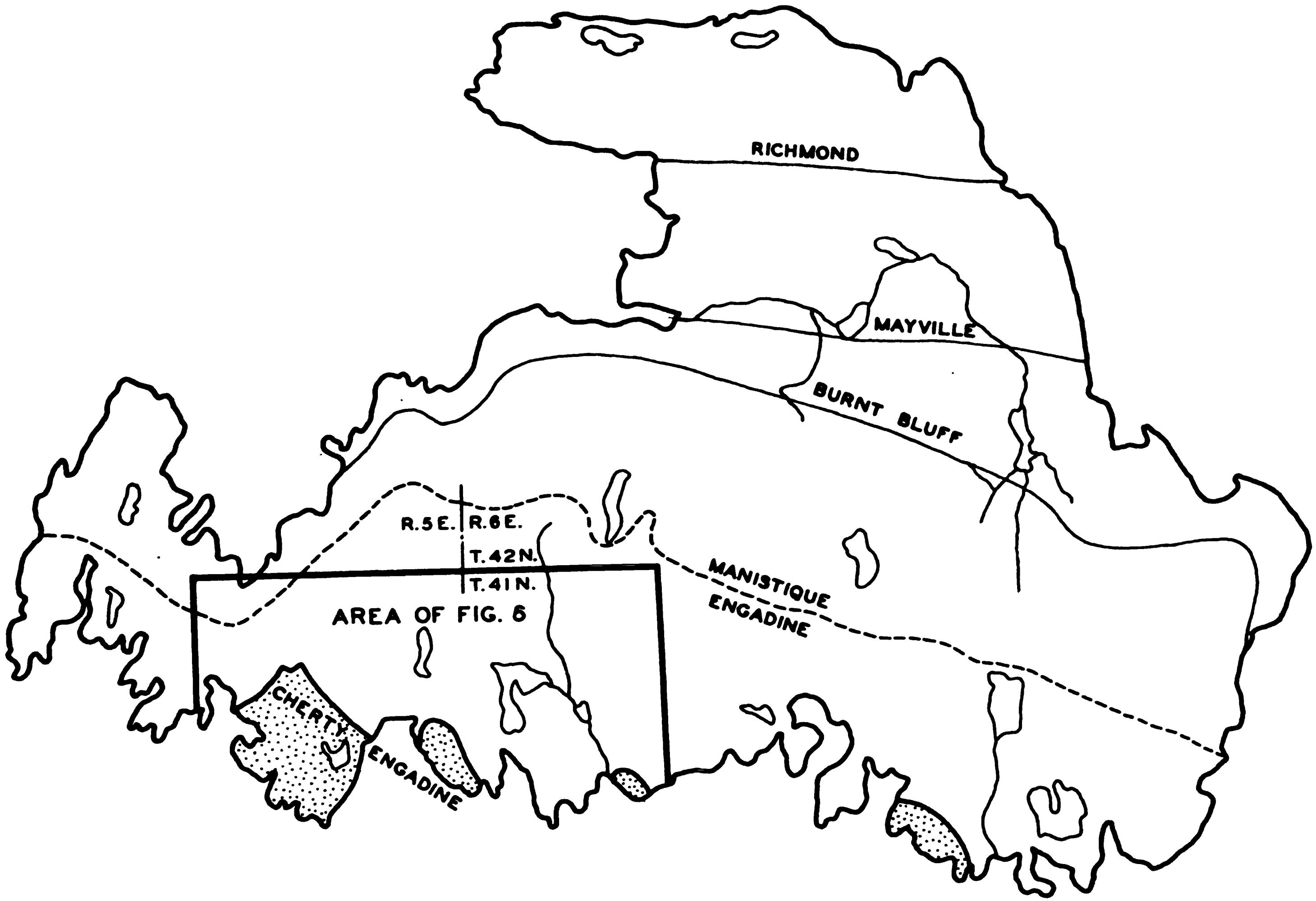
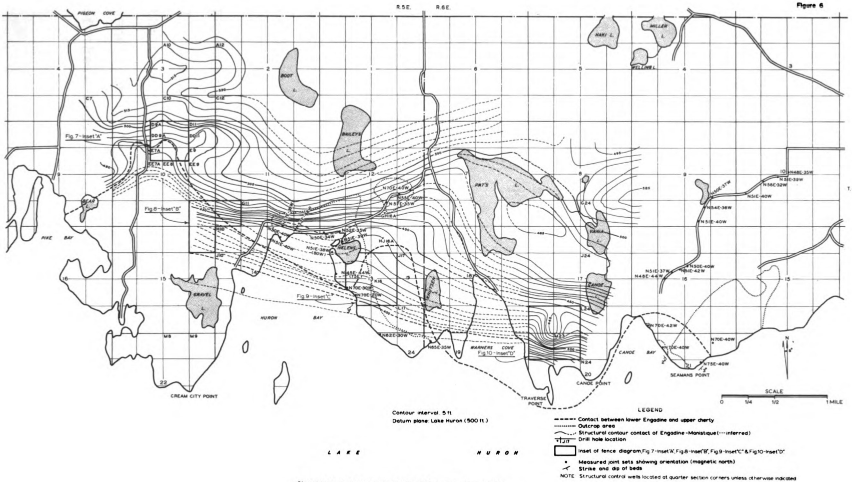


Figure 5. Index map of Drummond Island, showing formational contacts and the area of Figure 6.

Figure 6



Structural contour map of the Engadine-Manistique contact.

Southern Drummond Island

lettering system covers from A to N, from North to South. Letter "I" is conventionally ommited. The distance between any two succeeding letters is one-quarter of a mile. In other words, line B is one-quarter mile South of A. A double letter such as DD means the drill hole is an eighth of a mile to the south of "D" line, or half the distance between D and E lines. Numbers following the letters are from 7 to 26 and represent the east-west coordinate. An "A" following the number indicates that the location is an eighth of a mile to the east of that number. There is a break in the numbering system between lines DD and E, because of a change in the drilling program. All the lines beneath DD11, however, are still numbered in sequence. Hence, line DD11 lies directly north of E9.

Figure 6 not only shows the Upper Cherty-Upper White contact, but also, shows the areas in which the fence diagrams of Figures 7, 8, 9, and 10 were taken. The fence diagrams of Figures 7, 8, 9, and 10 show the complexity of the interfingering facies of these Niagaran strata.

Figures 7 and 8 show the usual sequence of facies within the Engadine Formation that is found on Drummond Island. Figure 7, however, shows many blue-black mottled brown beds within the Gray Beds. The blue-black mottled beds are usually one foot or less in thickness. When there are five or six of these beds present, they are within the upper

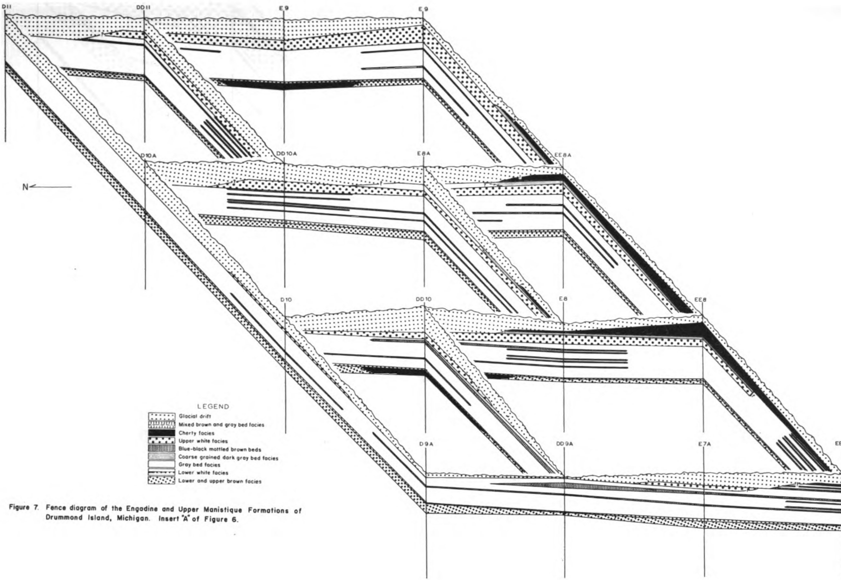


Figure 7. Fence diagram of the Engadine and Upper Manistique Formations of Drummond Island, Michigan. Insert "A" of Figure 6.

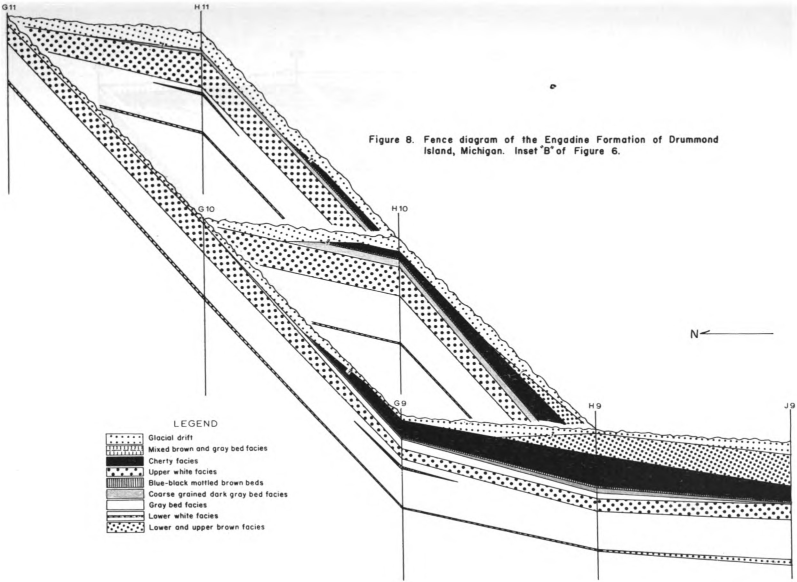


Figure 8. Fence diagram of the Engadine Formation of Drummond Island, Michigan. Inset "B" of Figure 6.

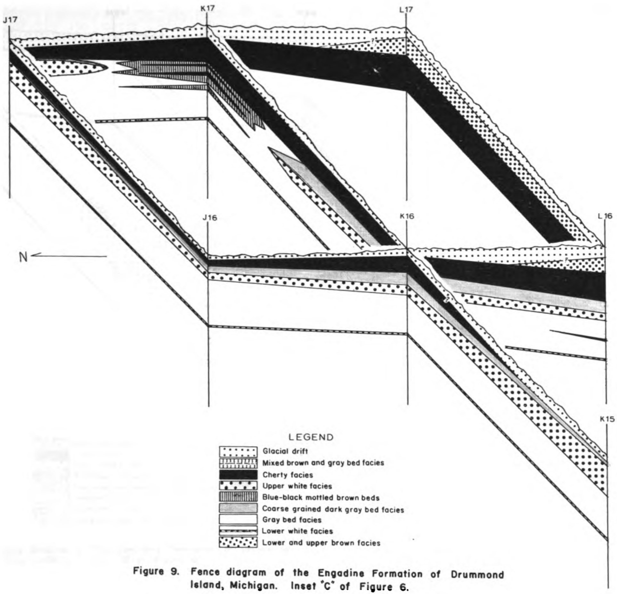


Figure 9. Fence diagram of the Engadine Formation of Drummond Island, Michigan. Inset "C" of Figure 6.

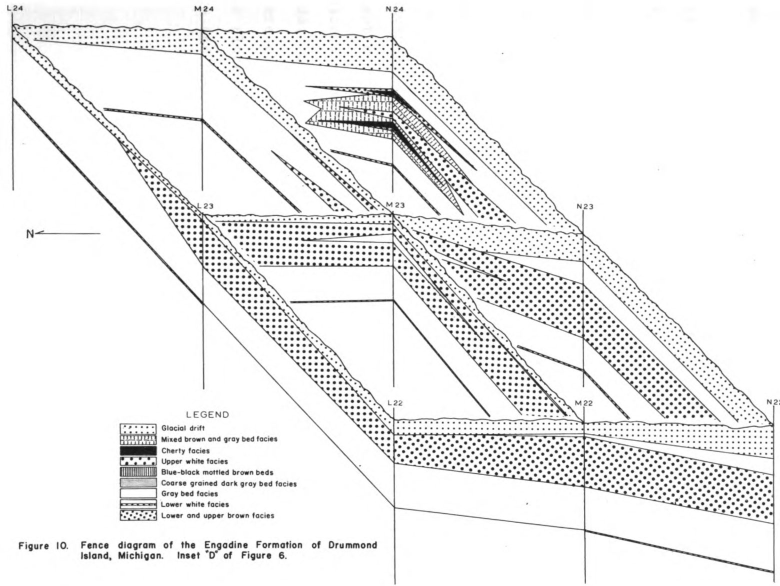


Figure 10. Fence diagram of the Engadine Formation of Drummond Island, Michigan. Inset "D" of Figure 6.

two-thirds of the Gray Beds. E8A does not have the Dark Blue facies above the Upper White. The Lower Brown has chert developed in E9 and DD10.

Figure 9 shows an abrupt lateral gradation between the Upper White and the Upper Cherty. In this case, however, the Dark Blue, as is the usual case, is developed between the Upper White and the Upper Cherty. Toward the south, the Upper Brown appears in the stratigraphic section.

Figure 10 shows how the Upper White and the Gray Beds interfinger southward into cherty beds with associated brown-colored beds. The Upper White in N23 carries through into N24, where it is located between two chert beds. M23 and M24, which have the Gray Beds developed to their maximum thickness, show the lateral gradation into N24. N24 has chert developed in the upper two-thirds of the Gray Beds, which is associated with brown and blue-black mottled brown beds. This is the only known locality on Drummond Island where the Dark Blue beds do not overlie the Upper White. The slope between N23 and N24 is greater than that between M24 and N24.

CHAPTER III

INTERPRETATION OF SEDIMENTARY AND STRATIGRAPHIC FEATURES IN THE MICHIGAN BASIN

Major Features

Chert Wedge

Figures 11 and 12 show two sections across the Michigan Basin given by Cohee (1948), and supplemented by Ehlers and Kesling (1962). In Figure 11, the well in Manistee County shows a nearly completely cherty dolomite section for the Engadine and Manistique Formations. Fifty miles to the north, the well near the edge of the Basin in Schoolcraft County shows a rock sequence very similar to that on Drummond Island. However, the chert within the Engadine starts at 140 feet above its base, whereas on Drummond Island, it starts about 40 to 50 feet above the base.

The well to the south of Drummond Island in Alpena County (Figure 12) shows a chert section in the middle of the Engadine Limestone. To the south, in Bay County, the section is pure limestone. If the well in Manistee County in Figure 11 were placed between the well in Chippewa County and the one in Alpena County in Figure 12, there would be a wedge of chert pointed toward the center of the Basin, which grades into limestone toward the center of the Basin.

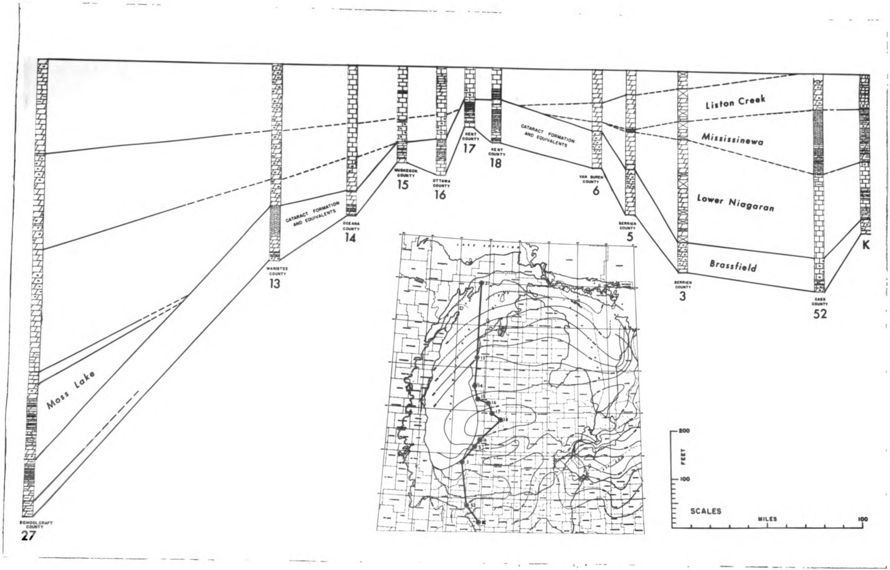


Figure 11. North-south cross sections of the Lower and Middle Silurian of the western part of the Michigan Basin. (After Ehlers and Kesling, 1962)

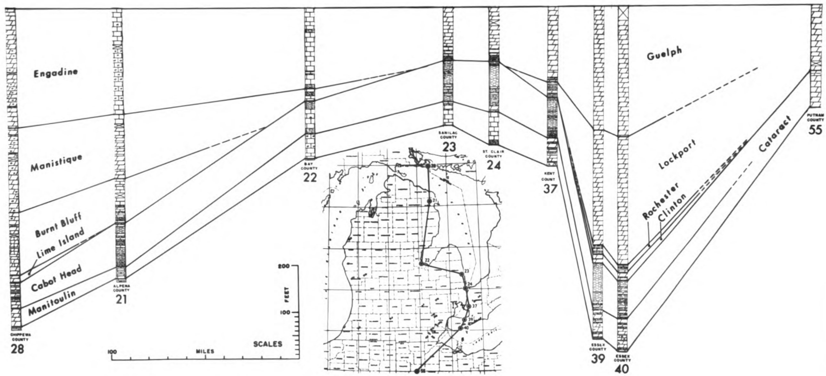


Figure 12. North-south cross sections of the Lower and Middle Silurian of the eastern part of the Michigan Basin. (After Ehlers and Kesling, 1962)

Further, the two minor interruptions in the chert in both the Manistee and Chippewa County wells indicate a wedge somewhat like the idealized one shown in Figure 13.

Figures 9 and 10 show that the gray and white dolomites of the Engadine Formation can grade laterally into cherty beds rather suddenly, or approximately within an eighth of a mile. A similar situation is present in Ontario where the medium to light-gray crinoidal Amabel Dolomite grades abruptly into the Ancaster Chert (Hewitt, 1960). This is shown in Figure 14. This particular lateral gradation does not occur within the Michigan Basin. These two cases of abrupt lateral gradation show that medium to light-gray dolomites can be the lateral equivalents of cherty dolomite.

Michigan Basin "Barrier Reef Complex"

The thickening of the Niagaran strata at the edge of the Basin may be a result of a "reef complex." The term "reef" or bioherm has been generally applied to a mound of lithified fossil material, lacking well defined bedding, with more impure flank beds surrounding it. In the Niagaran strata, these are only minor structures which are usually no more than a mile across. A considerable number of these structures might still be called a "reef complex" or a "barrier reef complex." The "barrier reef complex" may have restricted the seas, and brought about evaporite deposition in Salina time. Within the Engadine Formation, the

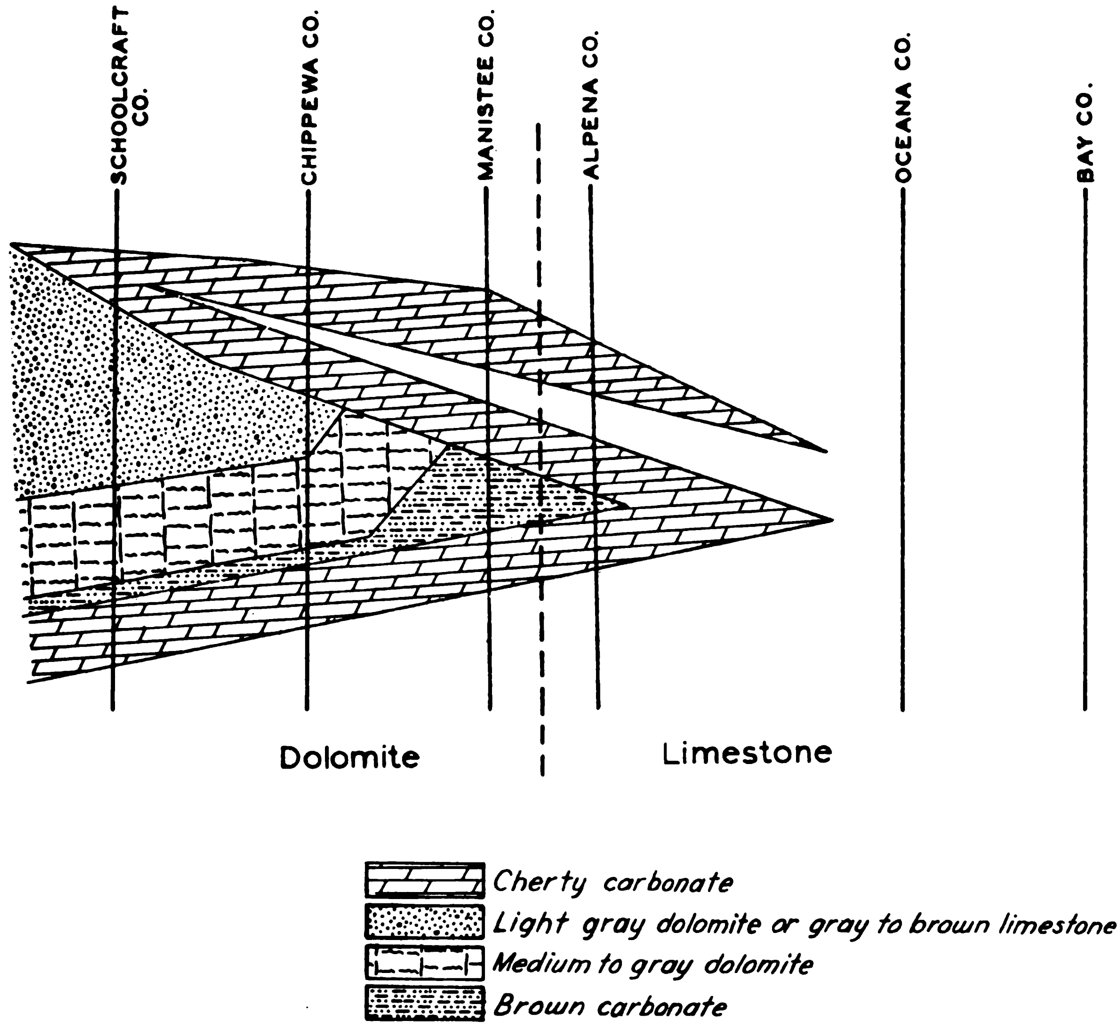


Figure 13. Transgression and regression of cherty facies within the Niagaran Formation of the Michigan Basin.

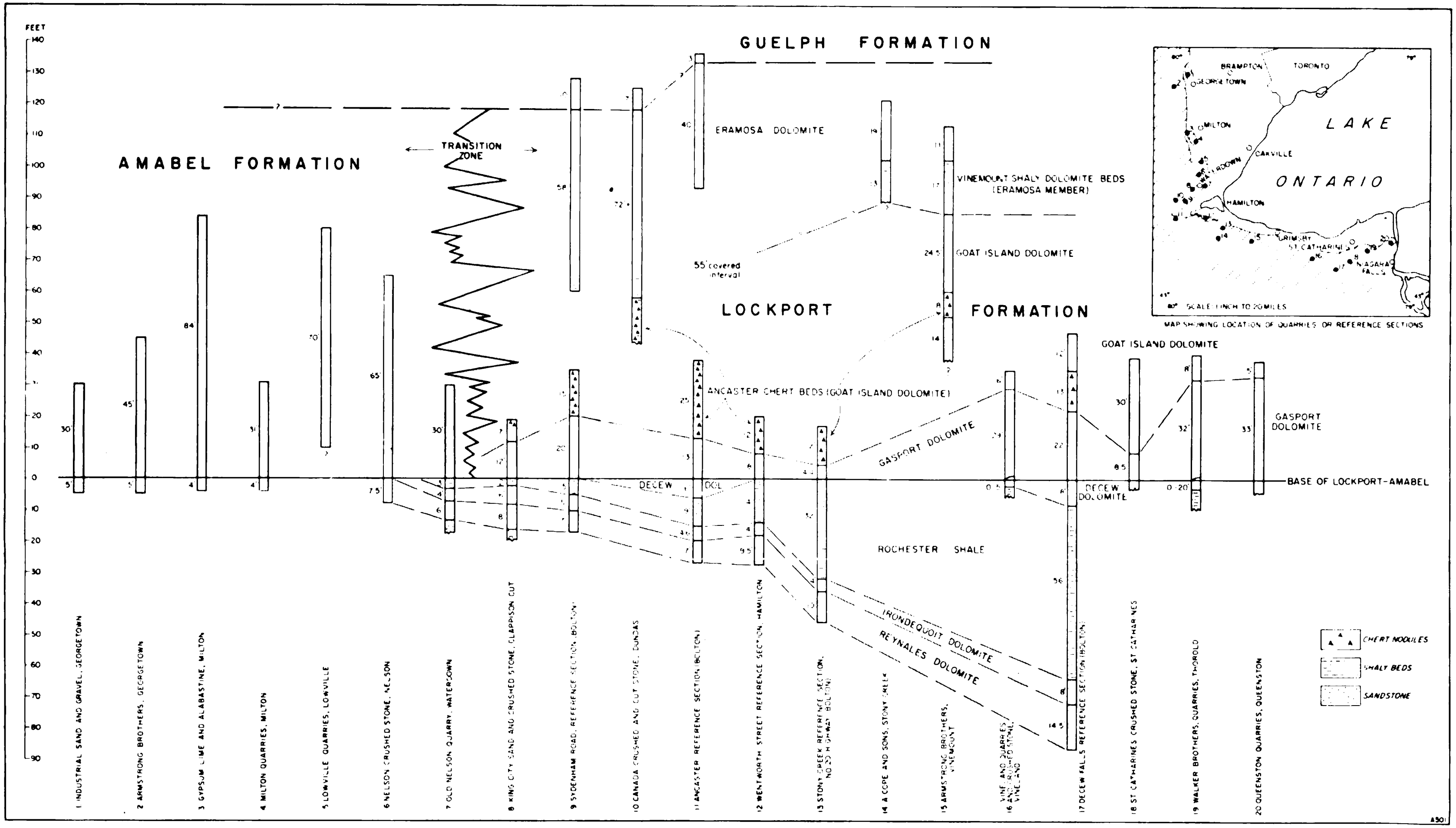


Figure 14. Geological Reference Sections and Quarry Sections, Lockport-Amabel Formations, Niagara Falls-Dundas-Georgetown Area. (After Hewitt, 1960)

brown cherty, more clay-rich beds may represent the flank beds of a part of the "barrier reef complex."

The factor that causes the reversal of the index of clasticity in these small bioherms, is the reversal of the bottom slope due to the growth of a reef offshore. Clastics can be washed from these bioherms by wave action. Could not tectonic deformation cause a similar slope reversal around the rim of an embryonic basin, which resulted in a reversal of clasticity in the Engadine-Manistique strata? This indicates that the Michigan Basin was forming and sinking during Niagaran time.

The medium-gray to blue-gray beds within the Engadine Formation may represent a restricted lagoonal environment within the "barrier reef complex." Referring back to Figure 9, the abrupt lateral gradation of the Upper White into the Upper Cherty may be the result of increased slope conditions, which shortened the lateral extent of a possible lagoonal environment represented by the Gray Beds. Comparison of the fence diagrams in Figures 9 and 10 with the structural contour map of the Engadine-Manistique contact in Figure 6 shows that the Upper White tends to grade more abruptly into the Gray Beds where there is a greater slope. If there is a lesser slope, the Gray Beds have a greater lateral extent.

If it is assumed that normal erosional processes occurred in a "barrier reef complex" of Silurian time in the Michigan Basin, lagoon and barrier facies might be preserved in these rock strata. If the "barrier reef complex" migrated toward the rim of the Basin, and further, if this took place quickly enough, then submergence may have produced a regular and even shoreline bordered by shallow waters. Sediment brought to the sites of deposition could be colloidal and dissolved carbonates. Further, the submerged surface may have had a slope less than that of the profile of equilibrium. Erosion of the "main reef" would ensue, and possibly barrier beaches with lagoons behind them toward the rim of the Basin would form on the landward side of the "barrier reef." These barrier beaches, formed from waves breaking some distance from the shore, may have been heightened by wind action.

Assuming a quick enough transgression, calcarenite sands may have progressed Basinward toward the lagoons and buried the latter, if submergence took place before the barrier moved back to the original shore. Also, at this time, sea level must have changed rather quickly, resulting in the protection of the lagoonal carbonate clay sediments. The thickness of the sands would tend to be erratic, because they were formed in stream channels. This sequence of events complies with the interpretation that the Gray Beds of the Engadine are lagoonal clays.

Additionally, a marine swamp may have formed in the lagoons, which can be full of sulfates and sulfate reducing bacteria. Some of the hydrogen sulfide formed could lead to the formation of iron sulfide. Pyrite is found in the Gray Beds in significant quantities at certain horizons, including the contact of the Engadine-Manistique strata. The gray color may preserve reducing conditions within the initial sediment.

The exposed section of the Niagaran of the Michigan Basin consists of an almost entirely dolomite section. These dolomites are crystalline, and have demonstrable lateral gradations within them. The fact that they are visibly crystalline indicates that they are probably not evaporite dolomites. And, since most reef environments today have either limestone or aragonite being deposited in them, as in the Bahamas and the great Barrier Reef of Australia, it might be assumed that the dolomite of the Silurian reefs represents replacement, whether early or late.

The almost complete obliteration of fossils indicates the secondary replacement of these former limestones. Furthermore, some of the porosity in these rocks may be the result of epigenetic dolomitization, since dolomite takes up less space than calcite or aragonite. However, many dolomitized cores of Niagaran bioherms have very little porosity within them.

It is thought by some stratigraphers that the Niagaran reef strata have been exposed to erosion many times, and that a subaerial dolomitization may have taken place by ground water processes. On the other hand, since many dolomites tend to occur near the edge of a basin or trough of deposition, the stagnation of near-shore waters and/or proximity to the source of magnesium supply may be the cause of such dolomitization (Prouty, 1948).

The stromatoporoids, stromatolites, and algae of the Gray Beds of the Engadine Formation are not incompatible with the interpretation of a lagoonal facies, since the quiet waters of lagoons encourage the growth of much floating vegetation and possible animal life, which tends to be relatively thin and flat lying.

The soft, sugary, loosely cemented, coarsely crystalline, light gray-beds of the Upper White may be calcarenites, although thin sections reveal no positive evidence of clastic origin. The very pure chemical composition of these beds (less than .5 percent silica) lends credence to the concept of a cleanly washed second cycle carbonate sand. Further, the loosely cemented grains have occasional rounded and frosted quartz sand grains and rounded almandine garnet grains within them (Ehlers and Kesling, 1962). This may indicate that the crystalline dolomite is composed of former clastic carbonate grains of sand size.

The cherty coralline beds in the Manistique have a different composite animal assemblage from the Gray Bed facies of the Engadine. This may represent the reef detritus of Shelden (1961), and should be quite different in animal assemblage, if it is compared to modern day reefs (Twenhofel, 1950). Also, anthozoan corals would grow in the clearer, more normally saline waters that were more oxidized, as in the Lower Cherty and Lower Brown facies of the Manistique Formation.

Silicification in the form of silicified fossils and chert probably occurred before dolomitization of the Niagaran strata. Silicified fossils are usually quite well preserved in contrast to the destruction of fossils by dolomitization.

The same type fossils are partially silicified in some beds (Lower Brown and Upper Brown) and completely silicified in others (Lower Cherty and Upper Cherty). For instance, Favosites is completely silicified in the Lower Cherty, while only partially so in the Lower Brown beds. This may be the result of time of exposure of the fossils to normal sea water. The more protected, somewhat deeper waters may have allowed complete silicification in the form of chert, whereas the somewhat less protected and less deep waters may have allowed only partial silicification of the outer parts of the organism. The silica had less time to replace in the latter case. In the Upper White and Gray Beds, there may not have been time enough for any silicification to take place. The waters may have been shallower and in more constant agitation.

Minor Features--Drummond Island

Chert Near Top of Manistique

The fence diagram of Figure 7 shows the outstanding minor features of the Engadine-Manistique strata. Well cores DD10 and E9, show one inch chert nodules in the top of the Manistique, just below the base of the Engadine. This chert is erratic in its occurrence. This is shown by the fact that nearly all the drill holes surrounding these two have identifiable cycles which have already been described for the Lower Brown beds. The structural contours of the Engadine-Manistique contact in this area, as shown in Figure 6, indicate the possibility that these were local structural lows. This chert may have been deposited in the more protected, slightly deeper waters of structural lows.

Cycles in Lower Brown

The question arises as to what the cycles in the Lower Brown actually mean in their sedimentary environment. The small cycles are amazingly similar to the larger cycle in the overlying Engadine. The Gray Beds Upper White; Dark Blue; brown, blue-mottled one foot; Upper Cherty sequence corresponds to the some blue-mottling, siliceous; light-tan one foot; latter facies mottled at top brown, blue-mottled and less siliceous sequence in the smaller cycles in the Lower Brown beds.

The slightly mottled rock below the coarser, lighter one foot bed in the Lower Brown beds corresponds to the non-mottled but gray beds beneath the Upper White. The larger crystal size of the very light-tan phase is similar to the larger grain size of the Upper White of the Engadine. The coarser part of the cycle might represent small mounds of carbonate sand that accumulated on the seaward side of lagoons.

Figure 15 shows a four foot section of rock in well core E9. This may indicate that chert was being deposited at the same time as the coarser one foot of dolomite in the Lower Brown cycles. This requires the assumption that the mottled phase carried through from one facies to the other. Comparison of the fence diagrams in Figures 7, 9, and 10, shows that the mottled phase of the interfingering cherty strata may carry through into the Gray Beds as interrupted stringers. The mottled stringers which occur in approximately the upper two-thirds of the Gray Beds correspond in position with the mottled beds of the interfingering cherty facies.

If this interpretation is accurate, the coarser one foot section of the lower brown cycles may be small mounds of carbonate sand that formed at the same time as chert. At the same time these small mounds of sand were accumulating, it is possible that the sediment in the slightly deeper waters had a longer contact with less agitated sea

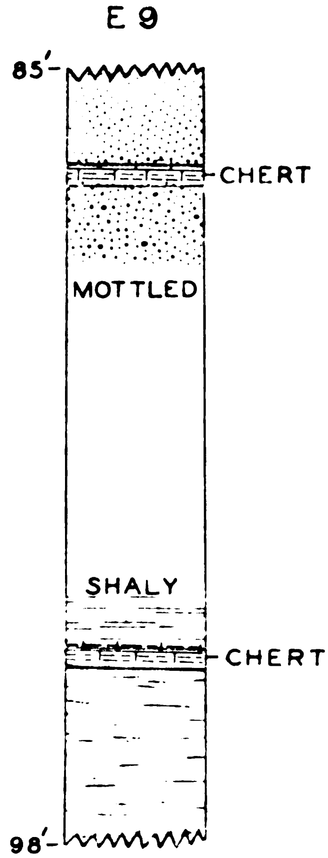


Figure 15. Brown dolomite, with chert, mottling, and shaly subfacies near the top of the Manistique Formation.

water, and consequently became chertified. Otherwise, chertification may depend on the carbonate sediment being exposed to sea water for a sufficient length of time in a relatively protected location where agitation of the water was limited.

The blue mottled phase at the top of each cycle in the Upper Brown becomes thicker and thicker through ascending cycles. This could possibly represent a minor restricted environment similar to a lagoon, which finally culminates in the Gray Beds within the relatively large cycle within the Engadine Formation above.

Small bioherms in the Wiarton Member of the Amabel Formation of Ontario have a similar narrow blue-mottled zone which is better developed on the top than on the bottom of these small mounds of fossil organic material. This may parallel the situation found in the Lower Brown beds of Drummond Island. It is hard to believe that these amazing similarities are not related in some way.

In Figure 15, the pattern of mottling within the dolomite above and below the chert is similar to the pattern of shaly partings above and below the chert. This suggests that the shaly partings, when present in the cherty beds, may correspond in relative position with the mottled phase. The mottled phase may result from a delicate increase in the agitation of the sea water. It must be noted, however, that the shaly zone is restricted mostly to the Lower Cherty facies. Because of its much greater number of shaly partings, it seems that the Lower Cherty represents a time of considerable clay influx, whereas, during the deposition of the Upper Cherty, less clay was coming into the Basin. However, in the latter case, differences in the amount of agitation might still have controlled the type of facies that formed, as mottling is found in the Upper Brown.

Chalky White Facies

One last minor feature of some interest concerns small sections of rock within the Gray Beds. These contain very finely crystalline chalky white dolomite. Several instances were observed in cores where this subfacies was penetrated by joints. In several instances the chalky white area, which was immediately adjacent to the joint, disappeared about one-quarter to one-half inch away from the joint. This suggests that the finely comminuted chalky white dolomite may be due to weathering by surface waters. The weathered outcrop of these strata has a layer of this same chalky white dolomite. This again appears to indicate that surface weathering produced this variety of dolomite.

CHAPTER IV

STRUCTURAL GEOLOGY

General Statement

The Michigan Basin trends northwest-southeast in a roughly ovate form. Structure maps prepared from subsurface data of the Devonian and Mississippian formations show dominant northwest-southeast structural trends in the central Basin area. Some known faulting parallels this trend. These structures may be due to a Basinal slump which resulted in tensional faults and consequent minor folding (Lockett, 1947). The studies of Ver Wiebe (1928) and Burns (1962) indicate that some of the areas away from the central Basinal areas toward and near the rim of the Basin may have undergone radial tangential compression as the Basin was sinking. However, the literature is seemingly deficient in studies of joint analysis in regard to the Michigan Basin.

Southern Drummond Island

General Structure

The structural contour map of the Manistique-Engadine contact of Figure 6 shows two north-south trending synclines, one between Pike Bay and Huron Bay, and the other between Helens Lake and Knutsen Lake. The latter structure appears to have more of a northeast-southwest trend. However, the structural depression containing the cherty beds, trends north-south. In both cases the Upper Cherty and the remaining Engadine strata are found in structural depressions, and this causes the cropping out, or sub-cropping out, of the Upper Cherty. Also, in the more southerly suboutcrops, the Upper Brown, which is the highest formation present on this part of the island, is present.

To the north of Traverse Point, the structural contours of the Manistique-Engadine contact show a small north-south trending anticline. Another small north-south trending anticline was mapped from the outcrops at Seaman's Point. The structural contours of the Manistique-Engadine contact consist of more gentle rolls to the north of the north-south anticlines and syclines.

As the Lower Brown has a very consistent thickness of about 20 feet, and the Gray Beds are fairly constant in thickness throughout the area, it might be assumed that the above mentioned folds are structural arches. Further, it is possible to assume that these strata have been subjected to a northeast-southwest compression which formed the northwest-southeast trending anticlines and synclines. The latter compression is nearly at right angles to the northwest-southeast trending ovate form of the Basin in Salina time. This, together with the many northwest-southeast trending anticlines and synclines within the Basin, suggests that the Michigan Basin was subjected to a dominant northeast-southwest compression from Salina time onward. If this compression deformed the Niagaran rocks, the northeast-southwest compression of Drummond Island may be evidence that radial folding occurred around the edges of the sinking Basin.

Figure 6 also shows a number of recorded joint patterns in the area. All strikes were measured with reference to magnetic north. Since a joint angle of less than 90 degrees within rock faces the compressive force in a brittle deformation of rocks, these strike directions are in accordance with a brittle east-west compression. We can assume only that these rocks underwent a brittle deformation.

There is a change in the joint pattern from the north of Seaman's Point down to the southern shore of the island. The joint sets change from about N. 50 E. - N. 40 W. to N. 75 E - N. 40 W. into the higher strata of the Upper White, and finally into the Upper Cherty.

The Upper White--Upper Cherty contact is present along the entire southern shore of the Island. It is possible to judge where the more southerly cherty beds are approached, because the joint pattern progressively changes from N. 50 E.-N. 40 W. to N 70 E.-N. 40-W. and thence to the cherty beds with a N. 75-N. 40 W joint set. Towards the very cherty beds at Bass Cove on the southeastern part of the island, the pattern changes from N. 50 E. - N. 40 W. to N. 70 E. - N. 40 W. to N. 80 E. - N. 40 W., with the last being in the very cherty beds.

Figure 16 shows how this may be interpreted as evidence for a east-west compression of brittle dolomite, which becomes more at right angles to a possible northeast-southwest compression of the Basin in situations "B" and "C" of the figure. The latter situation in the cherty beds on the southern shore of the island may, in part, be stratigraphically higher than the Upper White facies. This could possibly represent the start of the northeast-southwest compression which formed the northwest-southeast trending Basin of Salina time.

Plate 3 shows a lateral change in the joint pattern at the old quarry on the southwestern part of the island. The change occurs entirely within the Gray Beds, and is similar to the one described above. When the joint set changes from N. 45 E. - N. 45 W. to about N. 75 E. - N. 40 W., there is a correspondingly slight increase in the silica content. This slight increase in silica, (.5%), greatly increases the difficulty of drilling. However, the N. 75 E. - N. 40 W. joint set, which again indicates a more nearly northeast-southwest compression, appears to be on the same stratigraphic level with the N. 45 E. - N. 45 W. joint set. Chemical composition may have played an important role in

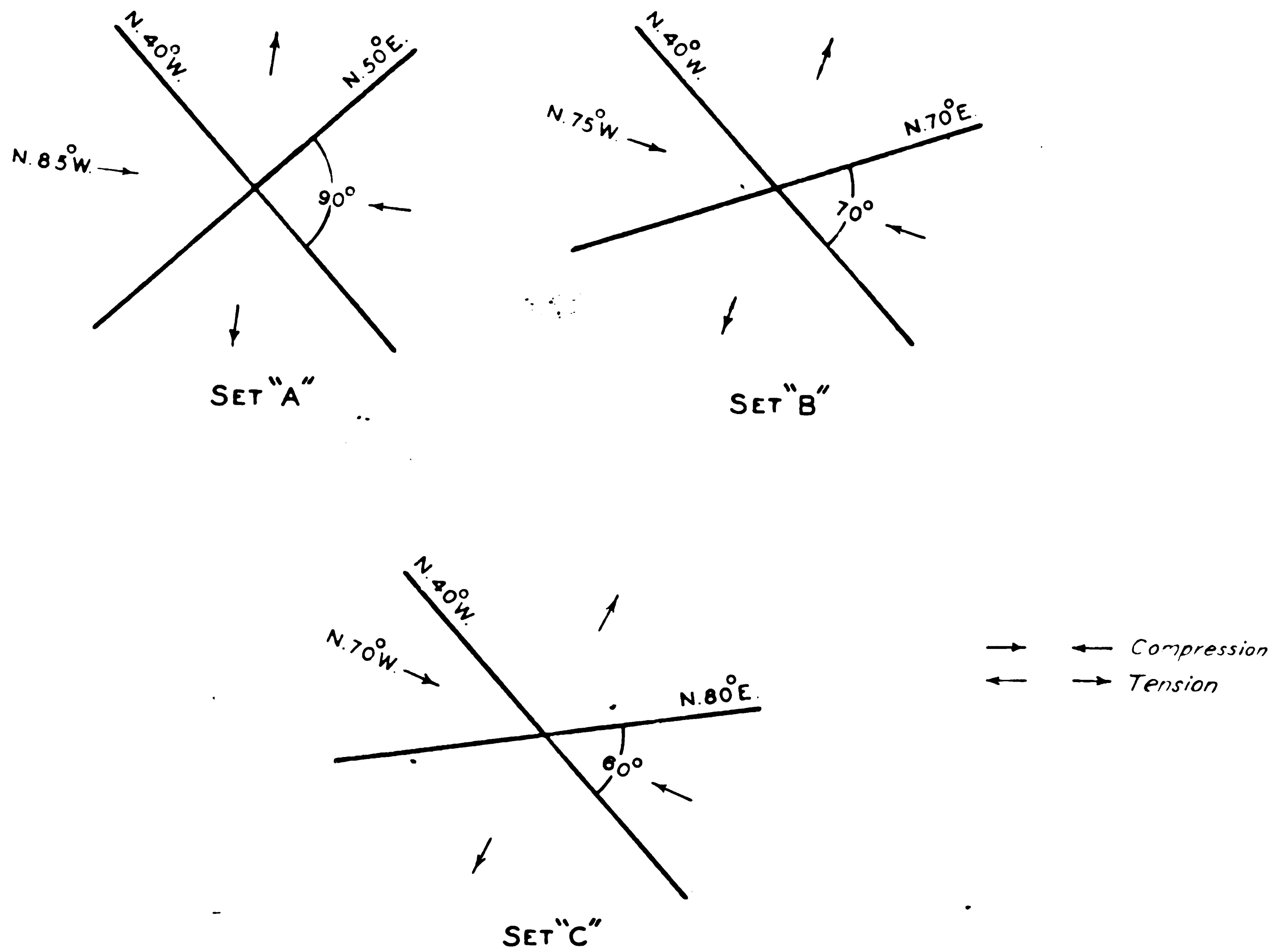
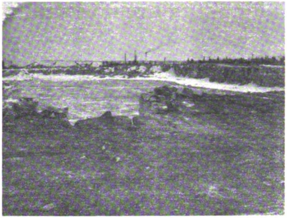
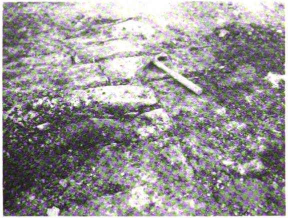
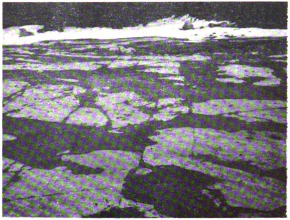


Figure 16. Change in joint sets when approaching the southern shore of Drummond Island from the north.





Above: Looking southwest at N45E,-N45W, joint set in old quarry.
Below: Close up of picture above.



Above: Looking N75E, at N75E,-N40W, joint set in slightly more siliceous rock at same horizon shown at left.
Below: Close up of picture above.

PLATE 3

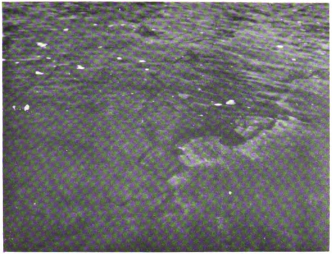
controlling the strike directions of the joints. An increase in silica may have made the rocks more brittle.

Plate 4 shows a local situation at the lateral gradation between the Upper White and the Upper Cherty. The Upper White has a dominant N. 80 W. joint direction with a minor set at right angles to it. The dominant joint direction carries a short distance into the Upper Cherty, as shown in the picture. The Upper Cherty has a dominant N. 70 E. joint direction with a minor set at right angles to it. In one locality a few hundred feet to the west, the "marker horizon" had one minor N. 80 W. dominant joint with subsidiary joints at right angles to it (Figure 6). This may indicate a local wrenching in the stress pattern within the area of abrupt lateral gradation or it may be due to a change in composition.

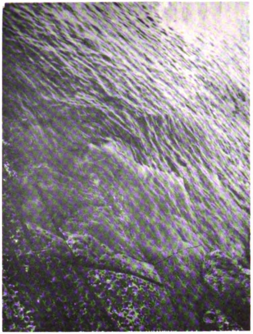
Fabric and Structure

Figure 17 shows the results of a study which attempted to determine whether there might possibly be some fabric in the sedimentary dolomites of the Gray Beds of the Engadine Formation. The spacial orientations of dolomite "c" axes were determined with the universal stage microscope. All sections shown are horizontal, with magnetic north marked on them. In all cases the bottom hemisphere is plotted.

All the thin sections were taken within the Gray Beds, a few hundred feet from well core D9. At this locality,



Looking southwest at N70E-N20W joint set overlying N10E-N80W set. The N80W joints continue a short horizontal distance into the upper layer.
Picture taken close to Helen's Lake, near the lateral gradation between the Upper White and the Upper Cherty.



Looking west at surface of layer with N70E-N20W joint set showing typical surface weathering of the Upper White facies.
Picture taken immediately adjacent to picture at left.

PLATE 4

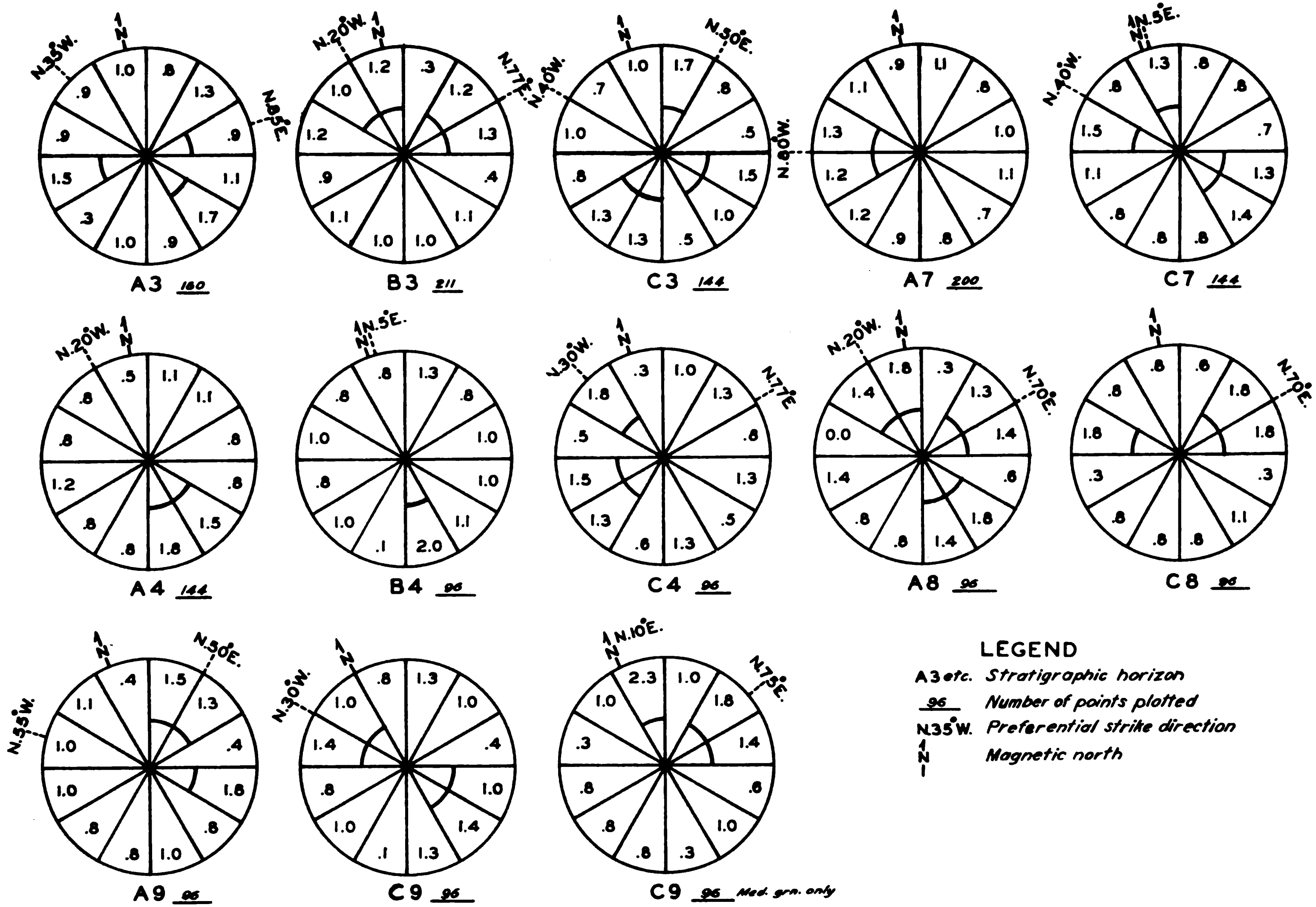


Figure 17. Petrographic azimuth analysis of fabric within the Engadine Dolomite of Drummond Island, Michigan, using "c" axes of dolomite.

however, four discontinuous stringers, of finely crystalline, blue-mottled, light-brown dolomite are present within the Gray Beds. These range from one-half to three feet in thickness.

Examination of the fabrics reveals that only weak 1% contours plus a very rare 2% contour can be obtained by the usual contour methods. However, there is a very noticeable 60 degrees of azimuth concentration in many of the fabrics. Further, in these same fabrics, there are approximately 30 degrees of azimuth on each side of the larger concentration, which have a relatively low concentration of dolomite "c" axes. In view of these observations, it appears logical to divide the fabric into 12 equal radial parts, making sure that one 30 degree radial part includes the lowest concentration of axes on the fabric diagram.

Figure 17 is the result of this type of azimuthal analysis, which is also a preferential strike analysis. A value of 1.0 in Figure 17 indicates that a particular radial azimuth division has the number of axes that would be expected if there were no preferential concentration. A value of .3 means that the radial division has only .3 the number of axes expected in a chance distribution.

A3, B3, and C3 represent a transitional Gray Bed facies, which is actually more blue-gray "mottled" than the usual Gray Beds. Chemical analysis shows that this facies has a slightly higher acid insoluble and silica content than the usual Gray Beds. Microscopically, the silica content appears to be concentrated in very small and rare patches of crystalline quartz.

A7 and C7 are normal Gray Bed strata. A4, B4, C4, A9, and C9 are the finely crystalline blue-mottled more thinly bedded brown beds that occur as relatively thin interrupted stringers within the Gray Beds. A8 and C8 are coarser, medium-crystalline portions of the latter facies. A minor coarser, medium-crystalline section within slide C9 is also plotted.

B3, C4, A8, C8, and C9, medium crystalline only, have a 60 degree radial division of azimuthal concentration with a deficient 30 degree division on each side of it. B3, A8, and C8 have the middle of the 60 degree concentration striking N. 70 E. The middle of the concentration in C4 strikes N. 77 E., and in C9, medium crystalline only, strikes N. 75 E. From outcrop data, N. 70 E. is a preferential strike direction of the joints in transitional facies, of which all these sections are composed.

C3 has a N. 50 E. - N. 40 W. preferential strike concentration, which is known in outcrop as a joint set which changes to a predominant N. 70 E. - minor N. 40 W. joint set, to the south on Drummond Island. A3 has a preferential strike direction, which is similar to the set in the slightly more than normal siliceous Gray Beds of the old quarry. Also, as in the old quarry, the facies of A3 has slightly more silica and insoluble residue than the usual Gray Beds of the region.

B3 and A8 have a N. 70 E. - N. 20 W. preferential concentration of dolomite axes. On the southern part of the island to the south of Helens Lake, this joint set occurs close to and within the transitional lateral contact of the more siliceous cherty beds. C7, B4, and C9, medium crystalline only, show a concentration of dolomite "c" axes which correlates with this direction.

A small 50 foot surface of natural outcrop, adjacent to the place where the microscopic sections were taken, shows a jumbled assemblage of joints which includes all the directions shown in the preferential strike concentrations of the dolomite axes.

Although these data are inconclusive, slight preferential fabric is indicated within these dolomites. The fabrics may be related to the joint patterns or stress patterns in a rather complicated manner. There is a lateral as well as a stratigraphic change in joint patterns which may be related to the internal fabric. Future concentrated work on rock with known joint patterns may produce more definite correlations.

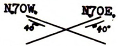
Regional Structural Geology

Joint Sets at Cedarville

Plate 5 shows the dominant joint set at Cedarville, Michigan, which is about 20 miles to the west of Drummond,

Above: Looking N70E, at joints dipping 40°S, in Cedarville quarry, twenty miles west of Drummond Island.
Below: Looking west at joints on the southeastern part of Drummond Island, orientation as above.

Looking S70E, at joints dipping 40°S. in Cedarville quarry, twenty miles west of Drummond Island.



Joint set at
Cedarville, Michigan

PLATE 5

and within the same sequence of Niagaran rocks. This N. 70 E. - N. 70 W. joint set indicates an east-west compression for these northern Niagaran rocks. However, the southerly dip of the joints indicates that the direction of least compression was more upward than lateral. Plate 5 also shows a southerly dipping set of joints which strike N. 70 E. and are on the southeastern part of Drummond Island. These are near the abrupt lateral gradation of the Upper White into the Upper Cherty. It is difficult to ascertain why the least compression should be slanted upward, but it may be related in some way to the abrupt lateral gradation of these facies.

Joints at Quarry, Wisconsin

At Quarry, Wisconsin, joints are in a facies similar to the blue-gray dolomites of the Engadine Formation. These joints are only found on the top of the quarry. They have a N. 50 E. - N. 40 W. joint set, while the floor of the quarry, which is composed of dense brown dolomite, has a N. 25 E. - N. 20 W. joint set. Again, this may represent compression that is roughly at right angles to the rim of the Basin, and which occurs near the edges of the Basin.

Anticlinal Structures of Southern part of Basin

Burns (1962) has plotted the anticlinal structures of the southern part of the Michigan Basin, which are essentially perpendicular to the edge of the Basin. These suggest tangential compression of the southern part of the Basin.

This concept should be more intensively studied by further mapping of joints and anticlinal trends throughout the Basin.

CHAPTER V

REGIONAL LATERAL GRADATION WITHIN THE MICHIGAN BASIN

Cross Sections of Michigan Basin

Figure 18 shows several cross sections of the Niagaran rocks of the Michigan Basin. The word "Clinton" is used only to point out a horizon in these rocks, which oil men are constantly trying to identify. In many wells the top of the chert is not identifiable.

Basinward Lateral Gradation

Well number 4 has more gray dolomite than well number 3, and well number 7 has more gray dolomite than well number 6. This may indicate that the dolomites tend to become darker in color toward the interior of the Basin. This situation is similar to that on Drummond Island where the rocks grade laterally from light-gray to medium-gray to brown dolomite. Gray dolomite grades laterally into brown dolomite toward the Basin interior.

The brown dolomites in turn consistently grade laterally into brown limestones in the interior of the Basin. The index map shows the approximate area of Niagaran limestones within the Michigan Basin.

Brown limestones grade laterally into gray limestones, which tend to be slightly more argillaceous than the dolomites, and are red tinted. Two levels of red tinted, slightly argillaceous limestones may be the result of small amounts of clay coming through the inlets of a barrier reef complex.

CHAPTER VI

COMPARISON OF MICHIGAN BASIN SILURIAN REEFS WITH DRUMMOND ISLAND, MICHIGAN

The Klint at Cedarburg

Shock (1939) describes a small reef or klint at Cedarburg, Wisconsin, which has a core of medium-gray dolomite. The flank beds are of unuaual purity, and dip a few degrees away from the "reef" or klint. These flank beds are nearly white in color, coarse grained, and loosely cemented. These factors indicate that the white flank beds probably are or were originally a calcarenite. The most common type of Silurian reef, with the exception of some Guelph reefs in Ontario, has a relatively high purity dolomite core. Flank beds have a higher clay, quartz sand, and chert content. The small klint in Wisconsin, described by Shrock, does not have this common reverse index of clasticity. Possibly it was an erosional remnant that had second cycle sands deposited on top of its flanks.

This description of the flank beds at Cedarburg is close to that given in this paper for the Upper White of Drummond Island. Drill cores from the Upper White can be broken very easily with one's hands, indicating that it breaks around the dolomite grains very easily. This may indicate a calcarenite origin.

Marine City Field

In outcrop, the Gray Beds are characterized by major clay partings varying from 0 to 1 foot in thickness, which occur regularly at 10 foot intervals. If these clay partings are the result of original deposition, this facies is similar to the "gray" Niagaran of the Marine City Field (Alguire, 1962). The "gray" Niagaran shows up as a slightly more shaly zone on the electric logs.

However, in the Marine City Field the "gray" Niagaran is underlain by a considerably thick "white" Niagaran. This is the reverse of the situation on Drummond Island, where the thickest white facies overlies the Gray Beds.

In the Marine City Field, the "brown" facies overlying the "gray" Niagaran has reefing in it, with up to 300 feet of relief over a horizontal distance of usually less than a mile. The reefs closest to the interior of the Basin have the maximum amount of relief (Ells, 1961).

If the lateral change Basinward within dolomites toward deeper water, as previously suggested, is from white to gray to brown dolomite, a possible transgression represented in the vertical sequence in the Marine City Field should be present on Drummond Island. The Upper White does grade upward into a 1 to 12 foot zone of Dark Gray beds, and thence into the Upper Cherty. This may represent the same transgression as is found in the Marine City Field. In this case, however, the thickness of the gray phase is considerably less than in the Marine City Field, where it is about fifty feet. This could possibly indicate that on Drummond Island the environment of the Gray Beds was closer to that of the Upper White when the transgression occurred. It might also mean that a part of the original Dark Gray beds was removed by erosion. The gradual change from the Lower Brown of Drummond Island upward to the Upper White may be absent in the Marine City Field, due to the fact that this gradual change only occurred near the edge of the Basin.

Quarry, Wisconsin

Figure 19 shows the bioherm at Quarry, Wisconsin. The chert appears in the flank beds, and this is a similar situation to that of Drummond Island where the portion of the Upper Cherty is Basinward relative to the Gray Beds. Clay partings increase away from the bioherm core. The protected, less agitated waters may have been preferential locations where small amounts of clay could settle in thin layers, and also chert could form.

Thornton Bioherm

Figure 20 shows a cross section of the Thornton Bioherm. Similarities to Drummond Island occur as chert in the following beds again suggest the possibility of

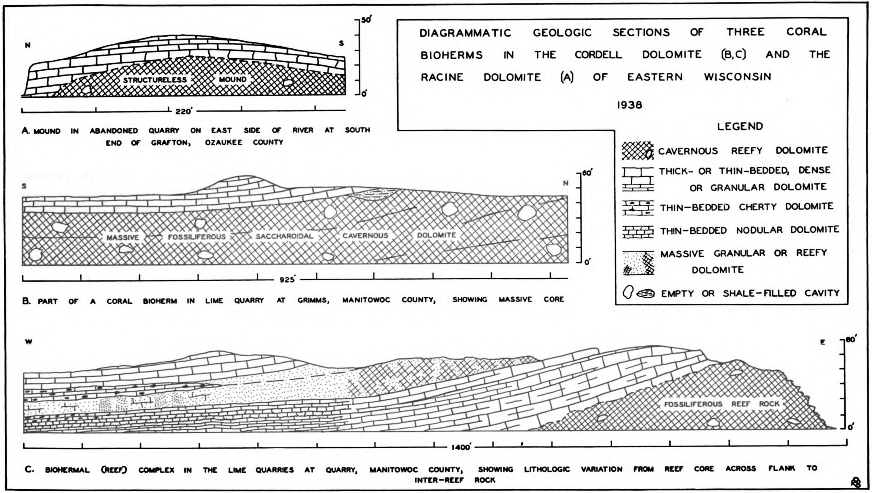


Figure 19. Diagrammatic cross sections of coral bioherms of Eastern Wisconsin. (Modified after Shrock, 1939)

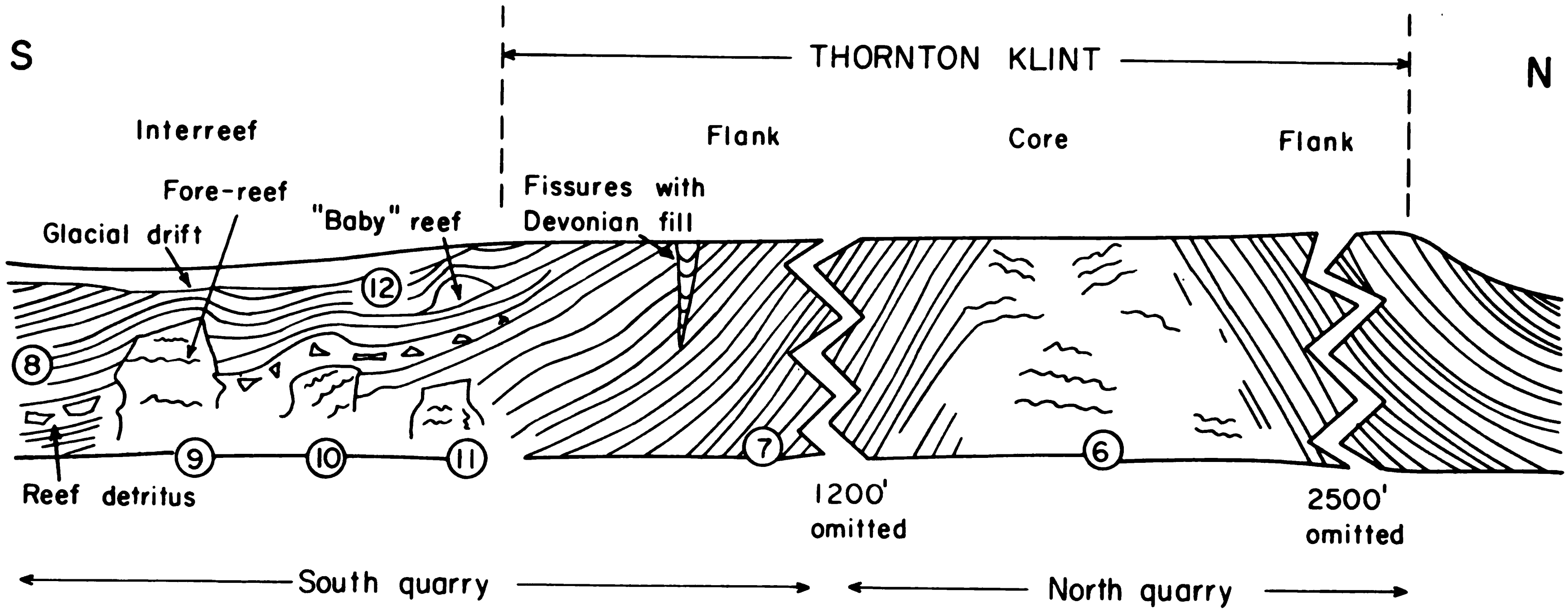


Figure 20. Diagrammatic cross section of the Thornton reef showing relations of stops projected onto west wall of the Material Service Corporation quarries. (After Willman, et. al., 1962)

chert being formed in an environment, which had a slightly deeper, somewhat more protected waters. In general, it may be said that the bioherms of the Racine Formation of Wisconsin, which is the lateral equivalent of the Engadine Formation of Michigan, have a relatively pure, porous biohermal rock core with argillaceous, silty and cherty inter-bioherm rock (Willman, 1962). The core lithology is similar to the Gray Beds, and the flank beds similar to the cherty strata on Drummond Island.

Figure 14 shows the Amabel formation of Ontario grading laterally into the Ancaster Cnert beds (Hewitt, 1960). This again indicates a reverse index of clasticity for Niagaran rocks. Similar to the case in Michigan, the more cherty beds occur toward the interior of the basin.

CHAPTER VII

COMPARISON OF NIAGARAN REEFS WITH OTHER PALEOZOIC AND PRESENT-DAY REEFS

Permian Reef Complex

Both in the Permian Reef Complex and the ideal outcrop of reef facies given by Link (1950), the reef core consists of lighter colored dolomites and limestones. The fore-reef facies has more black bituminous material than the lighter oil-bearing reef, and is stained brown. Both of these facts are similar to the situation found on Drummond Island. The fore-reef is represented by the Upper Cherty of the Engadine, while the lighter white weathered dolomites of the reef are represented by the Gray Beds and the Upper White.

The alternation of clastics in the dolomites in the backreef lagoonal sediments of Drummond Island, which may be represented by the Burnt Bluff Group (Shelden, 1961), have a parallel in the Permian Reef Complex.

The back reef, reef, and reef detritus of the Permian Reef Complex (Newell, *et al.*, 1953) are generally dolomitized, while the deeper sediments are dark colored limestones. This parallels the Niagaran reefs where the edge of the basin dolomites grade laterally into the interior limestones, which are generally darker colored. As the Permian Reef Complex involves a restricted basin (Delaware Basin), there is even more similarity. The reverse index of clasticity in the Delaware Basin parallels the known situation in the Michigan Basin.

Devonian LeDuc Field of Alberta

At Drummond Island, however, the lateral extent of the "reefal" facies (Lower White, Gray Beds, and Upper White) may be more similar to the Devonian LeDuc Field of Alberta (Waring & Layer, 1953), which is relatively flat lying and five to ten miles in lateral extent. The latter may be bedded, as it has small shale interruptions, which may parallel the Engadine of Michigan, or the "gray Niagaran" of the Marine City Field. Michigan Niagaran reefs tend to become more biostromal as one approaches the edges of the Basin (Ells, 1961, and Lowenstam, 1950). This leads more to the possibility of the Drummond Island reef complex paralleling the so called fringing reef with its lesser slope (Henson, 1950). Also, the possibility of fore-reef shoals in the Lower Brown transitional beds, which is the same facies as the Lions Head (Bolton, 1957) of Ontario, may exist if a lesser slope and broader reefs were developed.

Coral Reefs of Australia

The Lower Brown may represent an alternation of lagoonal and sand sedimentation. This possibility is suggested by the coral reefs of Australia with their development of Mangrove swamps and their consequent covering by calcareous sands (Fairbridge, 1950). Further, the gray-green glauconitic sands, which have some pyrite and are overlain by coral sand in the coral reefs of Australia, have some similarity to the Gray Bed--Upper White sequence of Drummond Island.

The tendency of calcareous sands to form on the landward lee side of the Australian coral reefs with the mangrove swamps forming the windward side may find some parallel on Drummond Island, where it appears the best interpretation of lateral gradation is that the white calcarenite beds grade laterally into lagoonal gray beds, and thence into cherty flank beds toward the center of the Basin.

There seems to be no duplicate of the Niagaran reefs of Michigan, but there are many similarities to the ancient and recent reefs of the world.

CHAPTER VIII

SUMMARY

The variegated facies of the Niagaran both on Drummond Island and within the Michigan Basin suggest a "barrier reef." Interior Basinal facies appear consistently more siliceous and more argillaceous than those closer to the edge of the Basin. This suggests that clay came through the inlets of a barrier reef into the more interior parts of the Basin. The lack of numerous, recognizable fossils may be due to dolomitization.

The Upper Manistique and Engadine Formations of Drummond Island, Michigan have a cyclic regularity within the vertical sequence of facies. The larger cycle, which starts with the Lower Cherty facies and progresses upward through the Lower Brown-Lower White-Gray Beds-Upper White-Dark Gray sequence, starts to repeat itself in the Upper Cherty-Upper Brown sequence.

The above is the larger cycle present on Drummond Island. There are smaller cycles present within the facies of the major cycle. Within chert and shale cycles of the Lower Cherty, the cycles with the greater number of shaly partings may have been deposited farther from shore, or the source area. This indicates the clay may have come through the inlets of a "barrier reef."

The small cycles present in the Lower Brown have a decreasing chert content upward. The sequence of facies upward within these cycles in the Lower Brown is essentially the following: Cherty brown dolomite light-tan coarsely crystalline dolomite blue-black-mottled in the top of the latter cherty brown dolomite with less chert than the first mentioned facies of the cycle. This sequence is similar to the major cycle, with the exception that the chert decreases in each succeeding upward cycle within the Lower Brown facies. This culminates in the larger cycle, which consists of the top of the Lower Brown; Lower White; Gray Beds sequence; then back to the white facies in the Upper White; Dark Gray sequence. Finally, the Upper Cherty; Upper Brown sequence appears. It may be concluded that the chert is cyclic in both the large and the smaller cycles. The amount of chert rhythmically decreases upward in the smaller cycles of the Lower Brown. Similar to this within the larger cycle, the Upper White has the least amount of chert.

The observation that chert apparently occurs preferentially on the flanks of known reefs as the Thornton at Chicago, Quarry, Wisconsin, and probably Drummond Island, suggest that chert forms in more protected, less agitated waters, where the sediment has a longer contact with sea water.

Within cyclic deposition of facies, it is to be expected that lateral gradations of the facies will occur. It can be shown by following a marker zone in outcrop on the southern part of the island that the Upper White grades laterally into the Upper Cherty. This change occurs over a horizontal distance of several hundred feet. Cross-sections of this part of the island also show that the Gray Beds grade laterally into the Upper White. The Basinward sequence of lateral gradation is Gray Beds, Upper White, Upper Cherty. A similar lateral gradation occurs within the Niagaran of Ontario, where the gray Amabel grades laterally into the Ancaster Chert.

The small structural folds and the joint patterns found on Drummond Island suggest the possibility that tangential compression occurred near the rim of the Michigan Basin during Silurian time. Much more evidence around the rim of the Basin is required to substantiate this possibility.

Fabric studies in the facies of Drummond Island indicate a slight preferential orientation of the "c" axes of dolomite, which parallels known joint patterns. Additional study is needed to substantiate this observation further.

Regional Niagaran cross-sections within the Michigan Basin suggest that the Basinward lateral gradation is the following: light-gray beds, darker-gray beds, dark-brown or dark-gray cherty beds. These lateral gradations occur in dolomite. Dolomite facies appear to grade laterally into much thinner brown and then to gray limestones toward the center of the Michigan Basin. The gray limestones have at least one major and one minor slightly argillaceous, red-tinted or red-colored limestone, which may represent temporary drops in sea level during Niagaran time.

The stratigraphic picture in the Michigan Basin shows some similarities with the Permian Reef Complex of the Southwest. Similarly, the Permian Reef Complex has dolomites near the edge of its basin, with darker colored limestones in the interior. Dolomitization occurs toward the edges of most basins and may be the result of increased salinity towards the edges of a sedimentary basin. The interior of the Permian Reef Complex is also more clastic, as in the Michigan Basin.

Drummond Island Niagaran rocks show certain similarities to the Devonian LeDuc Field of Alberta, which is relatively flat lying, and five to ten miles in lateral extent. This reef may be flay lying due to the reef being formed on a lesser bottom slope. Also, in this situation, fore-reef shoals should be found more frequently. The Lower Brown of Drummond Island, which is similar to the Lions Head of Ontario, may have these shoals within it.

The tendency of calcareous sands to form on the landward lee side of the Australian coral reefs with mangrove swamps forming on the windward side may be similar to the Upper White-Gray Beds lateral gradation on Drummond Island.

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APPENDIX

APPENDIX A

LOGS OF EXPLORATORY CORES DRILLED BY DRUMMOND DOLOMITE INC. ON DRUMMOND ISLAND, MICHIGAN

Legend of abbreviations in stratigraphic sequence:

Top:
- UB - Upper Brown
- UC - Upper Cherty
- BB - Blotchy brown, similar to upper brown, but without any chert.
- BM - Thin blue-black mottled brown beds, fine grained, at least 1 foot thick.*
- UW - Upper White
- DB - Dark Blue beds
- GB - Gray Beds
- BT - Brown transitional beds similar to lower brown facies (N24 only)
- GBB - Gray Beds and brown beds, mixed (N24 only)
- LW - Lower White
- LB - Lower Brown

Bottom:
- LC - Lower Cherty

#EE6 - Position of drill core
-C549 - Collar elevation, Datum Plane: Lake Huron - 500 feet

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*Fence diagrams include coarse grained brown facies, which at times is less than 1 foot thick.

NOTE: The thickness of the glacial drift is given by the difference in feet between the collar elevation and the first footage recorded for a diamond drill core.

APPENDIX A

#EE6-C549

GB 31-64
LW 64-65
LB 65-70

#H6-C511

UB 9-44
UC 44-47

#E6A-C539

GB 26-31
BM 31-32
GB 32-39
BM 39-42
GB 42-62
LW 62-63
LB 63-71

#B7-C527

LB 24-42

#C7-C527

GB 10-20
LW 20-24
LB 24-46

#D7-C520

LB 16-40
LC 40-45

#E7-C537

UC 13-21
GB 21-38
BM 38-39
GB 39-60
LW 60-62
LB 62-83
LC 83-86

#F7-C553

UC 17-33
BB 33-42
UW 42-43
BB 43-45

#G7-C553

UB 12-26
UC 26-45

#H7-C543

UB 17-45

#J7-C510

UB 18-60
UC 60-64

#E7A-C549

UW 18-24
BM 24-27
GB 27-66
LW 66-69
LB 69-79

#EE7A-C546

UC 15-18
GB 18-20
BM 20-21
GB 21-72
LW 72-73
LB 73-80

#B8-C530

LB 19-39

#C8-C540

GB 11-24
LW 24-27
LB 27-44

#CC8-C554

GB 14-42
LW 42-43
LB 43-58

#D8-C553

GB 14-36
LW 36-37
LB 37-60
LC 60-80

#DD8-C550

GB 30-57
LW 57-59
LB 59-61

#E8-C555

UC 12-14
DB 14-17
UW 17-30
GB 30-78
LW 78-79
LB 79-84

#EE8-C566

UC 10-30
DB 30-34
UW 34-44
GB 44-90
LW 90-93
LB 93-98

#F8-C561

UB 5-11
UC 11-33
DB 33-42
UW 42-44

#G8-C553

UB 11-39
UC 39-60

#H8-C543

UB 16-46
UC 46-47

#M8-C511

UB 16-31
UC 31-57
UW 57-60
GB 60-69
BM 69-70
GB 70-111
LW 111-112
LB 112-116

#CC8A-C542

GB 10-23
LW 23-25
LB 25-46
LC 46-60

#D8A-C538

GB 11-29
LW 29-30
LB 30-35

#DD8A-C541

GB 17-21
BM 21-22
GB 22-27
BM 27-31
GB 31-32
BM 32-37
GB 37-46
LW 46-47
LB 47-58

#E8A-C572

GB 25-33
UW 33-42
GB 42-92
LW 92-93
LB 93-104

#EE8A-C571

UC 10-18
DB 18-23
UW 23-38
GB 38-88
LW 88-91
LB 91-98

#B9-C538

GB 10-13
LW 13-14
LB 14-36

#C9-C538

GB 1-19
LW 19-20
LB 20-33

#CC9-C539

GB 10-20
LW 20-21
LB 21-42
LC 42-60

#D9-C545

GB 3-17
BM 17-20
GB 20-37
LW 37-38
LB 38-46

#DD9-C538

BM 13-14
GB 14-43
LW 43-44
LB 44-60

#E9-C573

UW 29-44
GB 44-88
LW 88-90
LB 90-99

#EE9-C575

UW 9-34
GB 34-85
LW 85-87
LB 87-93

#F9-C574

UW 11-34
GB 34-84
LW 84-85
LB 85-93

#G9-C559

UC 6-24
DB 24-25
GB 25-35
UW 35-45
GB 45-95
LW 95-96
LB 96-100

#H9-C541

UB 4-26
UC 26-59
DB 59-71

#J9-C527

UB 13-45
UC 45-63
DB 63-64
UW 64-81
GB 81-122
LW 122-127
LB 127-139

#M9-C528

UB 35-45
UC 45-62
DB 62-65
UW 65-81
GB 81-130
LW 130-131
LB 131-134

#CC9A-C539

GB 3-23
LW 23-24
LB 24-32

#D9A-C549

GB 7-43
LW 43-44
LB 44-58

#DD9A-C542

GB 2-8
BM 8-16
GB 16-49
LW 49-50
LB 50-54

#E9A-C574

UW 34-40
GB 40-88
LW 88-89
LB 89-96

#EE9A-C576

UW 17-37
GB 37-51
LW 81-82
LB 82-87

#A10-C557

GB 5-34
LW 34-35
LB 35-56
LC 56-60

#B10-C549

GB 5-36
LW 36-37
LB 37-55
LC 55-60

#C10-C547

GB 10-27
LW 27-28
LB 28-49
LC 49-57

#CC10-C554

GB 11-37
LW 37-40
LB 40-58
LC 58-60

#D10-C565

UW 19-23
GB 23-62
LW 62-65
LB 65-76

#DD10-C580

UW 36-45
GB 45-88
LW 88-90
LB 90-97

#E10-C551

UW 2-21
BM 21-22
GB 22-28
BM 28-29
GB 29-61
LW 61-62
LB 62-73

#EE10-C557

UW 2-17
GB 17-60
LW 60-61
LB 61-63

#F10-C562

UW 2-21
GB 21-62
LW 62-63
LB 63-71

#G10-C557

UW 5-35
GB 35-79
LW 79-82
LB 82-90

#H10-C533

UC 12-21
DB 21-28
UW 28-58
GB 58-106
LW 106-107
LB 107-112

#CC10A-C560

GB 25-63
LW 63-66
LB 66-69

#D10A-C582

GB 32-70
LW 70-73
LB 73-86

#DD10A-C576

UW 25-39
GB 39-80
LW 80-84
LB 84-90

#E10A-C552

UW 5-15
GB 15-29
BM 29-33
GB 33-40
BM 40-42
GB 42-60
LW 60-64
LB 64-75

#EE10A-C558

UW 4-16
GB 16-20
BM 20-21
GB 21-27
BM 27-28
GB 28-34
BM 34-38
GB 38-58
LW 58-59
LB 59-66

#A11-C558

GB 6-25
LW 25-26
LB 26-47
LC 47-60

#B11-C569

GB 22-52
LW 52-53
LB 53-68

#C11-C577

GB 15-49
LW 49-50
LB 50-62

#CC11-C576

GB 11-28
BM 28-30
GB 30-53
LW 53-57
LB 57-65

#D11-C579

GB 26-68
LW 68-69
LB 69-79

#DD11-C575

UW 19-29
GB 29-35
BM 35-37
GB 37-80
LW 81-81

#E11-C555

GB 5-52
LW 52-53
LB 53-60

#EE11-C560

GB 2-54
LW 54-55
LB 55-61

#F11-C563

GB 2-57
LW 57-58
LB 58-80
LC 80-90

#G11-C557

UW 9-28
GB 28-66
LW 66-70
LB 70-83

#H11-C537

DB 18-21
UW 21-56
GB 56-62
BM 62-63
GB 63-102
LW 102-103
LB 103-113

#CC11A-C575

GB 13-51
LW 51-52
LB 52-61

#D11A-C578

GB 21-65
LW 65-67
LB 67-78

#DD11A-C577

UW 22-37
GB 37-79
LW 79-84
LB 84-90

#E11A-C554

GB 2-46
LW 46-47
LB 47-61

#EE11A-C562

GB 3-54
LW 54-55
LB 55-60

#A12-C555

GB 16-24
LW 24-28
LB 28-47
LC 47-60

#B12-C540

GB 6-20
LW 20-23
LB 23-42
LC 42-60

#C12-C569

GB 10-36
LW 36-37
LB 37-59
LC 59-60

#CC12-C568

GB 10-46
LW 46-47
LB 47-60

#D12-C558

GB 4-46
LW 46-48
LB 48-65
LC 65-78

#DD12-C558

UW 2-17
BM 17-22
GB 22-66
LW 66-67
LB 67-68

#E12-C541

GB 16-25
LW 25-26
LB 26-49
LC 49-57

#F12-C546

GB 2-36
LW 36-37
LB 37-60

#G12-C522

GB 14-34
LW 34-35
LB 35-49

#H12-C527

GB 26-85
LW 85-88
LB 88-105

#CC12A-C565

GB 6-41
LW 41-43
LB 43-53

#D12A-C569

UW 6-19
GB 19-55
LW 55-56
LB 56-62

#DD12A-C559

UW 5-19
GB 19-25
BM 25-28
GB 28-36
BM 36-37
GB 37-60
LW 60-61
LB 61-70

#C13-C554

GB 3-21
LW 21-22
LB 22-44
LC 44-57

#CC13-C557

GB 6-14
BM 14-17
GB 17-24
BM 24-25
GB 25-30
LW 30-35
LB 35-51

#D13-C562

GB 10-43
LW 43-44
LB 44-60

#DD13-C551

GB 0-22
BM 22-23
GB 23-44
LW 44-45
LB 45-59

#E13-C531

LB 32-45
LC 45-57

#G13-C531

GB 0-27
LW 27-29
LB 29-55
LC 55-60

#GH13-C519

GB 4-31
LW 31-34
LB 34-58
LC 58-65

#H13-C510

GB 30-64
LW 64-65
LB 65-73

#CC13A-C558

GB 6-27
LW 27-29
LB 29-48
LC 48-60

#D13A-C548

GB 6-24
LW 24-26
LB 26-50
LC 50-60

#DD13A-C544

GB 9-32
LW 32-33
LB 33-54
LC 54-60

#G13A-C532

GB 5-29
LW 29-31
LB 31-52
LC 52-65

#GH13A-C520

GB 5-32
LW 32-33
LB 33-54
LC 54-65

#H13A-C511

UW 5-12
GB 12-60
LW 60-61
LB 61-65

#C14-C553

LB 16-37
LC 37-60

#D14-C555

GB 15-27
LW 27-28
LB 28-59
LC 59-63

#F14-C535

GB 2-10
LW 10-13
LB 13-41
LC 51-55

#G14-C538

GB 9-36
LW 36-41
LB 41-60

#GH14-C524

GB 11-43
LW 43-44
LB 44-63

#H14-C513

UW 10-15
GB 15-59
LW 59-60
LB 60-79

#G14A-C534

GB 9-37
LW 37-39
LB 39-60
LC 60-64

#GH14A-C513

GB 5-36
LW 36-37
LB 37-60
LC 60-65

#H14A-C510

UW 5-12
GB 12-56
LW 56-57
LB 57-66

#D15-C546

LB 14-34
LC 34-57

#G15-C526

GB 5-33
LW 33-34
LB 34-55
LC 55-60

#H15-C511

UW 10-18
GB 18-58
LW 58-60
LB 60-82

#K15-C508

DB 5-9
UW 9-40
GB 40-83
LW 83-84
LB 84-90

#GH15A-C509

GB 6-34
LW 34-36
LB 36-55
LC 55-65

#HJ15A-C502

UW 4-16
GB 16-62
LW 62-63
LB 63-78

#F16-C522

LB 19-42
LC 42-63

#G16-C513

GB 4-27
LW 27-28
LB 28-49

#H16-C517

UW 14-20
GB 20-70
LW 70-71
LB 71-80

#J16-C507

UC 6-12
DB 12-18
UW 18-25
GB 25-71
LW 71-72
LB 72-84

#K16-C512

UC 7-24
DB 24-35
UW 35-45
GB 45-85
LW 85-87
LB 87-95

#L16-C512

UB 10-26
UC 26-55
DB 55-66
UW 66-74
GB 74-92
BM 92-94
GB 94-112
LW 112-114
LB 114-117

#GH16A-C524

GB 6-51
LW 51-53
LB 53-65

#HJ16A-C521

UC 12-14
DB 14-21
UW 21-35
GB 35-80
LW 80-81
LB 81-89

#F17-C534

GB 5-34
LW 31-34
LB 34-57
LC 57-61

#G17-C535

GB 9-53
LW 53-57
LB 57-60

#H17-C526

UW 7-26
GB 26-73
LW 73-75
LB 75-83

#J17-C527

UC 10-20
DB 20-21
UW 21-41
GB 41-84
LW 84-85
LB 85-90

#K17-C527

UC 12-37
BM 37-39
UC 39-40
BM 40-46
UC 46-50
BM 50-58
GB 58-60
BM 60-64
GB 64-92
LW 92-94
LB 94-99

#L17-C526

UB 10-29
UC 29-65

#E18-C542

GB 19-28
LW 28-29
LB 29-52
LC 52-59

#F18-C539

GB 18-49
LW 49-51
LB 51-67

#G18-C538?

GB 25-70
LW 70-71
LB 71-80

#H18-C538

GB 34-83
LW 83-85
LB 85-96

#J18-C516

UW 8-16
GB 16-48
BM 48-49
GB 49-62
LW 62-64
LB 64-73

#C19-C532

LC 23-60

#E19-C521

LB 30-36
LC 36-60

#F19-C523

GB 15-41
LW 41-43
LB 43-60

#J19-C544

GB 36-82
LW 82-83
LB 83-86

#B20-C539

LB 12-18
LC 18-60

#C20-C535

LB 13-31
LC 31-60

#D20-C529

LB 19-34
LC 34-60

#C21-C529

LB 18-21
LC 21-60

#D21-C524

LC 27-60

#K21-C518

GB 16-51
LW 51-55
LB 55-79
LC 79-86

#B22-C553

LB 8-25
LC 25-60

#C22-C542

LB 6-30
LC 30-60

#E22-C539

LB 51-63

#H22-C547

GB 32-59
LW 59-63
LB 63-85
LC 85-93

#J22-C548

GB 21-56
LW 56-57
LB 57-81
LC 81-83

#K22-C537

UW 7-13
GB 13-61
LW 61-64
LB 64-72

#L22-C528

UW 16-46
GB 46-92
LW 92-93

#M22-C523

DB 11-14
UW 14-67
GB 67-112
LW 112-113
LB 113-121

#N22-C520

GB 35-52
UW 52-104
GB 104-154
LW 154-155
LB 155-165

#B23-C558

GB 1-9
LW 9-11
LB 11-36
LC 36-60

#C23-C549

GB 5-14
LW 14-16
LB 16-38
LC 38-60

#D23-C542

LB 6-34
LC 34-55

#E23-C537

GB 12-28
LW 28-32
LB 32-54
LC 54-65

#H23-C521

GB 10-36
LW 36-38
LB 38-62
LC 62-65

#J23-C527

GB 8-37
LW 37-38
LB 38-64
LC 64-65

#K23-C550

UW 5-25
GB 25-64
LW 64-65
LB 65-89
LC 89-90

#L23-C538

UW 7-54
GB 54-93
LW 93-94
LB 94-95

#M23-C515

UW 10-21
GB 21-30
UW 30-55
GB 55-90
LW 90-91
LB 91-100

#N23-C515

GB 28-51
UW 51-108
GB 108-141
LW 141-143
LB 143-150

#B24-C549

LC 31-60

#E24-C542

UW 8-24
GB 24-40
LW 40-45
LB 45-64

#F24-C534

GB 14-32
LW 32-33
LB 33-59

#J24-C520

GB 13-32
LW 32-34
LB 34-56
LC 56-65

#K24-C522

GB 10-31
LW 31-35
LB 35-57
LC 57-61

#L24-C527

GB 14-77
LW 77-78
LB 78-85

#M24-C522

GB 25-93
LW 93-95
LB 95-97

#N24-C516

GB 37-55
BT 55-58
UC 58-62
BT 62-63
GBB63-79
UW 79-86
GBB86-90
UC 90-98
BT 98-99
GBB99-107
GB 107-135
LW 135-136
LB 136-142

#E25-C551

GB 21-58
LW 58-59
LB 59-75

#F25-C543
GB 10-33
LW 33-34
LB 34-45

#G25-C537
GB 5-19
LW 19-21
LB 21-46
LC 46-60

#E26-C542

GB 0-48
LW 48-49
LB 49-64

#F26-C538

GB 11-22
LW 22-24
LB 24-49
LC 49-59

#G26-C545

GB 7-19
LW 19-21
LB 21-43
LC 43-58

#H26-C533

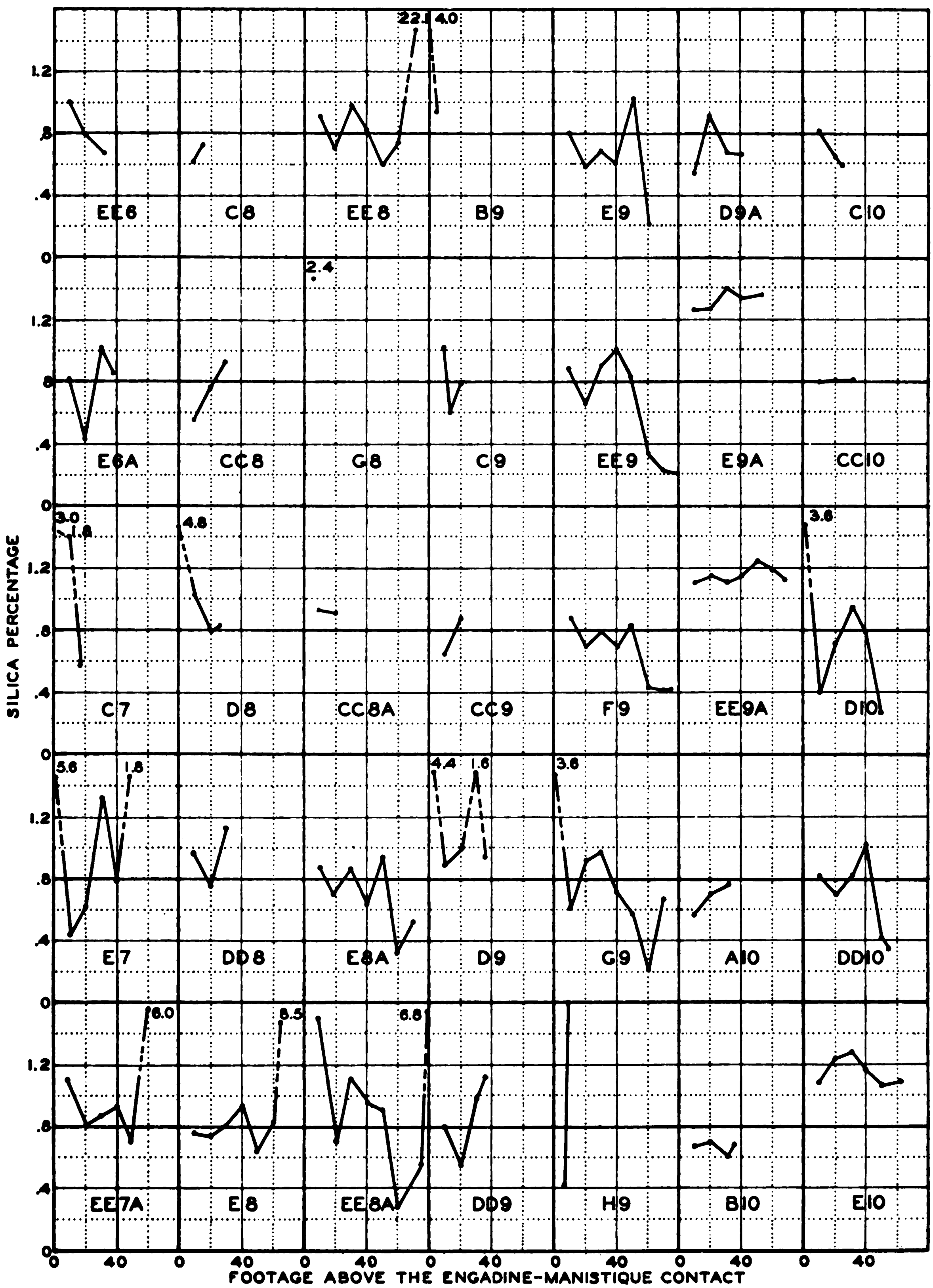
GB 8-29
LW 29-30
LB 30-57
LC 57-60

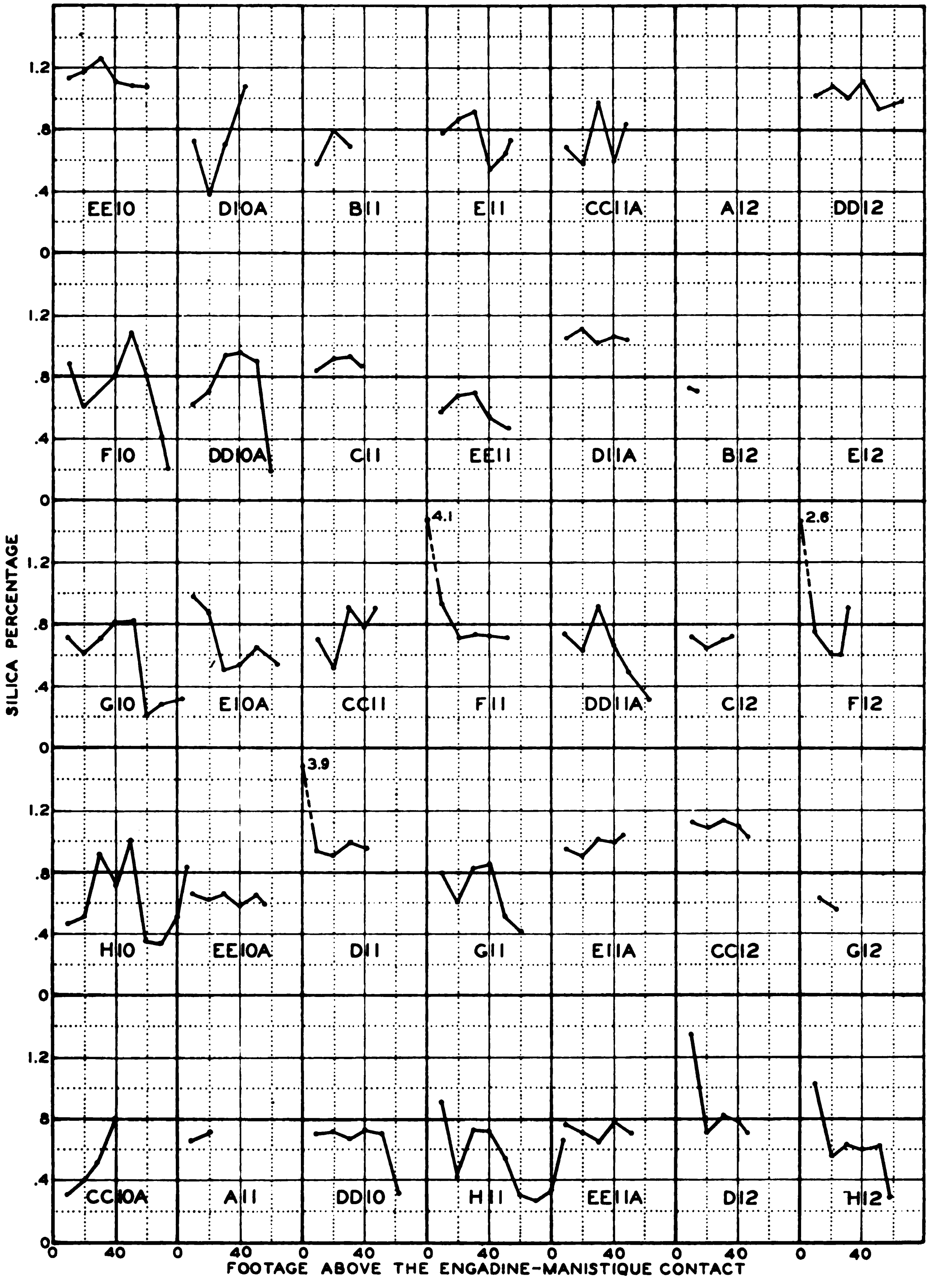
APPENDIX B

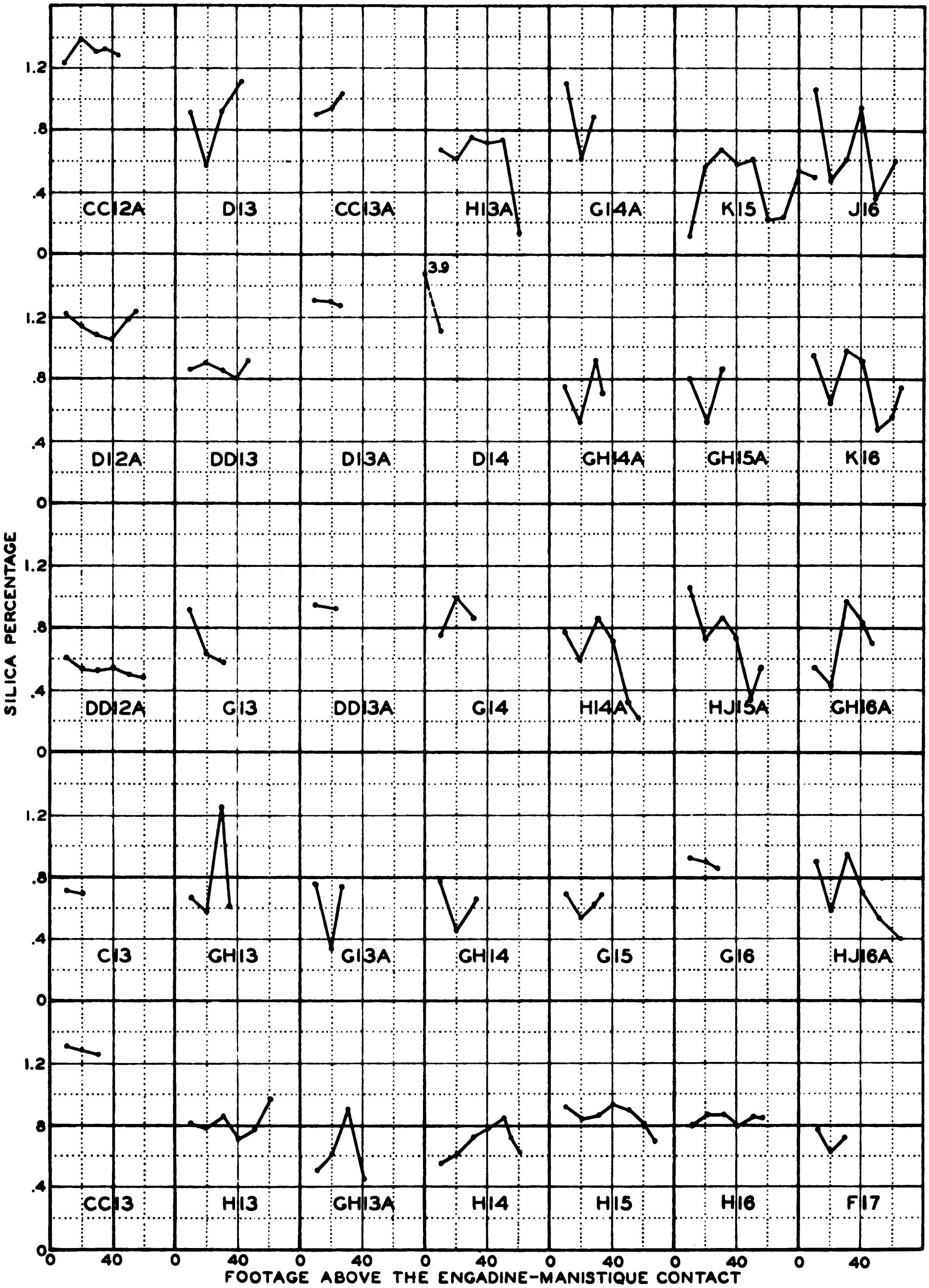
SILICA PERCENTAGES OF DIAMOND DRILL CORES INTERSECTING THE ENGADINE FORMATION OF DRUMMOND ISLAND, MICHIGAN

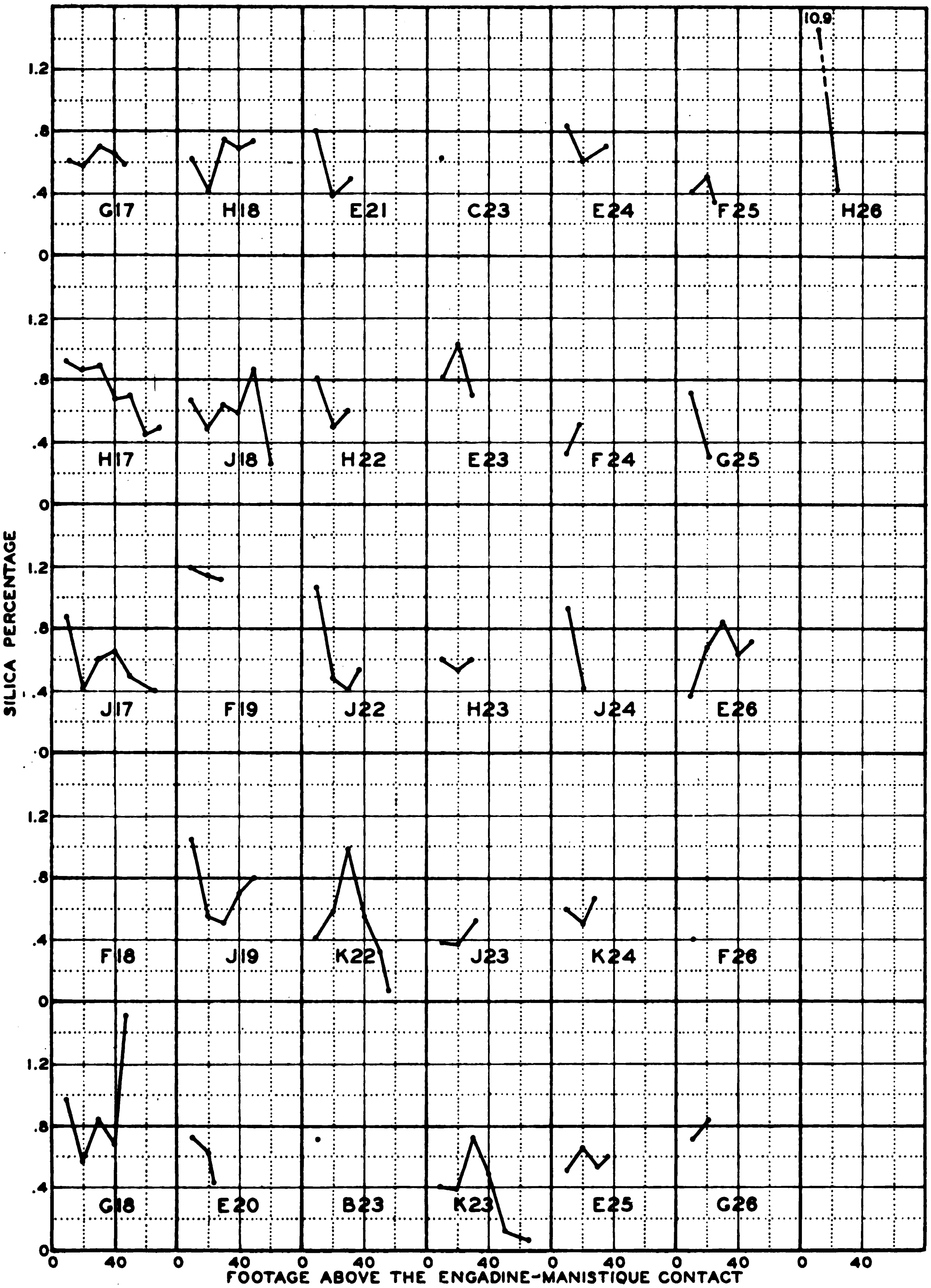
GH13A - Diamond drill core location.

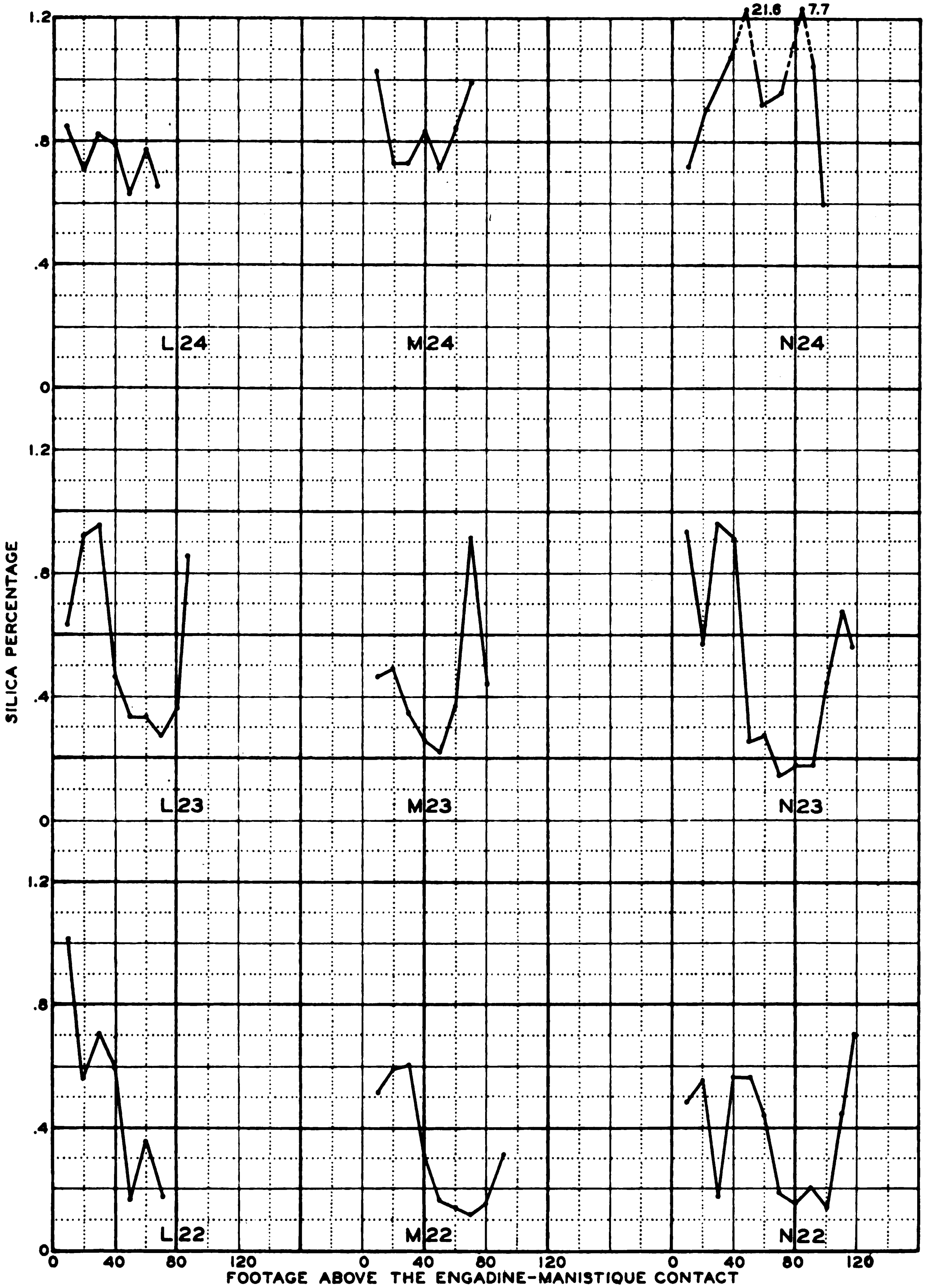
NOTE: Each point is a sample point, and each diamond drill core has a separate curve.


SILICA PERCENTAGE
FOOTAGE ABOVE THE ENGADINE-MANISTIQUE CONTACT
EE6
C8
EE8
B9
E9
D9A
C10
E6A
CC8
G8
C9
EE9
E9A
CC10
C7
D8
CC8A
CC9
F9
EE9A
D10
E7
DD8
E8A
D9
G9
A10
DD10
EE7A
E8
EE8A
DD9
H9
B10
E10
22.1
4.0
2.4
3.0
1.8
4.8
3.6
5.6
4.4
1.6
6.0
8.5
6.8
1.2
.8
.4
0
40


SILICA PERCENTAGE
FOOTAGE ABOVE THE ENGADINE-MANISTIQUE CONTACT
EE10
D10A
B11
E11
CC11A
A12
DD12
F10
DD10A
C11
EE11
D11A
B12
E12
G10
E10A
CC11
F11
DD11A
C12
F12
H10
EE10A
D11
G11
E11A
CC12
G12
CC10A
A11
DD10
H11
EE11A
D12
H12
4.1
2.6
3.9
1.2
.8
.4
0
40


CC12A
D13
CC13A
H13A
G14A
K15
J16
D12A
DD13
D13A
D14
3.9
GH14A
GH15A
K16
DD12A
G13
DD13A
G14
H14A
HJ15A
GH16A
C13
GH13
G13A
GH14
G15
G16
HJ16A
CC13
H13
GH13A
H14
H15
H16
F17
SILICA PERCENTAGE
1.2
.8
.4
0
40
FOOTAGE ABOVE THE ENGADINE-MANISTIQUE CONTACT


10.9
G17
H18
E21
C23
E24
F25
H26
H17
J18
H22
E23
F24
G25
J17
F19
J22
H23
J24
E26
F18
J19
K22
J23
K24
F26
G18
E20
B23
K23
E25
G26
SILICA PERCENTAGE
1.2
.8
.4
0
0
40
FOOTAGE ABOVE THE ENGADINE-MANISTIQUE CONTACT


SILICA PERCENTAGE
1.2
.8
.4
0
21.6
7.7
L 24
M 24
N 24
L 23
M 23
N 23
L 22
M 22
N 22
0
40
80
120
FOOTAGE ABOVE THE ENGADINE-MANISTIQUE CONTACT

APPENDIX C

SUBSURFACE FACIES LOGS OF THE NIAGARAN OF THE MICHIGAN BASIN

Key to Abbreviations:

SH - Shale
BD - Brown dolomite
LBD - Light-brown dolomite
CBD - Cherty brown dolomite
ARLBD - Slightly argillaceous, red-tinted, light-brown dolomite
GD - Gray dolomite
LGD - Light-gray dolomite
VLGD - Very light-gray dolomite
CGD - Cherty gray dolomite
ARGD - Slightly argillaceous, red-tinted, gray dolomite
BL - Brown limestone
LBL - Light-brown limestone
CBL - Cherty brown limestone
ARBL - Slightly argillaceous, red-tinted, brown limestone
ARBL (max.) As above, with maximum red tinting
ARLBL - Slightly argillaceous, red-tinted, light-brown limestone
GL - Gray limestone
LGL - Light-gray limestone
CGL - Cherty gray limestone
ARGL - Slightly argillaceous, red-tinted, gray limestone
ARGCL - Slightly argillaceous, red-tinted, cherty gray limestone
AOGL - Slightly argillaceous, orange-tinted, gray limestone

1. Forrest H. Linsay, Anne Kirt No. 1, Permit 22627 6-30N-11W, Suttons Bay Township, (Leelanaw County) Contractor Union Rotary Corporation.

Niagaran Top 3857 feet

LGD	323 feet
BD	75
LGD	37
CBD	253
BD	174
Total	862

Top Cataract -4719

Total 862

2. Forrest H. Lindsay, Lawrence Wolgamott No. 1, Permit 22639, 19-32N-8W, Banks Township (Antrim County), Contractor Union Rotary Corporation.

Niagaran Top 3835 feet
?Top A-1 Schj. 3815

BD	20 feet
GD	15
LBD	15
LGL	5
LGD	15
LGL	30
LGD	235
BD	50
GD	15
LGD	50
CBD	175
BD	45
LGD	50
BD	20
LBD	15
BD	5
GD	65
BL	10
??	5
BL	20
Total	860 feet

Top Cataract -4675

Total 860 feet

3. R. G. Lawton, Theodore Romaniak *et al*. No. 1, Permit number 23304 D.P. No. 1370, 7-32N-4W, Hudson Township (Charlevoix County), Contractor McClure Drilling Company, Rotary 4700-5246: Goll, Graves and Mechling, Inc., Cable 0-4700

Top Niagaran 4038 feet

BD	14 feet	
LGD	90	
GD	15	
BD	309	
BL	31	
LGD	9	
CGD	177	
LGD	17	
???	7	
BD	133	
GD	58	
BD	29	Top Cataract - 4929
Total	889 feet	Total 889 feet

4. The Ohio Oil Company, State-Boyne Valley No. 1, Permit 19194, 24-32N-5W, Boyne Valley Township (Charlevoix County) Contractor Gordon Drilling Company (Rotary).

Top Niagaran 4175 feet
Brown Niagaran 4160

BD	15 feet	
GD	5 feet 9 inches	
LGD	46 feet 8 inches	
GD	18 feet	
LGD	19 feet 8 inches	
GD	3 feet	
LGD	2 feet 10 inches	
GD	4 feet 7 inches	
LGD	22 feet 7 inches	
BD	297 feet 2 inches	
LBD	5 feet	
BL	24 feet	
CBL	101 feet	
BD	145 feet	
BL	22 feet	
BD	12 feet	
BL	12 feet	
BD	31 feet	
BL	56 feet	
GD	3 feet	Cataract Top 5006
Total	842 feet 51 inches	Total 846 feet

5. Forrest H. Lindsay, Paul Selke No. 1, Permit 22638 20-34N-5E, Belknap Township (Presque Isle County) Contractor Union Rotary Corporation (Rotary).

		Niagaran Top 3355
		Brown Niagaran 3330
BL	40 feet	
BD	5	
BL	5	
BD	5	
BL	35	
BD	10	
BL	110	
CBL	130	
LBL	40	
BL	20	
BD	45	
BL	15	
BD	10	
BL	7	
BD	23	Cataract Top 2830
Total	500 feet	Total 500 feet

6. Bell and Marks, Basin Oil Company and Muskegon Development Company, Dale Joe VandeWege No. 1, Permit 23462, 17-4N-15W, Fillmore Township (Allegan County) Contractor Muskegon Development Company (Cable).

		Niagaran Top 2885
		Brown Niagaran 2870
BL	2 feet	
BD	6	
VLGD	28	
GD	10	
VLGD	15	
CBD	28	
BD	5	Cataract Top 2964
Total	94 feet	Total 94 feet

7. Gene M ller Inc., C F Seaman No. 1, Permit 22918, 15-11N-13 W, Ashland Township (Newago County) Contractor Gene Miller, Inc. (Rotary)

		Top Niagaran	4937 feet
		Brown Niagaran	4916
BD	24 feet		
GD	73		
LGD	17		
CBD	55		
BD	18	Top Cataract	5103
Total	187 feet	Total	187 feet

8. Empire Oil Company, Burley Gray *et al*. No. 1, Permit 23010, 339N-16W, Norton Townshin (Muskegon County) Contractor Flory Drilling Company (Rotary 0 to 549), J. W Lang Co. (Cable 549 to 3636).

		Top Niagaran	3460 feet
		Brown Niagaran	3444
BD	16 feet		
LBD	3		
LBL	17		
LBD	2		
ARLBD	19		
BLD	10		
ARLBD	4		
LBD	14		
ARLB	13		
BL	30		
CBD	30		
BD	19	Cataract Top	3624
Total	180 feet	Total	180 feet

9. C. J. Simpson, Harris-State-Grant No. 1, Permit 23149, 10-11N-12N, Grant Township (Newago County) Contractor Hack Drilling Company (Rotary).

		Niagaran Top	5261
		Brown Niagaran	5247
BL	14 feet		
ARBL	19		
ARBL (Max.)	40		
ARBL	15		
ARBL (Max.)	20		
BL	10		
CBD	68	Top Cataract	5433
Total	186 feet	Total	186 feet

10. Whitehall Oil Incorporated. Sheridan Township No. 1., Permit 22849, 26-12 N-14W, Sheridan Township (Newago County), Contractor Hack Drilling Company (Rotary).

		Top Niagaran	4699 feet
		Brown Niagaran	4670
BL	14 feet		
BD	15		
ARGL	81		
Sh	22		
ARGL	17		
CGL	67		
BL	18		
Sh	3		
BL	17	Cataract Top	4924
Total	254 feet	Total	254 feet

11. Whitehall Oil, Incorporated, Cornelius Siersma No. 1. Permit 22866, 26-13N-14W Dayton Township (Newago County), Contractor Hack Drilling Company (Rotary).

		Top Niagaran	5050 feet
		Brown Niagaran	5020
BD	13		
ARGL	94		
GL	13		
ARGL	14		
Sh	12		
CGL	10		
GL	6		
CGL	8		
CBL	12		
CGL	23		
CBL	7		
CGL	16		
CBL	20		
CBD	22		
GL	14	Top Cataract	5304
Total	284 feet	Total	284 feet

13. James O. Kelley, Howard Dunlap No. 1, Permit 22108 22-1S-5W, Lee Township (Calhoun County), Contractor Union Rotary Corporation (Rotary).

		Niagaran Top	3204 feet
BD	120		
VLGD	103		
GD	60	Cataract Top	3490
Total	283 feet	Total	283 feet

14. Davis Drilling Company, Inc. Reardon No. 1, Permit 22110, 27-2S-2W, Sanstone Township (Jackson County) Contractor Davis Drilling Company, Inc.

		Niagaran Top	3052 feet
		Brown Niagaran	2978
BD	74 feet		
LGD	156		
BD	22		
VLGD	215	Top Clinton Cataract	3445 feet
Total	467 feet	Total	467 feet

15. C. W. Collin, Bidal-Frucher-Levrau No. 1, Permit 23796, 10-3N-15E, Ira Township, (St. Clair County) Contractor C. W. Collin (Rotary 0-2717) (Cable 2717-4494).

		Top Niagaran	2587 feet
		Brown Niagaran	2567
BD	20 feet		
LGD	106-Clinton		
Sh	21		
LGD	12	Top Cataract	2726
Total	159 feet	Total	159 feet

16. McClure Oil Company and Thomas Mask, Victor Jonckhere No. 1, permit 19063, D.P. No. 985 36-3N-3E, Handy Township, (Livingston County), Contractor McClure Drilling Company (Rotary A2240, 2890-5763) (Cable 2240-2890).

		Top Niagaran	4506 feet
		Brown Niagaran	4471
BD	35 feet		
VLGD	110		
BD	26		
Sh	27	Cataract Top	4669
Total	198 feet	Total	198 feet

17. Sunray Mid-Continent Oil Company, H. G. Richardson No. 1, Permit 22534, 18-6N-12E, Almont Township, (Lapeer County), Contractor Calvert Drilling Company (Rotary).

		Top Niagaran	4507 feet
		Brown Niagaran	4499
BD	8 feet		
GD	90		
Sh	22	Top Clinton Shale	4597 feet
Total	120 feet		98
		Tcp Cataract	4619
		Total	120 feet

18. Don Rayburn, Watchorn and Wells, Comm. No. 1, Permit 20209, D.P. Number 1117, D.P. Number 1119 D.P. Number 1122, 5-10N-9E, Watertown Township (Tuscola County), Contractor Gordon Drilling Company (Rotary).

		Top Niagaran	6836 feet
		?Brown Niagaran	6833 feet
BL	3 feet		
ARGL	60		
GL	4		
Sh	23		
GL	9.5	Top Cataract	6933 feet
Total	99.5	Total	100 feet

19. C. J. Simson, Peter, and Mary Wisniewski No. 1, Permit 23899, 21-18N-13E, Dwight Township (Huron County), Contractor North American Drilling Company (Rotary).

		Niagaran Top	6500 feet
		Brown Niagaran	6491
BD	9 feet		
GL	7		
?	3		
ARGL	52		
GL	6		
AOGL	60		
GL	11	Top Clinton Cataract	6639
Total	148 feet	Total	148 feet

20. The Pure Oil Company, Morton Emery No. 1, Permit 23849, 21-13N-1W, Porter Township, (Midland County) Contractor North American Drilling Company (Rotary).

			Top Niagaran	7916 feet
			Brown Niagaran	7910
BL	6 feet			
GL	39			
ARGL	30			
GL	5			
ARGL	7	Clinton		
GL	23			
BL	5		Top Cataract	8025
Total	115 feet		Total	115

21. Gulf Refining Company, Wm. Bateson No. 1, Permit 5441, D.P No. 181, 2-14N-4E, Monitor Township (Bay Company), Contractor Parlser Drilling Company (Cable-Rotary).

		Top Niagaran	8270
BL	10 feet		
GL	24		
ARGL	45		
GL	2		
ARGL	4		
GL	20		
ARGL	20		
BL	21		
GL	30	Top Cataract	8446
Total	176 feet	Total	176 feet

22. Ohio Oil Company, Reinhardt Consolidated No. 1, Permit 12898, 35-22N-2E, Contractor Ohio Oil Company, (Rotary).

		Niagaran Top	8547 feet
		Brown Niagaran	8537
BL	10 feet		
CGL	8		
ARGCL	30		
GL	8		
ARGCL	27		
GL	13		
BL	8		
CGL	85		
CBL	54		
CGL	39	Top Cataract	8829
Total	292 feet	Total	292 feet

23. Ohio Oil Company, Reinhardt Consolidated No. 1, Permit 12898, 35-22N-2E, West Branch Township (Ogemaw County), Contractor Ohio Oil Company, (Rotary).

Top Niagaran 8547 feet
Brown Niagaran 8537

BL	10 feet
CGL	8
ARGCL	65
GL	13
BL	8
CGL	59
CBL	14
CGL	26
CBL	50
CGL	39
Total	292 feet

Top Cataract 8829
Total 292 feet

24. Charles W Trater, Nevins, No. 1, Permit 2960, 18-32N-6E Long Rapids Township, (Alpena County) Contractor Charles W. Teater (Cable).

Top Niagaran 4030 feet

BL	85 feet
CBL	123
BD	7
BL	225
Total	440

Top Cataract 4470 feet
Total 440 feet

25. Brazos O l and Gas Company, State-Chester "HE" No 2, Permit 17455, 10-29N-2W, Cherster Township (Otsego County), Contractor Slape Drilling Company (Rotary).

Niagaran Top 6638 feet
?Brown Niagaran 6650' 4"

BD	7' 8"
ARGD	17
CBD	4' 7"
CBL	140' 11"
BL	47' 6"
Total	217' 8"

Top Cataract (Not
Reached total 6868.6"
Total 218.2"+

CLINTON-NIAGARAN CROSS-SECTIONS OF THE MICHIGAN BASIN

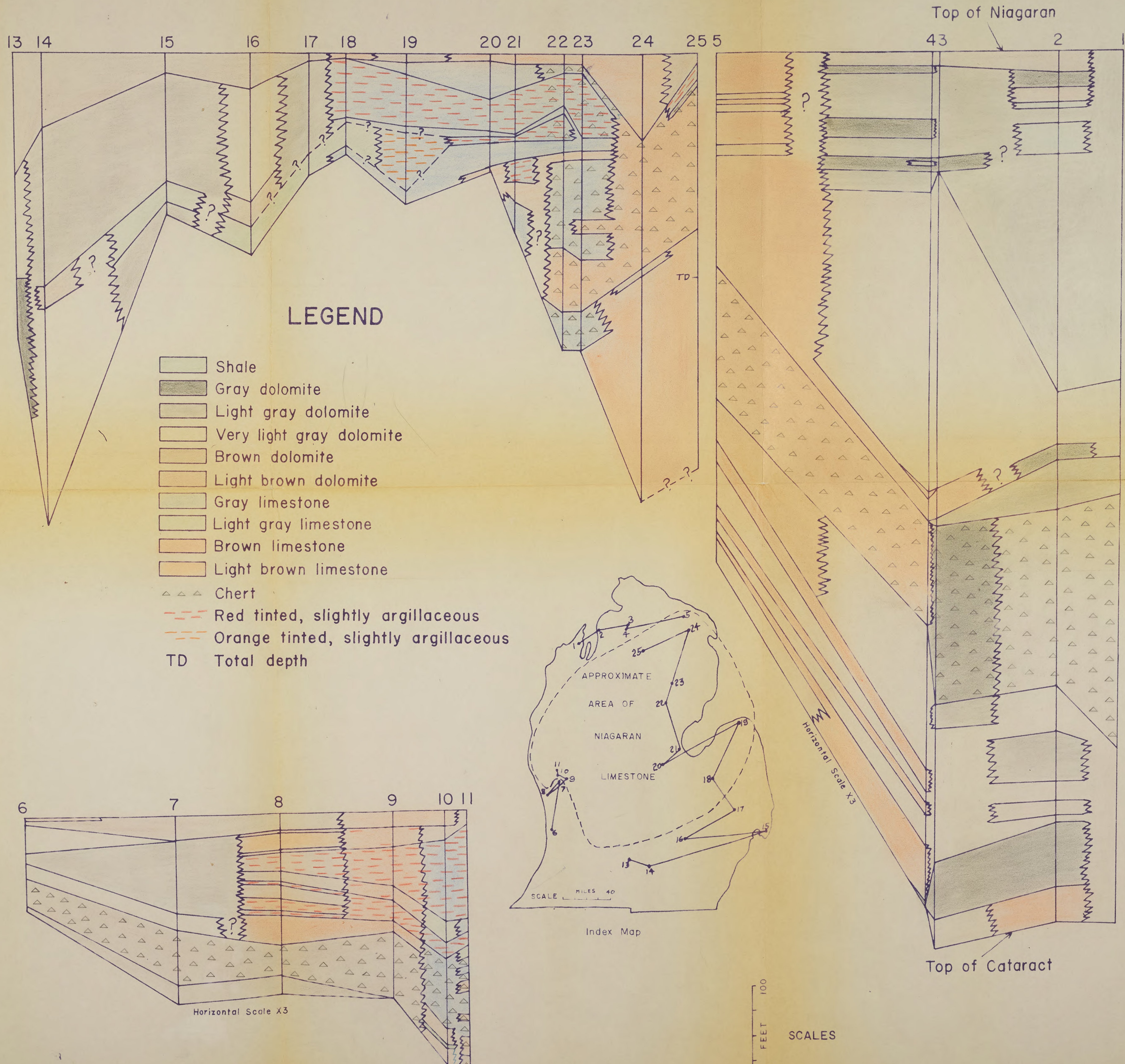


Figure 18

SUPPLEMENTARY
MATERIAL