A STRATIGRAPHIC ANALYSIS OF THE TRAVERSE GROUP OF MICHIGAN

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ABSTRACT

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TRAVERSE GROUP OF MICHIGAN

By

Stephen Lane Runyon

The Middle Devonian Traverse Group, in the past, was a major producer of hydrocarbons. Though it hasn't been actively explored for many years, new technology and a substantial increase in drilling activity in the last ten years warrants an updated examination of this group. This stratigraphic analysis attempts to reinovate some concepts concerning its development, especially those related to future hydrocarbon exploration, and reemphasize some of those already in existence.

This study provides completely updated structure and isopach maps constructed from tops derived from 306 gamma ray-neutron logs, in addition to, those obtained from samples of sixty wells widely distributed throughout the state. Lithofacies trends were diagnosed from these well cuttings and a clastic ratio, a limestone to dolomite ratio, evaporite and chert percent maps were generated to determine the paleoenvironment and history during a time when Michigan and surrounding areas were widely inundated by seas.

Many significant concepts concerning the Traverse Group are evidenced by this investigation. Support for the

orientation of the major structural trends in the Michigan Basin is demonstrated by the isopach and structural study. The various features delineated by these maps coincide with the structural trends evident in the Basin at the present time. Isopach thinning over present anticlinal features suggest that some movement in the Basin was concurring with deposition. Many of the major structures evident today though, were not apparent during Traverse time emphasizing that the main diastrophism, which resulted in these structures, occurred later. A substantial number of features delineated by the structure and isopach maps coincide with present oil and gas producing fields suggesting the validity of future predictions for hydrocarbon exploration as gleaned from them. Sharp, assymmetrical folds in southwest, south and southeast Michigan suggest faulting. These faults tie in isolated oil and gas fields and cross major, known hydrocarbon producing structures such as the linear, Albion-Scipio trend. In many producing fields where cross-fractures intersect, pronounced dolomite development, hence porosity, has been found. The cross-structure relationship of these faults suggests that possible hydrocarbon prospects exist along these features. Other features have also been cited as possible future exploration areas. The apparent complexity of the Howell Anticline area, suggested by a preliminary investigation there, indicates that a more detailed analysis is needed to unravel its history.

Stephen Lane Runyon

The various lithofacies trends generated in this study help to explain the paleoenvironment and history of the Michigan Basin during Middle Devonian, Traverse time. Dolomite and clastic lithofacies patterns indicate an eastern source area which is either lowlying and peripheal or an intermittantly rising eastern source area. They also disclose that the Findlay Arch stood slightly higher than the other frame structures directly related to the Michigan Basin at that time. The clastic ratio map indicates that the Kankakee Arch was also a source of clastics. A north to south high dolomite trend on the west side of the state can be related to shallowing on the Wisconsin Arch or a result of a west Michigan Barrier. For this barrier, a model has been postulated to help explain its relationship to the limestone, dolomite and evaporite trends in existence in the Basin during Traverse time. A more detailed examination of the widespread occurrence of chert in the Traverse Group is warranted to ascertain its significance.

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A THESIS

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DEDICATION

I would like to dedicate this thesis to my late Grandfather, Virgil Runyon, who helped pioneer the Michigan oil and gas fields, to my parents, Jack and Rosella Runyon whose hard work and devotion instilled in me the traits of hard work and perseverance and to my wife, Sue and son, Jason whose love helped me complete this study.

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INTRODUCTION

General Statement

The Middle Devonian, Traverse Group of Michigan has been in the past and still is a large producer of hydrocarbons. The Traverse Group along with the Rogers City-Dundee formation stimulated great exploration activity in the 1930's. Today there is a total of 181 fields which have produced out of the Traverse Group singularly or in combination with other horizons with cummulative production, through 1974, as great as 16,860,442 BBLS. from the Walker field alone. At the present time, the Traverse Group is not an exploration target, though many, more subtle traps are yet to be found. An understanding of the paleoenvironment and history together with new exploration techniques could help to renew interest in the horizon.

Scope and Purpose

This study will attempt to update structure and isopach interpretations, and discover, plot and contour lithologic variations present in the Middle Devonian, Traverse Group of Michigan. Structure and isopach contour maps will be reconstructed from tops picked off gamma ray-neutron logs and percentages of limestone, dolomite, quartz, shale, chert, pyrite and evaporites will be derived from well samples throughout the southern penninsula of Michigan. (Directions referred to herein after are in terms of Southern Michigan only).

Isopach maps of the Traverse Group were first published by Newcombe (1933). Records of drilling after that date show that his map was seriously in error in Charlevoix and Antrim counties. Later, Cohee (1947) provided a more accurate estimate of Devonian thickness as along with a structure contour map based on the available well records to 1947 which penetrated the entire Traverse Group section.

Since this time, considerably more wells have been drilled penetrating the Traverse Group in search of hydrocarbons. The increasing production success of the northern and southern Silurian Reef Trends and the Ordovician Albion-Scipo play in the extreme south have spurred a new search for hydrocarbons in the deeper, older strata of the Michigan Basin providing a substantial increase in new data. In addition to this, recent technology has provided us with a relatively new and accurate tool for examining carbonate strata, the gamma-ray neutron log. In light of this an updating of the thickness of the Traverse Group is appropriate.

Gustafson (1960), investigated the Traverse Group in the Lansing area and generated structural and isopach maps of this area. Fisher (1969), examined the Traverse

Formation, the top unit of the Traverse Group, and completed a structural contour map on the top of the Traverse Group. A preliminary investigation by the writer found that his picks were inconsistent in many instances and were quite different than the tops picked in this report. Therefore, a new and further updated structure contour map is justified.

Previous work on the lithology of the Traverse Group usually involved a general description of the divisions of the Group and how they vary from one part of the state to another. A composite Devonian lithofacies in the Michigan Basin, including the Traverse, was constructed by Dice (1955); and Ross (1957) constructed lithofacies maps involving a sand-shale ratio, clastic ratio, quartz-chert ratio and evaporite ratio of the complete Traverse Group using a quantitative, sedimentary analysis. To date, no one has attempted a qualitative, lithofacies study of the Traverse limestone. The Traverse limestone for purposes of this study is that unit between the top of the Bell Shale and the base of the Traverse Formation. This investigation will endeavor to update previous thickness and structure maps of the Traverse Group and shed light on the source of clastics, dolomite, chert and evaporite trends of the Traverse Limestone in conjunction with the structure and thickness contour maps.

Previous Work

The Traverse Group has been studied in outcrop since the early 1800's. Pioneer work was first done in Emmet and Charlevoix counties, Michigan by Christopher C. Douglas in 1841, Winchell and Rominger in the latter half of the 1800's, Grabau (1902), Smith (1912) and then by Kesling, Segall, and Sorensen (1974). Grabau (1902) was the first to subdivide the Traverse Group and his nomenclature is still in use today. The Michigan Geological Survey in 1926 sponsored a field trip investigation of all Middle Devonian strata in the lower peninsula, the members including E. O. Ulrich (U.S.G.S.) E. Case, G. Ehlers, C. Deiss, and A. S. Warthin Jr., all of the University of Michigan. This work is incorporated as part of an updated study by Kesling, Segall and Sorensen (1974). Warthin and Cooper (1943) studied these rocks on the east side of the state while Pohl (1930) discussed them in the Little Traverse Bay area. Ehlers and Kesling further examined them in Alpena and Presque Isle counties in 1970.

In subcrop the Traverse Group has been studied extensively, because of its hydrocarbon importance. Discussion of the occurrence of these rocks throughout the state have been made in reports by Newcombe (1928, 1933), Hake and Maebius (1938); and in parts of Michigan by Riggs (1928), Pringle (1937), Newman (1937), Eddy (1936), Addison (1940), Landes (1945), and Cohee (1944, 1947). Most recent investigations have been concluded by Dice (1955), Gustafson (1960), and Ross (1957). Fisher (1969) focused his study on the Traverse Formation which he defined as a formal stratigraphic unit.

GENERAL STRATIGRAPHY

The Traverse Group and the rocks correlative to it are found all over the Michigan Basin from the southern peninsula of Michigan to northern Indiana, northwestern Ohio, southwestern Ontario and eastern Wisconsin. They are found at the surface (Fig. 1) in Alpena, Presque Isle, Cheboygan, Emmet and Charlevoix counties in nothern Michigan. Rocks of the Traverse Group also crop out in Lucus County, Ohio and Ontario, Canada. They subcrop (beneath glacial drift) in southeastern Michigan and northwestern Ohio along the Findlay Arch and along the north flank of the Kankakee Arch in Indiana. They are called the Hamilton Series where they extend across southwestern Ontario into the Appalachian Basin in the vicinity of the Chatham Sag. They probably also extend into Indiana through the Logansport Sag. Rocks of Traverse age are also on the southeastern side of Wisconsin along the shore of Lake Michigan from Cheboygan to Milwaukee.

The Traverse Limestone is divided into stratigraphic division or formations by Warthin and Cooper (1943), (Table 1). These units have been carried into the subsurface and in some cases over large areas, but lateral gradation from shales and argillacious limestones in eastern Michigan to pure limestone in western Michigan make it impossible to follow these units in the subsurface. The thinning and


MICHIGAN
Traverse Group Outcrop Areas
ONTONAGON
GOGEBIC
HOUGHTON
KEWEENAW
BARAGA
MARQUETTE
IRON
DICKINSON
ALGER
DELTA
SCHOOLCRAFT
LUCE
MACKINAC
CHIPPEWA
MENOMINEE
EMMET
CHEBOYGAN
CHARLEVOIX
OTSEGO
ANTRIM
LEELANAU
BENZIE
GRAND TRAVERSE
KALKASKA
CRAWFORD
OSCODA
ALCONA
MANISTEE
WEXFORD
MISSAUKEE
ROSCOMMON
OGEMAW
IOSCO
MASON
LAKE
OSCEOLA
CLARE
GLADWIN
ARENAC
HURON
BAY
OCEANA
NEWAYGO
MECOSTA
ISABELLA
MIDLAND
TUSCOLA
SANILAC
MUSKEGON
MONTCALM
GRATIOT
SAGINAW
KENT
LAPEER
GENESEE
OTTAWA
IONIA
CLINTON
SHIAWASSEE
OAKLAND
MACOMB
ALLEGAN
BARRY
EATON
INGHAM
LIVINGSTON
VAN BUREN
KALAMAZOO
CALHOUN
JACKSON
WASHTENAW
WAYNE
BERRIEN
CASS
ST JOSEPH
BRANCH
HILLSDALE
LENAWEE
MONROE

Figure 1

Table 1

GENERALIZED MIDDLE DEVONIAN COLUMN IN MICHIGAN

(modified after H. M. Martin)

Series	Group	Formation, Stage, Member, Bed	
			Squaw Bay[3]
		Petoskey[1]	Thunder Bay[3]
			Potter Farm[3]
		Charlevoix[1]	Norway Point[3]
			Four Mile Dam[3]
Middle Devonian	Traverse	Gravel Point[1,2]	Alpena[3]
		Gorbut[2]	Newton Creek[3]
		Kohler[2]	
			Killians[3]
			Genshaw[3]
			Ferron Point[3]
			Rockport Quarry[3]
			Bell Shale[3]

[1]Traverse group in Little Traverse Bay area.

[2]Traverse group in Cheboygan-Presque Isle counties.

[3]Traverse group in Thunder Bay Region.

Table 1 (Continued)

Thickness (feet)	Lithology
8	Limestone, brown fossiliferous overlain with dolomite
13-40	Limestone, interbedded with shale
70	Shale, alternating with sublithogarphic limestone
45	Shale, thinly interbedded with limestone
20	Limestone, biothermal with thin shale members
79	Limestone, pure to argillaceous
25	Limestone, dark
116	Limestone, dark
37	Shale, calcareous and thin shaly limestone
40	Limestone, dark with some interbedded shale
80	Shale, calcareous and fossiliferous with thin beds of limestone

disappearance of the Bell Shale in the southwest so that the Traverse limestone rests on the Dundee limestone, also confuses simple correlation.

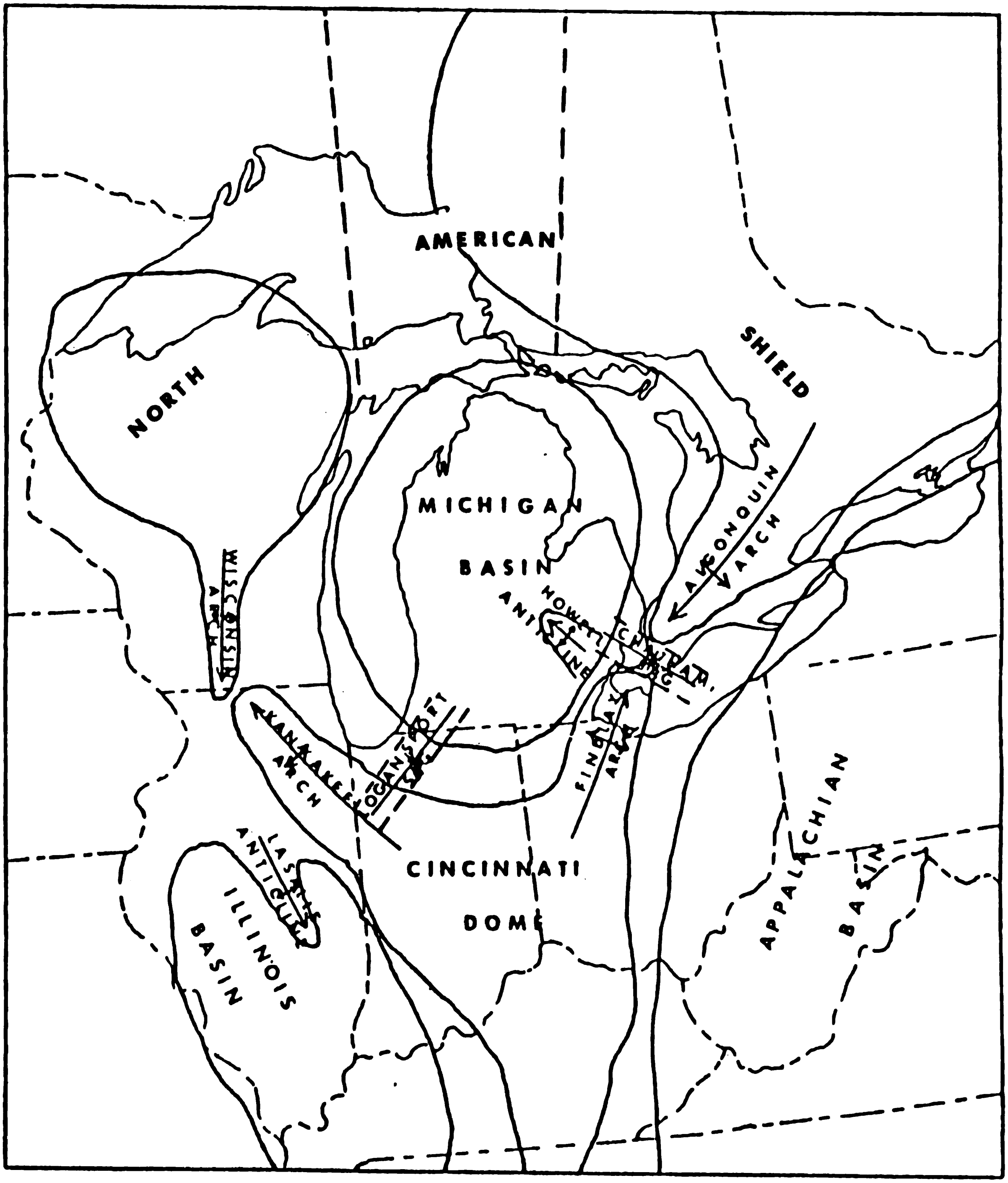
Cohee (1947) described lithology of the Traverse Group in the Michigan Basin as argillaceous limestone, shales and some pure limestone in eastern Michigan grading westward into calcareous shales with the limestone becoming more pure until the whole group becomes relatively pure limestones in western Michigan with some dolomite and dolomitic and argillaceous limestone. In northern Michigan, the Ferris Point, Genshaw, Newton Creek and Potter Farm formations contain gypsum while some gypsum in the lower part of the Traverse in southwestern Michigan is found with lithographic limestone. Relatively pure limestone contains abundant chert and some chert can be found in argillaceous limestone beds also. The thumb area of Michigan is typically shale in the lower part with some shale and limestone in the upper part. Only about 20% of this group is massive limestone. Hake and Maebius (1938) state, "The prominent feature of the lithology of the Traverse Group of sediment in Central Michigan is its composition of calcareous, argillaceous and silicious materials in varying degrees of admixture. These rocks range from remarkably pure limestone through cherty, dolomitic and shaly limestone and limy shales to nearly pure clay shales". They also state that the second outstanding characteristic of this group is the presence of abundant fossil debris which include fragments of corals, hydrozoans, bryozoans, crinoids, and brachiopods. Fossil reefs composed of the remains of hydrozoans, coral and algae also exist within this group.

TECTONIC FRAMEWORK OF THE MICHIGAN BASIN

The Michigan Basin is surrounded in the northeast, north and east by exposed Precambrian rocks of the North American Shield. Stonehouse (1969) suggests that the three provinces of this Shield Area, The Grenville Front to the east, Superior to the north and Penokean to the west meet under the Michigan Basin and comprise the basement rocks of the basin.

The origin of the Michigan Basin is debated by many. Significant theories have been postulated by Newcombe (1933), Pirtle (1932), Kirkham (1937), Lockett (1947), Cohee and Landes (1958) and Hinze (1963). A good summarization of these theories can be found in Ells (1969). These theories range from principal warping of the Michigan Basin by forces related to the Keweenawan Disturbance acting against the rigid Wisconsin Arch area to downwarp in the Basin chiefly resulting from movement of vast bodies of magma from one part of the earth's crust to another.

Many structural elements frame the Basin on all sides (Fig. 2). To the north, northeast, and east the North American bounds the Basin. It is constrained on the west by the Wisconsin Arch, and on the southwest by the Kankakee Arch in northern Indiana. In the south it is bounded by the Cincinnati Arch and in the southeast and east by the Findlay-Algonquin Arches.



MICHIGAN REGION TECTONIC MAP

FIGURE 2

METHOD OF INVESTIGATION

Structure and isopach maps were constructed from tops identified from 310 gamma ray-neutron logs obtained from the Michigan Geologic Survey and were recorded by Schlumberger Log Company. These logs measure and record radioactive emanations from strata exposed in the walls of wells. All rocks exhibit some degree of radioactivity and the variations in this property are sufficiently characteristic to afford a means of distinguishing between different sedimentary lithologies. Identification of different rock types can be made using this log and where a lithologic change occurs at the contact of two formations, tops can be picked. In addition to this, 60 tops were included from well samples selected throughout the state.

Tops were picked in accordance with the manner adopted by the Michigan Geological Survey (Fig. 3). The top of the Traverse Group has always been picked at the base of the Antrim Shale (Fig. 4) that is the top of the Traverse Formation. The Survey's method is to pick the top of the Traverse Group at the base of the first highly radioactive kick of the Antrim Shale going up the stratigraphic column.

This Antrim Shale is a black extremely carbonaceous shale found all over the Michigan Basin (Asseez, 1969). It has been recognized, because of its diagnostic color, as probably the best marker bed in the stratigraphic column of Michigan. Because of its high content of organic matter it

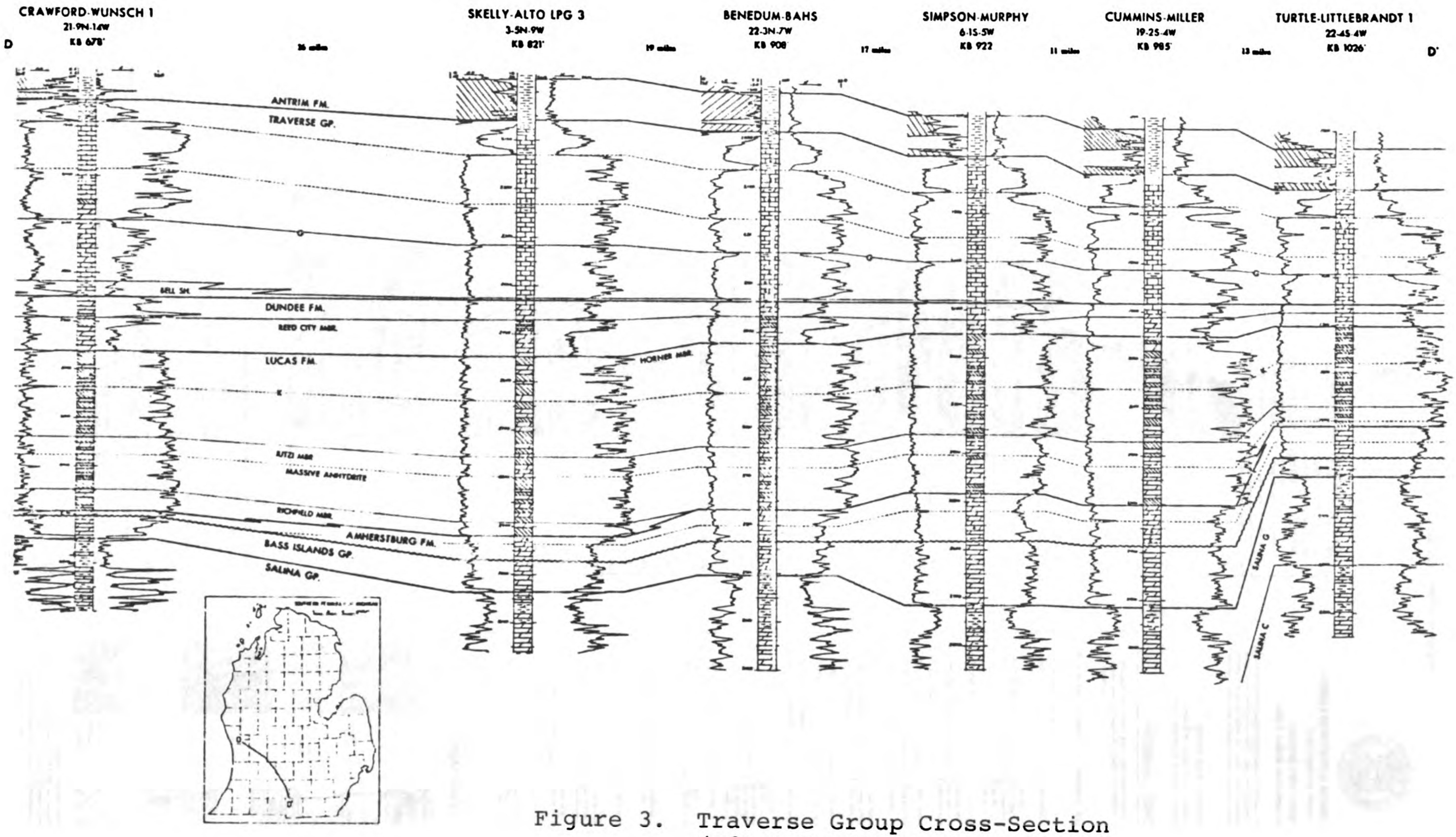


Figure 3. Traverse Group Cross-Section
(after Gardener, 1974)

STRATIGRAPHIC SUCCESSION IN MICHIGAN

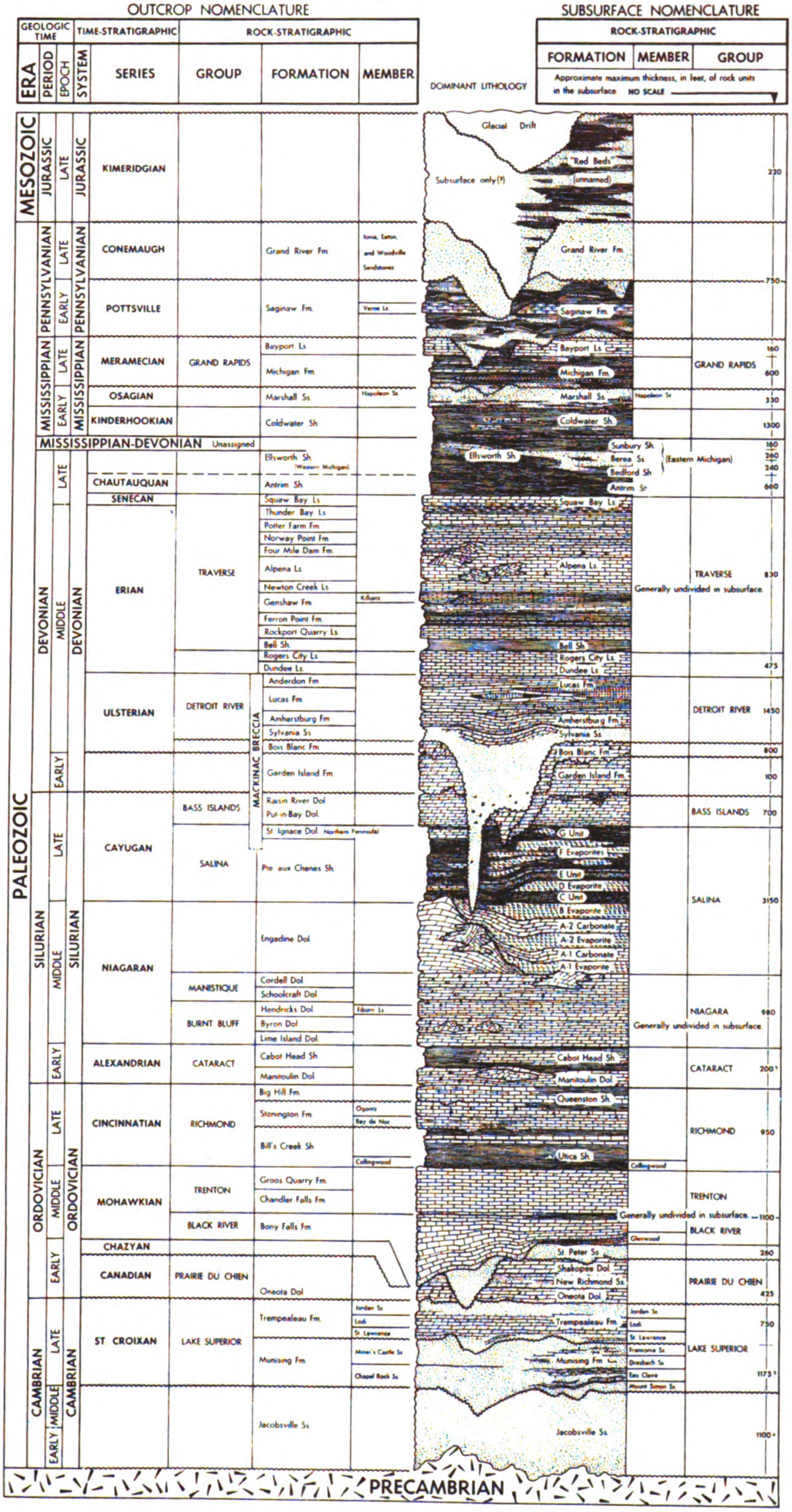
PALEOZOIC THROUGH RECENT

PLEISTOCENE NOMENCLATURE

ERA	SYSTEM	SERIES	STAGE	
CENOZOIC	QUATERNARY	RECENT		
		PLEISTOCENE	Wisconsin Glaciation	Valders Stade
				Two Creeks Interstade
				Mankato Stade (Pt Huron?)
				Cary Stade
				Tazewell Stade
			Sangamon Interglaciation	
			Illinoian Glaciation	

OUTCROP NOMENCLATURE

SUBSURFACE NOMENCLATURE



MICHIGAN DEPARTMENT OF NATURAL RESOURCES
Ralph A. MacMullan, Director

GEOLOGICAL SURVEY DIVISION
Arthur E. Slaughter, State Geologist and Chief

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GEOLOGIC NAMES COMMITTEE

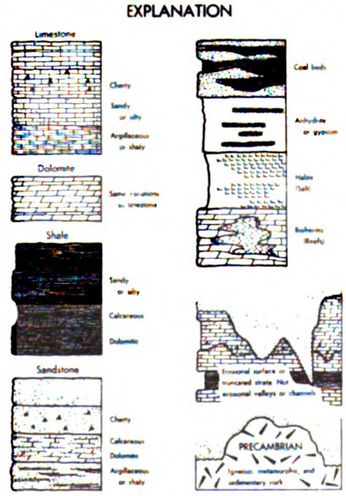
Garland D. Ells, Chairman; Robert W. Kelley, Secretary; Harry J. Hardenberg, L. David Johnson, Harry O. Sorensen

INFORMAL TERMS

Principal oil and gas pays, and informal terms used in petroleum exploration and applied to parts of formations or groups in the subsurface

STRATIGRAPHIC POSITION	INFORMAL TERMS	PAYS
Basal sandstones of Saginaw Fm.	Parma sandstone	
In lower part of Michigan	triple gyp	
	brown lime	
	stray-stray ss	Gas
	stray dol	
	stray ss	Gas & Oil
Marshall Ss		Gas & Oil
Coldwater Sh.	Coldwater lime	
	Weir sand	Gas
	Coldwater red rock	
In upper part of Ellsworth Sh	"Berea" (Western Michigan)	Oil & Gas
Berea Ss	Berea sand (Eastern Michigan)	Oil & Gas
Squaw Bay Ls	Squaw Bay	Oil & Gas
Upper part of Traverse Group in Western Michigan	Traverse formation	
	Traverse lime	Oil & Gas
	Stoney Lake zone	Oil & Gas
Rogers City Ls		Oil & Gas
Dundee Ls		Oil & Gas
Dundee Ls (?), Upper part of Lucas Fm. (?)	Reed City zone	Oil & Gas
In Lucas Fm	massive salt	
	big salt	
	sour zone	Oil & Gas
	massive anhydrite	
	big anhydrite	
	Richfield zone	Oil & Gas
Amherstburg Fm.	black lime	
Part of Salina Group E Unit	E zone (or Kintigh zone)	Oil
Divisions of A-2 Carbonate in Western Michigan	A-2 dolomite	Gas
	A-2 lime	
A-1 Carbonate	A-1 dolomite	Oil & Gas
Upper part of Niagaran Series	brown Niagaran	Oil & Gas
	gray Niagaran	
	white Niagaran	
Part of Niagaran Series	Clinton shale (Eastern Michigan)	
Trenton Group		Oil & Gas
Black River Group	Black River formation	Oil & Gas
	Black River shale	
	Van Wert zone	
Oneota Dol		Oil

EXPLANATION



GEOLOGIC NAMES COMPILATIONS: Harry O. Sorensen, Cambrian and Ordovician; Robert W. Kelley, Early and Middle Silurian; Garland D. Ells, Late Silurian through Detroit River Group of Devonian age; Harry J. Hardenberg, Dundee Limestone through Traverse Group of Devonian age; L. David Johnson, Antrim Shale through the Pennsylvanian System; F. Wells Terwilliger, glacial geology of the Cenozoic.

Figure 4

1964

SECOND PRINTING 1972

is extremely radioactive relative to other rock types and on the gamma ray-neutron log it is denoted by the highest radioactive deflection in the stratigraphic column. The first, diagnostic, off-scale kick of this shale signals the end of Traverse Group deposition. In this manner the top of Traverse Group becomes an extremely consistent pick. It is consistent in that the pick is made in the same place on the log and consistent in that the change, paleoenvironmentally, from the Traverse Transitional Formation to the start of the Antrim Shale reducing facies is correct.

The Bell Shale, which lies above the Dundee limestone, marks the beginning of Traverse deposition. It is very diagnostic on the gamma ray-neutron log and is widespread in Michigan except in the southwest where it thins out. It becomes difficult to determine the base of the Traverse Group in this area because both the Traverse and the underlying Dundee are limestone. The writer, in order to determine the Traverse Group-Dundee contact, used previously published cross-sections (Bloomer 1969, Gardener 1971), cross-sections drawn by personnel of the Geological Survey and published sample records to correlate the Bell Shale from its outcrop area in the north of the southern peninsula of Michigan to where it disappears in southern Michigan. This correlation was continued throughout southern Michigan so that the base of the Traverse would be a consistent and correct pick. It is interesting to note that the southern limit of the Bell Shale by correlation of logs was very close, if not the same, as that placed by Cohee (1947) from examination of well samples.

Three published sample descriptions were also used to help delineate a confusing area in Gladwin County.

Lithofacies variations were determined for the Traverse limestone alone or from that part of the Traverse Group which lies between the top of the Bell Shale and the base of the Traverse Formation (Fig. 4). The bottom of the Traverse Formation or the top of the Traverse limestone as determined by the Michigan Geological Survey is the very first kick representing 100 percent carbonates on the gamma ray-neutron proceeding from top to bottom of the log. This limestone kick represents the top of the Squaw Bay Limestone Unit. Fisher (1969) compiled detailed correlations using gamma ray-neutron logs and represented these as cross sections all over the state demonstrating the widespread character of this unit. The author used these cross sections in addition to cross sections drawn by the staff of the Geological Survey to verify the top of the Traverse limestone or bottom of the Traverse Formation, especially in marginal areas of the Basin where the Squaw Bay thins to fifteen feet or less. This writer supports Fisher's and Cohee's (1947) contention that the Squaw Bay merges with other, less shaly, limestone and dolomite fractions of the upper Traverse Group sediments as the western and southwestern parts of Michigan are approached.

In this way the top of the Traverse Limestone was also chosen from the well samples. All Traverse limestone tops were picked where 90-100 percent carbonate was encountered and then the lithologic description of all 60 of these wells were compared to the closest well where a gamma ray-neutron log was available to verify these tops.

The base of the Traverse limestone in well samples was chosen as the top of the Bell Shale, an easy pick in the northern two-thirds of the State where it consists of 100 percent gray shale. In the southwest corner, comparison of lithologic description of well samples to gamma ray-neutron logs was necessary to ascertain the break between the Dundee and Traverse Group limestones. In most cases, this break coincided with what geologists in the past had picked from well cuttings and recorded on printed logs.

The Traverse Formation was excluded from this study because serious doubt exists as to whether or not it should be placed within the Traverse Group. This formation is thought to be more closely associated with the Antrim Shale paleoenvironment than the Traverse Group. Hake and Maebius (1938) state that rocks of the Traverse formation are not typical of the Traverse Group and in some places they are underlain by black carbonaceous shale stringers characteristic of the Antrim Shale. Evidence of weathering at the top of the Traverse Limestone in southwestern Michigan, according to Bishop (1940), further suggests a break between the Traverse Limestone and shale period of deposition, where no such break occurs between the Antrim and Traverse Formation. Furthermore Fisher (1969), who studied the Traverse Formation, states that it is transitional between the Traverse Group and Antrim Shale and it is not part of the Traverse Group but a separate environmental unit unto itself.

The Bell Shale was not included in this study as it is not representative of the typical environment of the Traverse Group. It has definite boundaries, is almost 100 percent shale and is considered a separate, easily identifiable unit.

The main part of Traverse history is reflected in the interval between the Bell Shale and the Traverse Formation. Some of these subdivisions of the Traverse Limestone are not traceable over the whole Michigan Basin and the fact that this interval is represented by predominant carbonate deposition where small regressive fluctuations are responsible for some shale development indicates that the Traverse limestone was deposited within a single environmental period. Therefore, the inclusion of the Traverse Formation and the Bell Shale with different paleoenvironmental histories in this study would only confuse and hide the lithofacies trends which occurred during the main part of Traverse time.

Data for the lithofacies variations were determined from examination of well cuttings of sixty wells selected throughout the State. As the Traverse was a highly sought after hydrocarbon reservoir, no problem was encountered in finding adequate sample coverage for the State, though

sparse drilling precluded finding good information for Benzie and Grand Traverse counties, and locating wells with complete sections was somewhat of a problem. Samples were obtained from the Michigan State University and Michigan Geologic Survey sample libraries. The author chose one cable tool well per county thus providing a uniform scatter of the state. The advantages of cable tool samples over rotary are set forth by Krumbein and Sloss (1951). A preliminary examination of rotary samples revealed that at least 40-60 percent of each sample represented contamination from above. Therefore, much time was expended locating complete, cable-tool samples for the sake of accurate results.

Examination of cuttings employed the use of a reflected-light binocular microscope possessing a magnification range of 7X to 40X. A gridded eyepiece was used to assist in determining percentages of constituents and to account for size variation of the grains. All acid testing of samples used cold hydrochloric acid diluted with distilled water to acid rates of 7:1. Litholofic determination resulted from guidelines discussed in "Examination of Well Cuttings" (Quarterly of the Colorado School of Mines, v. 46, no. 4, 1951).

Facies changes are lateral variations in a rock unit and the most effective way of portraying them are by maps. An exact and detailed description of a stratigraphic unit is needed and then an expression of that data as a numerical value is necessary to permit the development of facies maps. Krumbein (1951) set forth the guidelines to be used in a quantitative approach to facies portrayal and interpretation. These guidelines also apply to a qualitative approach, which the writer used in this study. Determination of limestone, dolomite, shale, quartz, argillaciousness of carbonates, chert, pyrite, and evaporite percentages were determined from well cuttings. Then a dolomite to limestone ratio, described also by Krumbein was used to determine the degrees of dolomitization and its possible cause. In this case, because of the low number of wells containing appreciable amounts of dolomite, the writer inverted this ratio to obtain a large value to assist in ease of contouring. In this case, the smaller the numerical value for this ratio the more dolomite is found in the well. The most fundamental lithologic ratio, described by Krumbein and Sloss (1951) is the clastic ratio. It is expressed by the formula:

$$\text{Clastic Ratio} = \frac{\text{Conglomerate + Sandstone + Shale}}{\text{Limestone + Dolomite + Evaporite}}$$

The writer used a slightly modified version of this formula necessitated by the lack of conglomerates, low amounts of evaporite and the argillaceous character of the Traverse limestone. The expression developed for use in this study is the formula:

$$\text{Clastic Ratio} = \frac{\text{Quartz+Shale+Clay Content of Carbonates}}{\text{Limestone+Dolomite}}$$

To determine the degree of argillaceousness and obtain a value for the clay content of the carbonates, the author ascertained what percentage of the carbonates were argillaceous and to what extent it was argillaceous and incorporated that value in the clastic ratio formula. The writer determined the percentage of carbonates that had an extremely high clay content. From these percentage values, a thickness of carbonates was obtained and this value was incorporated into the clastic ratio formula as clay content. The author also inverted this ratio for ease in contouring. This, in no way, effected the pattern of contouring. The author also included an evaporite percent map expressed by the formula:

$$\text{Evaporite Percent} = \frac{\text{Evaporite}}{\text{Total Traverse Limestone}} \times 100.$$

and a chert percent map expressed as:

$$\text{Chert Percent} = \frac{\text{Chert}}{\text{Total Traverse Limestone}} \times 100.$$

Such small amounts of quartz and pyrite were found that no meaningful data could be mapped. The chert and evaporite accumulations were expressed as percentages rather than ratios because it is the opinion of the author that the percentage expression represents a truer paleoenvironmental picture of the whole group rather than during merely the carbonate depositional history of the group.

STRUCTURAL INTERPRETATIONS OF MICHIGAN BASIN ON THE TOP OF THE TRAVERSE GROUP

The structure contour map shows a relief of almost 3500 feet from the center of the basin to the outcrop area in northern Michigan (Fig. 5). The basin area has a elevation of almost 2500 feet below sea level while the outcrop area in Cheboygan County is over 1000 feet above sea level.

The basin as pictured here has an almost symmetrical, circular shape with two centers. The primary center is located over Isabella, Midland, Gladwin and Clare counties (see Fig. 6 for location of counties). The secondary center is located over southern Iosco and northern Arenac Counties and the eastern Saginaw Bay Area. This double centered basinal feature was first noticed by Cohee (1947) then by Bloomer (1969) on the Rogers City-Dundee structure map and later by Fisher (1969).

The major northwest-southeast structural trends (Fig. 7) associated with the Michigan Basin are readily verified by the somewhat linear northwest-southeast shape of the primary and secondary centers. The primary center has many features within it which delineate this trend such as the large anticline in northeastern Isabella County (T16N-R3W) and a small anticline adjacent to it in Midland County (T15N-R1W). Other anticlinal features with this trend are located in southern Oscoda County (T26N-R2E), adjacent to it in western Ogemaw is a doubly plunging anticline with smaller, more complex

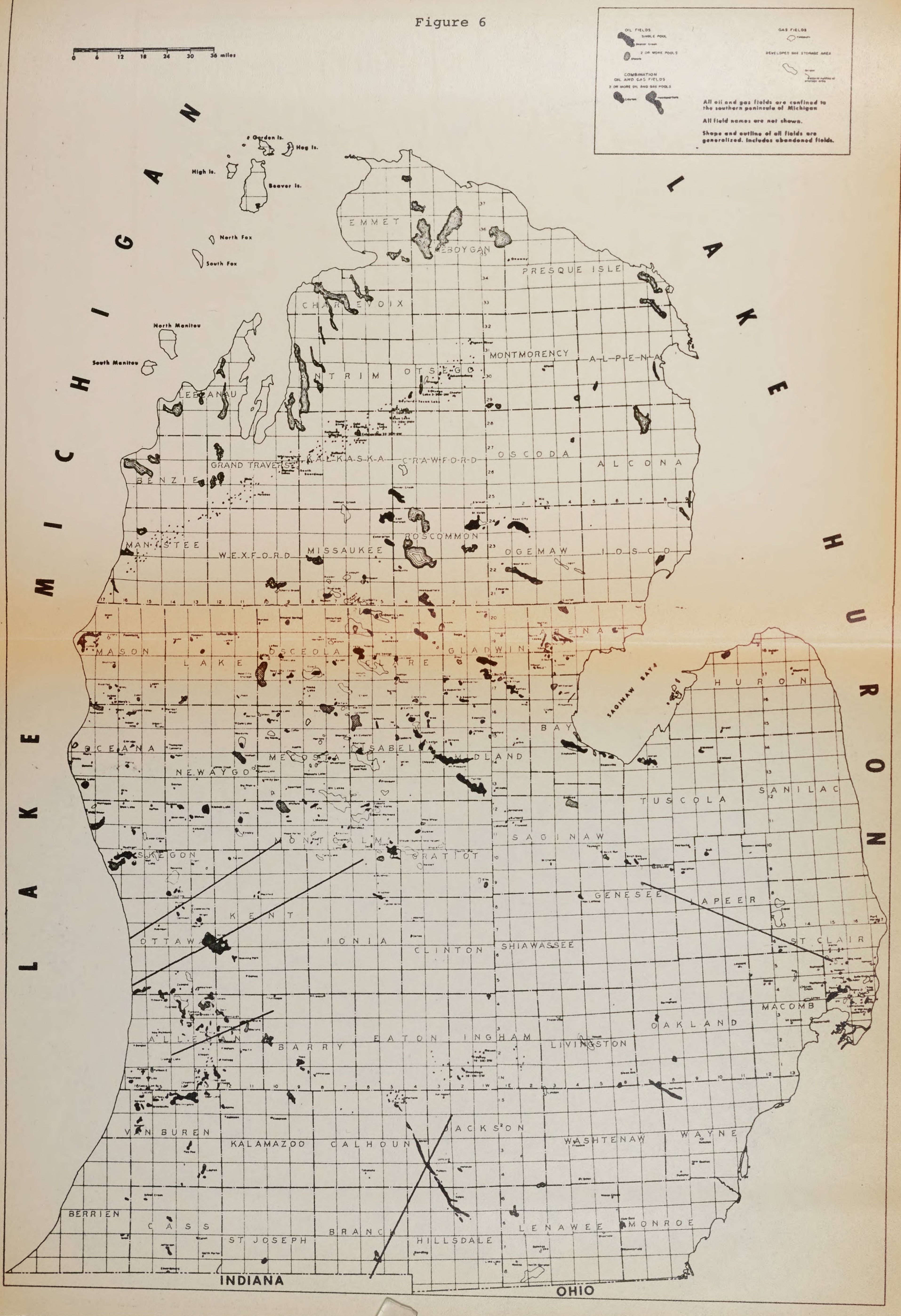

MICHIGAN
TRAVERSE GROUP
Structure
c.i. = 100'
N
TRAVERSE GROUP OUTCROP
TRAVESE SUBCROP

Figure 5

MICHIGAN OIL AND GAS FIELDS

SOUTHERN PENINSULA

Figure 6



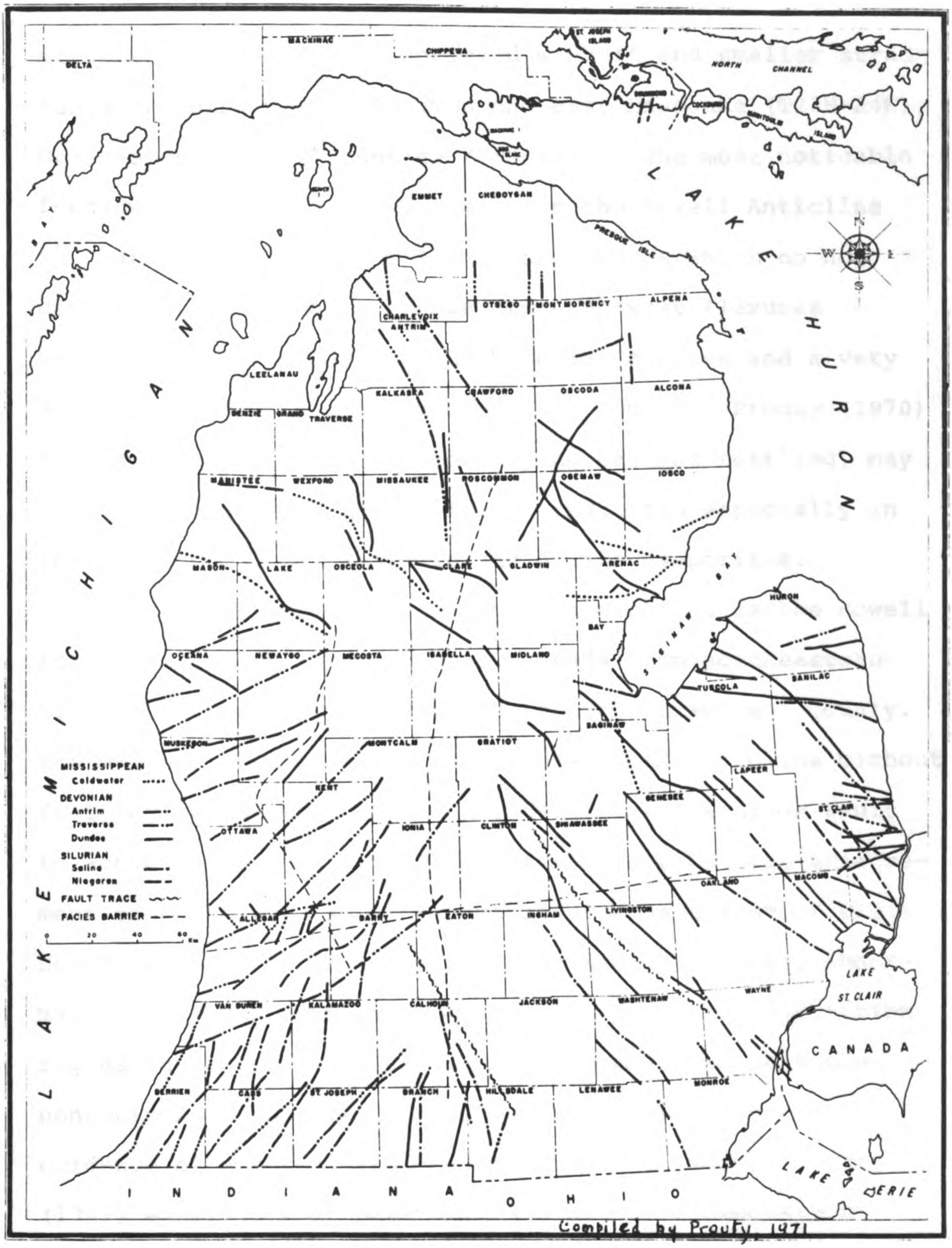


Figure 7. Major Structural Trends in the Michigan Basin (compiled by Prouty, 1971)

structures (T23N-R2E) associated with it and smaller structures crossing west Roscommon and east Missauke (T23N-R4W), Genesee and Lapeer Counties (T9N-R9E). The most noticable feature delineating these trends is the Howell Anticline in southern Michigan. The only structures which do not conform to these major trends are east-west flexures crossing northern Saginaw and Tuscola Counties and a very diagnostic fold in Osceola and Clare County. Prouty (1970) suggests that movement, accompanying basinal settling, may have developed such radial folds, indicated especially in the incompetent Antrim Shale and Salina evaporites.

The major structure in southern Michigan is the Howell Anticline. This large flexure extends from southeastern Livingston County northwestward through Shiawassee County. The writer attempted to contour this as an anticline without faulting it but the control points dictated a major fault to account for the large left-lateral, strike slip arrangement of contours. In a preliminary investigation of the Howell Anticline, this writer found many, extremely abnormally thick and thin sections of Traverse Group deposition suggesting a very complex isopach history with possible noncontemporaneous faulting. Newcombe (1933) showed evidence of a normal fault with 90 feet of throw. Cohee (1947) examined this same data and supports Newcombe's conclusion. Bloomer (1969) did not fault the center area of the Howell Anticline but his extremely tight contours suggest that a fault might be present. On the other hand, Fisher (1969) was able to contour this area without faulting it and, therefore, the interpretation for this area seems open to argument. Secondary anticlinal and synclinal features adjacent to the Howell Anticline are probably associated with the anticline itself. The well known Lucas-Monroe Monocline shows plainly along the southwest side of the Howell Anticline.

It is interesting to compare the features present on the structure contour map to oil and gas fields discovered in Michigan to date (Fig. 6). Foremost of these, of course, is the Howell gas field which lies abreast of the Howell Anticline. The Mt. Pleasant, Porter, Chippewa, Leaton, Geneva, Rosebush, Wise, Vernon, Currie, and Clare City oil fields all lie within the large anticlinal feature located in eastern Isabella County (T16N-R3W). The Rose City, St. Helen, and West Branch fields fall within the doubly plunging anticline in Ogemaw County (T23N-R2E). The Beaver Creek field is located on an anticline in southwest Crawford County (T25N-R4W). In southern St. Clair County (T4N-R14E) many oil and gas fields could be associated with a flexure in that area. The Taymorth, Birch Run, Birch Bela, Arbela, Otisville and Marathon fields lie on an anticlinal fold in nothern Genesee and Lapeer Counties and southern Tuscola County (T9N-R9E). Likewise, another flexure occurs where the Rich and Fostoria fields are found (T10N-R11E). There are many other fields in Michigan such as the Jerome field in Midland County (T15N-R1W), Martin field in Mecosta County (T15N-R8W), Freeman-Redding and Lake George fields in western Clare County (T18N-R6W) and all the fields in eastern Allegan County could be related to the structural folding indicated on the contour map. Many of these fields produce from other horizons than the Traverse Group, of course, but the structures associated with those producing intervals probably would be reflected in the Traverse Group as the main diastrophism occurred much later and would have affected most of the rocks below and above the Traverse. The large contour interval does preclude discerning most of the fields in Michigan such as the giant, Traverse producing Walker field in Ottawa and Kent Counties but it is interesting to see that even a 100 foot contour interval can delineate many structural trends.

ISOPACHOUS INTERPRETATION OF THE TRAVERSE GROUP

The Traverse Group isopach map does not portray the basin as symmetrical nor circular as the structure contour map though it does possess definite symmetry and roundness (Fig. 8).

The thickness interval or depocenter occurs in the Saginaw Bay Area where it has a maximum thickness of 875 feet. The Saginaw Bay area has been a depocenter intermittently from the Cambrian to the Devonian (Fisher, 1969). The group attains a thickness of 800 feet in parts of Gladwin, Iosco, Ogemaw, Roscommon, Oscoda, Crawford and Grand Traverse counties. North of the depocenter, the northern 1/3 of Michigan maintains a thickness of 700-800 feet. This broad area could only be isopached on a 10-foot interval from isopach line 775 and thicker instead of the 25-foot interval used in the rest of the map. In areas where sharp thinning and thickening occur, some lines were omitted for sake of clarity. North of this broad, thick area the Group crops out reaching a thickness of over 700 feet in Charlevoix County to 650 feet in Alpena County. To the south of the depocenter the Traverse thins consistently to 100 feet in the southwest and southeast in the subsurface area.

The regular pattern of east to west isopach lines and the general thinning of the Traverse Group southward (except in the depocenter) likely indicates that this area was


MICHIGAN
TRAVERSE GROUP
Isopach
c.i. = 25'
N
TRAVERSE GROUP OUTCROP
TRAVERSE SUBCROP

Figure 8

inundated from a general northward direction. Hake and Maebius (1938) state that inundation of the Michigan area probably came from the north or northwest direction. They cite for evidence that the Traverse Group thins to the northeast and very rapidly to the southwest in addition to substantial thickening of the Bell Shale in the northwest direction in Manistee County.

One of the most noticable features on the map is the presence of isopached enclosed, thick and thin pockets which trend in a northwest to southeast and northeast to southwest directions. The depocenter is an example of the former. The structural trends of the Michigan Basin (Fig. 7) have this same alignment. These structural trends are thought to denote zones of weakness in the basement along which folding or sinking has taken place. Thinning over major anticlinal folds in the state, noticed by Cohee (1947) and as denoted by the isopach map here, shows that some movement was taking place along these major structures and in other areas of northern Michigan as early as Middle Devonian time. One of the most dramatic examples of Traverse thinning over a present-day major anticlinal trend is located over and associated with hydrocarbon production of the North and South Buckeye, North and South Billings and Bently fields in Gladwin County (T18N-R1W) extending northwestward to the Beaver Creek Field in the southwest corner of Crawford County (T25N-R4W), (Figs. 6 and 8). Thus two very definite thin areas of Traverse Group deposition occur over an existing major structural trend. Thickening between these two areas as well as small areas of thickening adjacent and between the small structural highs in Gladwin County, in addition to, the orientation of these highs, infer that the synclines are associated with en echelon type of folding at that time, in some places. Many petroleum fields, such as those mentioned in Gladwin and Crawford Counties exist along these anticlinal thins gleaned from the isopach map, though hydrocarbon accumulation may have attended a later episode of folding. Other such fields like the Walker field in east central Ottawa County (T6N-R12W) which produces out of the Traverse Group, and the many fields located in the northeast corner of Allegan County could also be related to the folding inferred from the isopach map in these areas Both structure and isopach maps were prepared prior to any reference to petroleum field locations. Some other present-day, major structural trends in the Michigan Basin are believed post-Traverse in origin. The isopachs show no thinning along the major structural feature associated with the Porter, Mr. Pleasant, Chippewa, Leaton, Rosebush, Vernon, Currie and Clare City oil and gas fields (Fig. 6) establishing that movement related to the origin of this structure occurred after Traverse deposition.

Post-Traverse movement is also indicated in southwest, south and southeast Michigan where sharp bends in isopach lines suggest the possibility of faulting along the strike of the structural trends of the Michigan Basin. These hypothetical faults are indicated on the Isopach Map (Fig. 8) by solid lines. In northern Ottawa and Kent Counties, asymmetrical, sharp isopach bends suggest a right lateral, northeast to southwest trending fault (Figs. 6 and 8). Adjacent to this fault, south of it and parallel to it, is another area in central Ottawa and Kent Counties where isopach lines also suggest a fault of the same nature. Here though, the symmetry of the isopach lines might indicate folding instead, contemporaneous with Traverse deposition. Other areas where similar faulting can be postulated are Allegan County where the center of the fault is located approximately in T2N-R13W, in Branch and Jackson Counties, where a right-lateral northeast to southwest trending fault cuts through the center of the Albion-Scipio trend; and in Lapeer and St. Clair Counties, a northwest to southeast trending left-lateral fault is also postulated. These structures, inferred from 25-foot contours on the isopach map, are not apparent on the structure map probably because of the large, 100-foot contour interval. The alignment of the proposed faults on the isopach map in Allegan and Ottawa Counties tie in isolated oil fields, as indicated by solid lines (Fig. 6), and suggest a connection with the origin of linear producing fields. In southern Michigan, the hypothesized fault trending southwest to northeast through Branch and Jackson Counties crosses the linear Albion-Scipio field. Prouty (manuscript maps, 1976) has demonstrated that many of the oil and gas fields of Michigan produce where fractures intersect. He indicates that it is in these cross-structures that dolomitization is apt to be most marked. It is suggested that this fault which intersects the Albion-Scipio field might be related to this cross-faulting or cross-structure. The coincidence of the suggested faults in Ottawa and Kent Counties and Allegan County in crossing present day major structural trends and tending to fall on isolated oil fields, such as the Walker field (which incidently produces out of the Traverse Group), suggest that these might also be cross-structures occurring after Traverse deposition and related to the origin of the major structural trends. The east to west fault postulated in northern Oceana County (T16N-R14W) could be related to post-Traverse movement along radial lines of weakness accompanying basinal settling or be a part of the overall fracture pattern that may exist in the Basin. The wedge-shaped thick area located in the extreme southwest corner of the State (Fig. 8) could be related to movements during Traverse time, but might be better explained with additional well control available.

In southeastern Michigan, along the trend of the present Howell Anticline in Livingston County, an abnormally thin area projects northward. A more detailed investigation into the gamma ray-neutron logs of the area revealed that it is a very complicated area isopachously, perhaps involving faulting. Kilbourne (1947) could not contour the interval between the base of the Sunbury Shale and the top of Dundee limestone without faulting it. Six gamma ray-neutron logs listed in Appendix C revealed an abnormal thick area located approximately in the northeast quarter of section 18-T2N-R5E adjacent to it. This area should be approximately 325 to 350 feet thick but was found to vary anywhere from 350 to 650 feet thick. Using these six wells, in addition to other wells in close proximity, a broad area of thickening is evident, with a very small local area of abnormal thickening in the area of the six wells mentioned. Although isolated thicknesses of 650 feet occur within a very small area, the author limited this maximum isopach to 400 feet on the scale of Figure 8. Since the Howell Anticline is the subject of a current study, the writer did not carry his investigation into this area but based on Kilbourne (1947) conclusions, the complexity of the area isopachously with abnormal thickening and thinning in close juxtaposition, in addition to, a northward dragging appearance on the west side of the broad thick area directly adjacent to the abnormal thin area in T2N-4E, suggests the presence of a fault there. The author has taken the liberty of drawing a left-lateral fault (Fig. 8) tending northwest-southeast which falls in the same place as the present Howell Anticline which might explain some of the anomalies through the offset of isopachs. The origin of the before mentioned, very small, abnormal thick area in the northeast corner of 18-T2N-R58 can only be guessed at now. Perhaps a karst topography on the Dundee limestone surface can account for the thick sequence or solution of the underlying Detroit River or Silurian evaporites produced caving of the overlying beds before Traverse time.

One last thing to be mentioned about the isopach map is the obvious difference between the position of the structural center (Fig. 5) and the depocenter as delineated by the isopach map. The center of the basin in Traverse time has been pushed from the Saginaw Bay area to central Michigan. The forces which caused this event must have occurred after Traverse time as the center of the basin was in all probability where Traverse deposition was thickest.

FACIES INTERPRETATION

The various facies maps were constructed to delineate any regional trends and their association to events and/or structural setting in and around the Michigan Basin.

Carbonate Facies

The limestone to dolomite ratio is used to discover lithofacies trends in the predominant carbonate deposition of the Traverse limestone. In this map the zero contour line indicates a hypothetical 100 percent dolomite and any number larger than this reflects more limestone relative to dolomite. No well was encountered where dolomite exceeded the limestone content though the dolomite in the well in Oceana County equaled the limestone content. In fact, any value over 40 represents a very small amount of dolomite and shaded areas represent 100 percent limestone.

The high amount of dolomite along the west side of Michigan reflected in this map (Fig. 9) has been noted by Gardener (1971). Others, such as Hake and Maebius (1938) indicate that various counties on the west side of Michigan contain a higher amount of dolomite than usual. The north-south trend of this dolomitic zone suggests a possible relationship to the Wisconsin Arch (Another alternate hypothesis will be discussed later). Newhart (1976), in a study of the carbonate facies of the Middle Ordovician demonstrates a possible relationship to an evaporation-reflux dolomitization

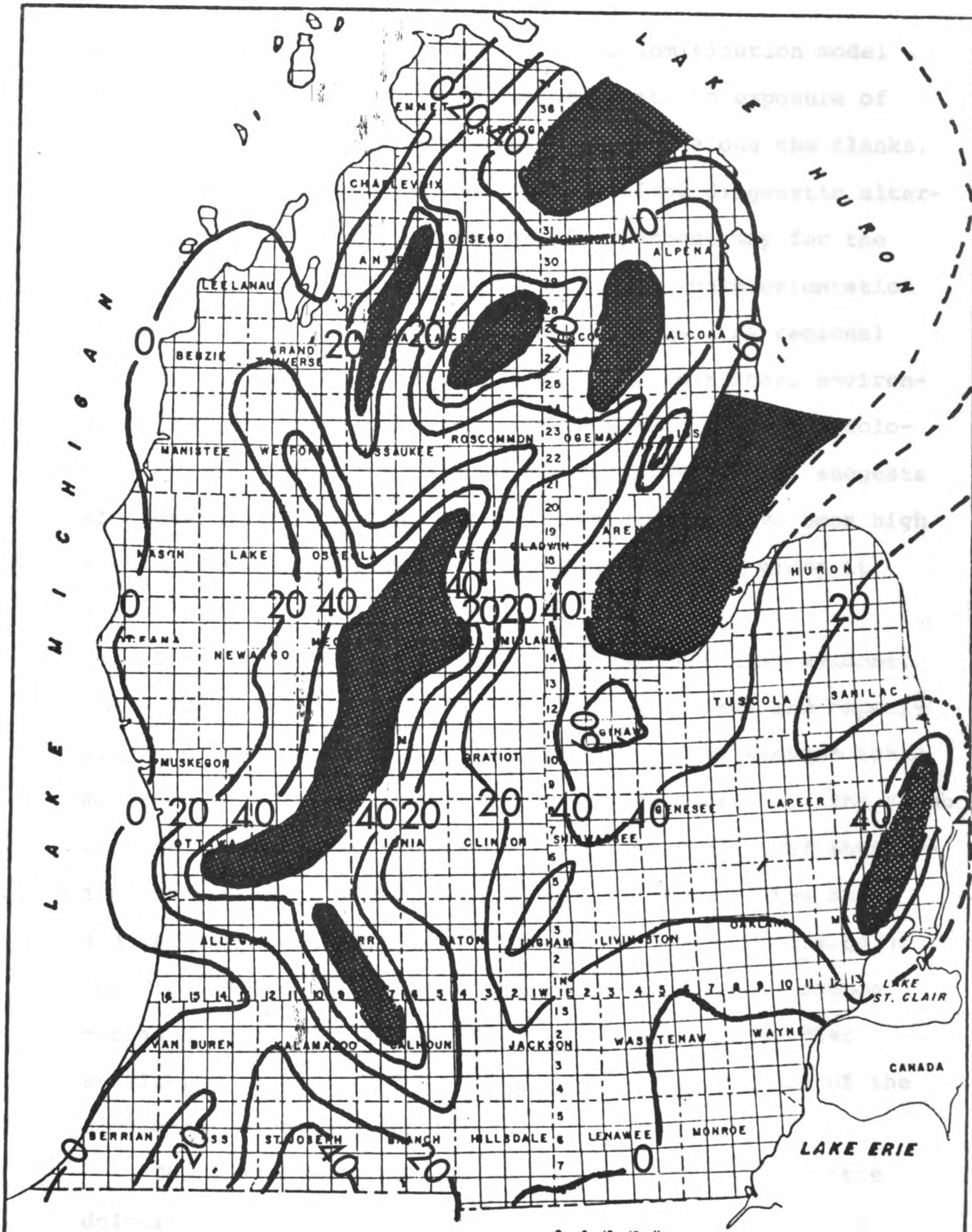


Figure 9. Carbonate Facies Map. (LS/DOL)

model after Deffeyes (1965) or Dorag dolomitization model after Badiozamani (1973). Evidence points to exposure of the Middle Ordovician carbonates, at least along the flanks, of the Wisconsin Arch at that time to allow diagenetic alteration of the limestone. His dolomite percent map for the Trenton carbonates have the same north to south orientation in western Michigan as that of the Traverse. As regional dolomite content may indicate a shallow, near-shore environment (Prouty, 1946), the presence of a high amount of dolomite in the same north to south trend as Newhart's, suggests the possibility that the Wisconsin Arch might have been high enough to cause shallowing of the Traverse seas along it also.

Other areas of high dolomite content are also evident. These are in the northeastern to east thumb area and especially the southeast corner of Michigan. On the clastic ratio map (Fig. 13) the highest clastic area is located in the thumb area and southeastern Michigan indicating again that shallowing was occurring along the southeastern edge of the basin and may have some implication in regard to the proximity of the Findlay Arch. The dolomite trend in the east, though not as high as that in the southeast, does suggest that shallowing is taking place farther eastward in light of the high clastic content there.

The shaded areas on the map contain extremely little dolomite or none at all. The high limestone area in the central part of the state is also relatively pure limestone with very little dolomite or clay content. A north-south trending barrier (which will be discussed later) has been postulated by several including Jodry (1954) and Hale (1941), in this general vicinity (Fig. 11). Reef buildup on this postulated barrier is evident in the Paris oil field (Jodry, 1954). If reefs developed along this barrier, it partly could have restricted sediments to the west side of Michigan in a logoonal environment of perhaps more saline waters, enhancing good limestone development to the east of it and accounting, in part, for the high dolomite content to the west. Comparison to the clastic ratio map (Fig. 13) shows some support for this theory as the clastic content drops off sharply in this area along a north-south line which could represent the barrier. However, it is possible that this area could be the westernmost extent of the clastics from the east. Other hypotheses concerning the various areas of high dolomite and high limestone will be discussed later. The isolated area of no dolomite in the area of the Chatham Sag might be caused by deepening, but would appear anomalous in regard to the high clastic ratio there.

Evaporite Facies

In the evaporite percent determination (Fig. 10) only a small amount was encountered and only a few wells contained enough to be meaningful. No Traverse limestone section contained over 2% of the evaporites. The wells plotted

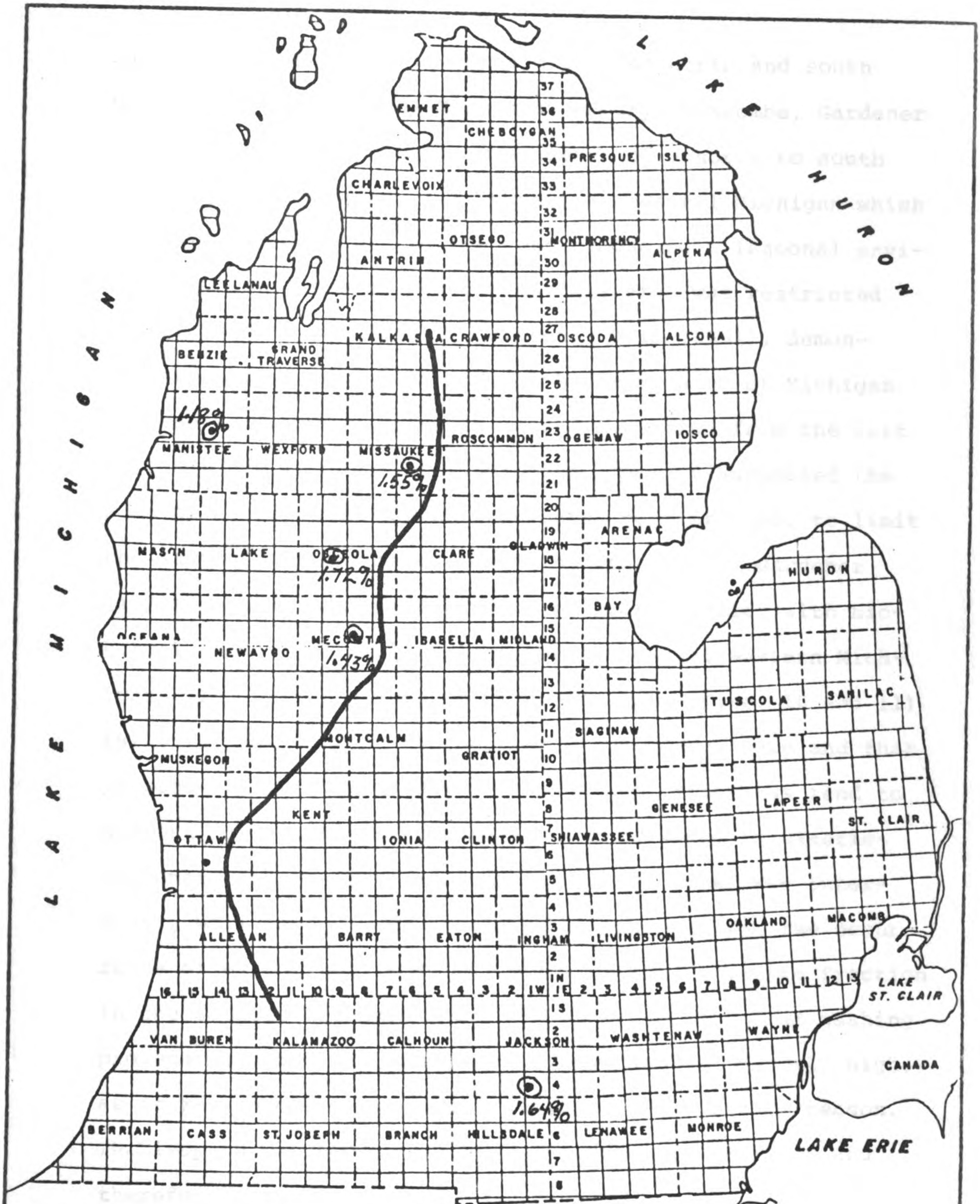


Figure 10. Evaporite Percent Map
Author's Barrier Axis =

indicate a high evaporite area extending north and south through western central Michigan. Jodry, Newcombe, Gardener and many others cite this as evidence of a north to south trending barrier (Fig. 11) in western central Michigan which restricted the waters to the west producing a lagoonal environment. In times of regression this area was restricted enough to have produced evaporites. Hale (1941), demonstrated that the western and southwestern area of Michigan represents a different basin of sedimentation from the rest of the state in lower Mississippian time and supported the idea of a structural or environmental barrier also, to limit the eastward extension of the Ellsworth Shale. Gardener (1974) also demonstrated a north to south barrier with biohermal and biostromal development in central western Michigan. The writer's area of high evaporite (Figs. 10 and 11) falls in part between the barrier proposed by Jodry and that proposed by Hale. The few wells showing evaporites tend to support the lagoon barrier model also inferred in clastic-carbonate facies distribution. It is not clear why intervening wells are so devoid of evaporites. Either the occurrence of evaporites is quite local, or the evaporite fraction in the samples may have been lost in drilling and/or washing procedures. The well in Jackson County is anomalously high, as it was in chert percentage-possibly for the same reason. The isopach map shows this area as probably shallower and therefore a more restricted environment.

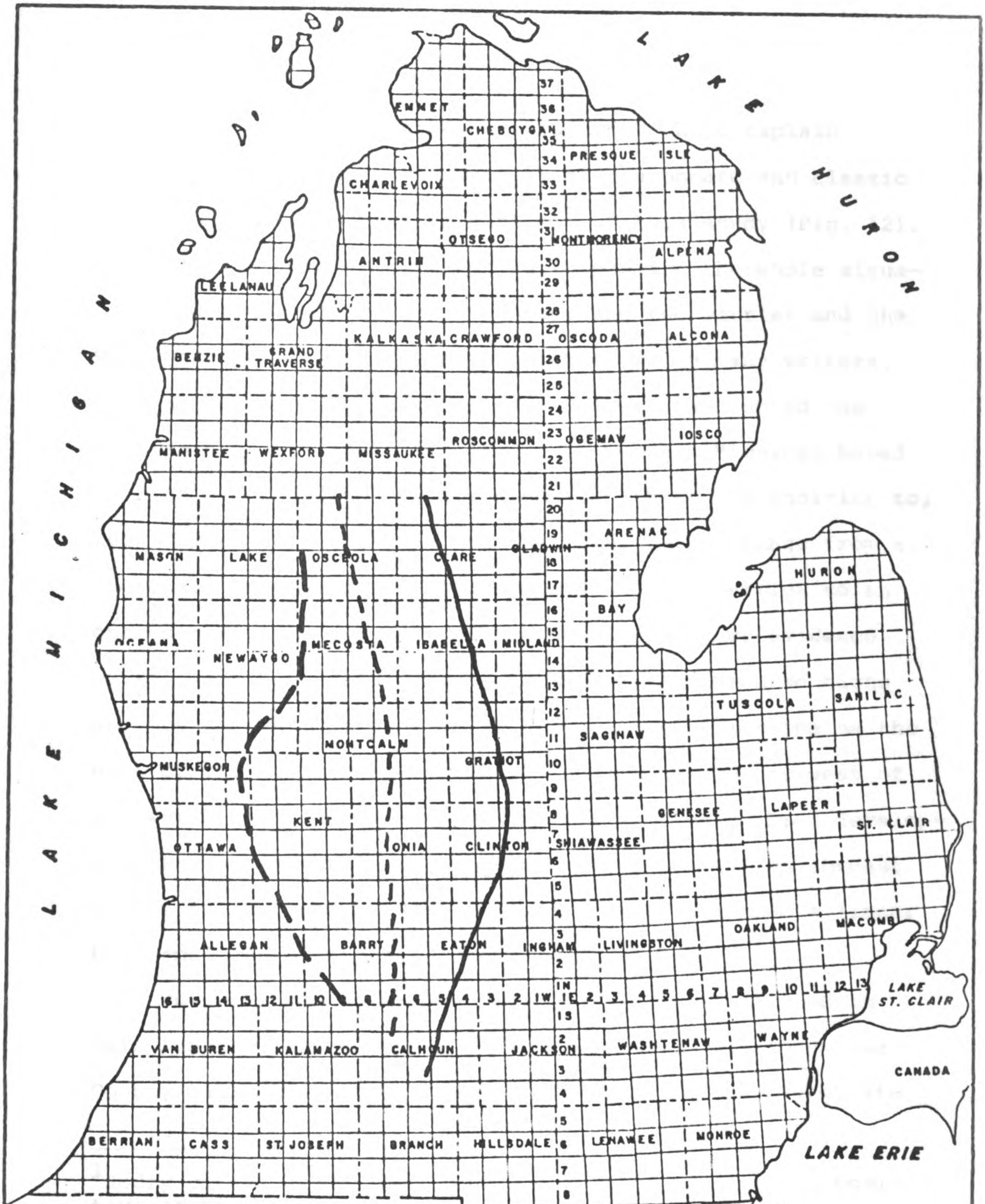


Figure 11. Previous Barrier Axis
Jodry's Barrier = - - - -
Hale's Barrier = --------
Newcombe Barrier = ______

Barrier Model

A simple model can be constructed to help explain the lithofacies trends denoted by the carbonate and clastic ratio and the evaporite percent map of this study (Fig. 12). In no way is this model intended to explain the whole situation or answer all questions concerning the barrier and the west Michigan lagoonal facies noted there by many writers.

As mentioned before, several writers have noted the existence of a structural barrier in western Michigan based on high dolomite and evaporite content there, in addition to, reef development along it and the lithofacies change from a lagoonal environment on the west side of the barrier to an open sea environment east of the barrier. Other evidence exists, such as gravity highs,[1] structural contoured highs and the change from chemically precipitated limestone on the east of the barrier to biohermal development to the west of it, which delineate this feature (Jodry, 1954). Reef development was noted by him in the Paris field which lies abreast of the barrier and by Gardener (1974) who indicated a linear biohermal and biostromal development along it also.

One well was anomalous to all other wells studied in this report. The Traverse limestone section in the Ottawa County well is 300 feet thick and contains about 15% pyrite

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[1]Jodry cites as additional evidence for his barrier a positive gravity anomaly as mapped by Loque (1954).

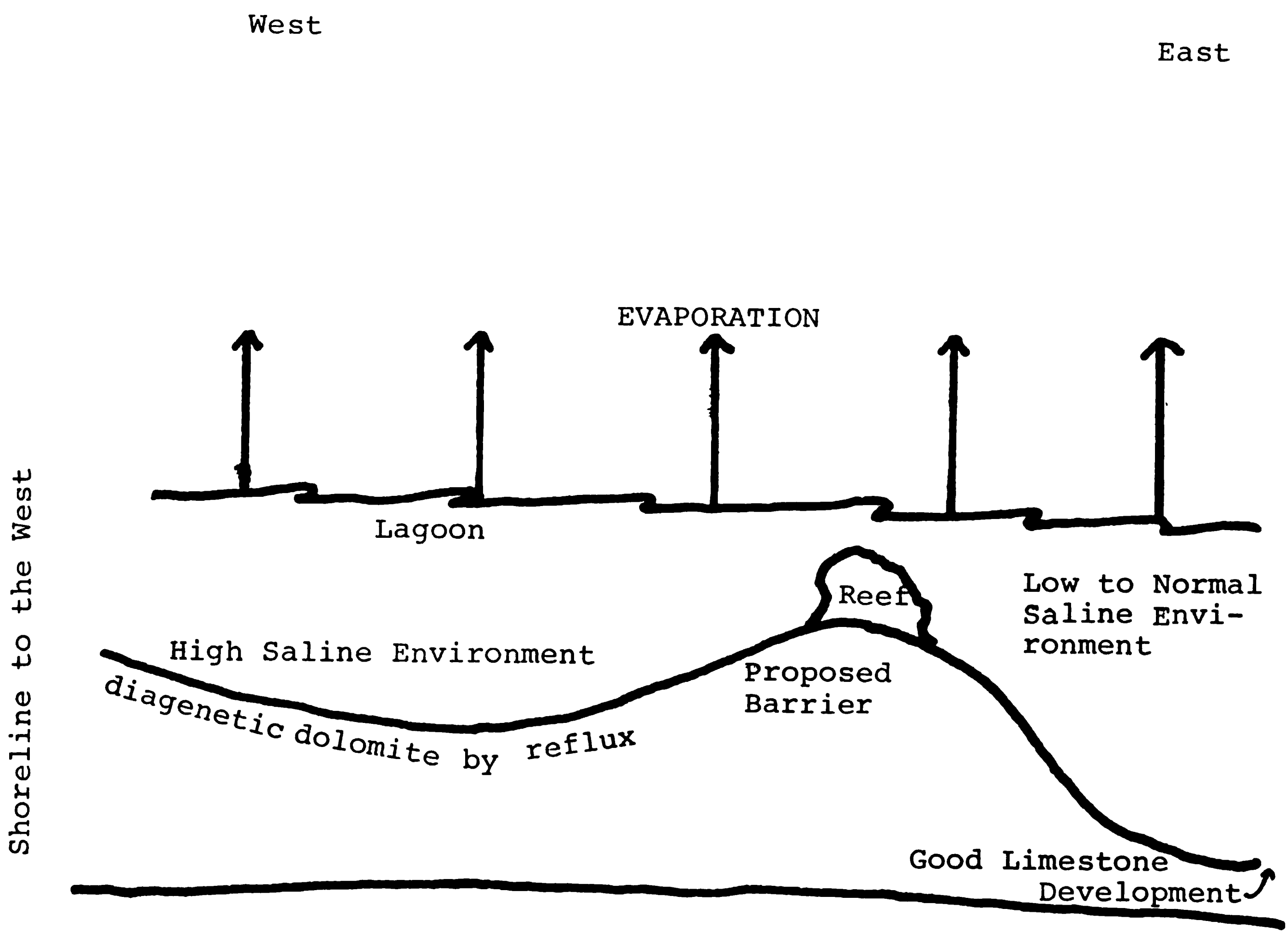

Figure 12. Barrier Model

with the other 85% consisting of reworked very clean, white coralline limestone. In no other well did the pyrite percent exceed .8% or consist of such predominent clean coralline limestone. Jodry, citing evidence for a hypothetical barrier in western Michigan, which separates lagoonal and deep water facies, states that east of the barrier dense chemical carbonates with minor development of coralline limestone or other fossil material predominates while west of the barrier, in the lagoonal facies, biohermal carbonates are abundant, as are limestones made up of reworked fossil material. The presence of such a large amount of pyrite supports a reducing environment interpretation for western Michigan and enhances the concept of a semi-protected lagoon where reefs and banks developed. It should be mentioned that high pyrite content can just be coincidental. Its presence in just one well is not necessarily sufficient evidence to definitely support a reducing environment. Using the evidence obtained from the well in Ottawa County as well as the linear trend evaporite high and the evaporite high in Manistee County the writer's proposed position of the barrier, denoted on the evaporite percent map as a solid line, would fall approximately in line with previous postulated axes (Fig. 11).

The presence of this barrier, with reef development existing abreast it could help explain the lithofacies trends present in this study. The restricted nature of the waters west of the barrier would develop a highly saline environment where diagenetic dolomitization might occur.

This would be especially enhanced when periods of slight regression lowered the water in the lagoonal area. The restricted nature of this lagoon could also have been augumented by the presence of the Wisconsin Arch to the west.

The evaporation evident in this western lagoonal area would develop highly saline waters. Dolomitization then would probably generate from an evaporative-refluxing model after Deffeyes (1965). Gardener (1974), on a common association of dolomite below anhydrite beds, also suggests this model for the origin of dolomite in the lagoonal area. On the east side of the barrier, normal salinity and deeper water existed in an open sea environment. The existence of the high limestone to dolomite area (shaded area in central Michigan on Fig. 9) east of this barrier infers that the limestone was deposited in an area of low salinity. The lack of clastics on the west side of Michigan indicates that the barrier was probably a physical barrier with respect to currents.

The local pockets of high limestone to dolomite content in the north and the general low dolomite content encountered there can be accounted for if a low normal sea water salinity is hypothesized. Gardener (1974), describes this northern area of Michigan as a shallow, subsiding marine carbonate shelf with biohermal development evident. Good limestone development like this will probably take place in normal ocean salinity. Another area of good limestone development occurs in the vicinity of the depocenter. Here rather normal salinity would be expected, in this open, probably deep water, area. Laseme (1975), in a study of the Bayport Formation, demonstrates a relationship of limestone with depth. As the depocenter area was in all probability the lowest part of the basin at this time it is suggested that the low dolomite content found there is a result of a combination of deep water and low salinity.

Clastic Facies

The clastic ratio (Fig. 13) was used here to delineate source areas of clastics and their relationship to the Michigan Basin. A value of one signifies an equal amount of carbonates and clastics and values less than one signify that more clastic material is found than carbonate material. Values of 10 or greater correspond to very low amounts of clastics. The north to south trend of the contours indicates that a regional clastic invasion from east to northeast occurred with the highest clastic content found in the east and grading westward to predominantly non-clastic sediments in the western third of Michigan. The high clastic content extending from Saginaw Bay to the thumb area and southeastern Michigan in addition to an indication of high dolomite content (Fig. 9) further east of the Basin than this study covers, suggests shallowing further eastward. These same areas indicate a source for clastics out of the east. A rising eastern source area is definitely indicated by Assez (1969) in the Bedford-Berea sequence and by Chung (1973) in the

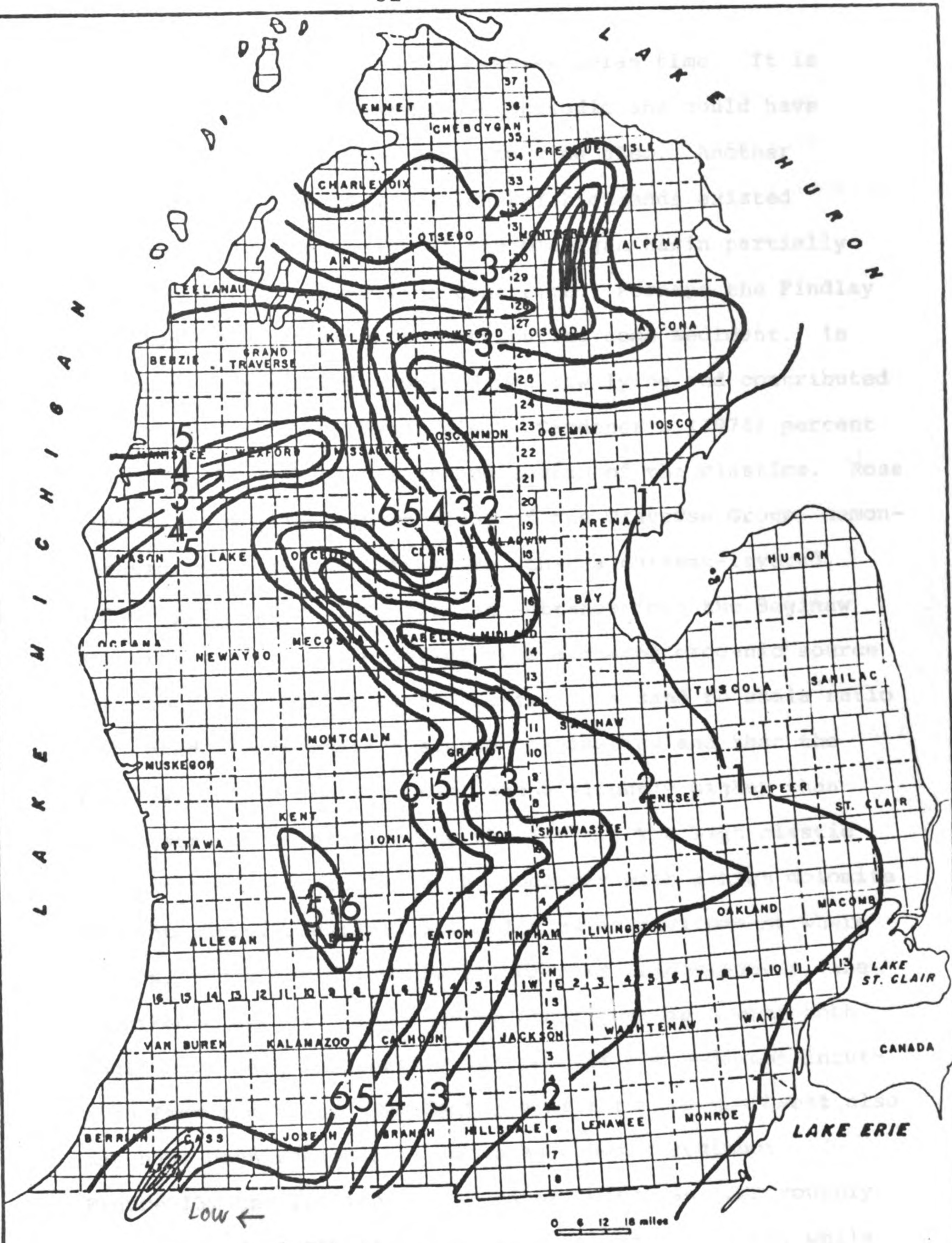

Figure 13. Clastic Ratio Map

Oth: Clastic

Coldwater Formation in early Mississippian time. It is possible that this movement was episodic and could have shown activity in Middle Devonian time also. Another alternative is that low, peripheral highlands existed to the east and southeast of the Michigan Basin partially or throughout Traverse limestone time. Perhaps the Findlay and Algonquin Arches were contributing some sediment. In the north, the Canadian Shield was low lying and contributed some clastics to the Basin also. Gardener's (1974) percent shale map focuses on a eastward source of the clastics. Ross (1957), in a quantitative study of the Traverse Group, demonstrated, in a clastic ratio map, that a current-layered, delta-type pattern indicated an entrance into the Saginaw Bay area of detrital material from a nearby orogenic source area to the northeast of the Basin. His sand to shale ratio indicated a more eastern source of clastics and that the Findlay Arch to the southeast stood slightly higher than other structures surrounding the Basin. The high clastic content near the Findlay Arch, together with a high dolomite content there, indicates a shallow water environment where reflux, secondary dolomites accompanies predominantly fine reworked clastics. The Findlay and Algonquin Arches both could have been responsible for part of the sediment incursion from the east. The Kankakee Arch to the southwest also may have been responsible for some clastic sediment. In Figure 13, the isoliths in southwest Michigan turn roughly westwart and northwestward subparallel to that arch, while a small dolomite content suggests deeper water.

Very little quartz was encountered in the Traverse limestone but that present would appear to indicate that at one time the grains were in dune phase or at least under short wind transport. The grains were very slightly frosted, fine to medium grained. The possibility does exist that some of the clastic sediment could have been wind transported but were deposited in the marine environment.

Chert Facies

The chert percent map (Fig. 14) shows that an area of high chert content is found in southern Michigan. Ross (1947) also found that most of the chert was restricted to the south and central area of the Michigan Basin. As the origin of chert is highly questionable, more detailed studies are needed to account for its widespread occurrence in the Traverse Group of Michigan, especially in the southern portion. The bedded character of the chert, in addition to a climate favorable to life indicates a possible organic origin for it. Perhaps it is a lithified diatomaceous or radiolarian ooze or lithified spiculites (Pettijohn 1957). However, no organic remains were observed. A second hypothesis is that this chert is post-Traverse in origin and is a result of replacement by ground water. The high evaporite content present in the Jackson County well (T4S-R1W), (Fig. 10), suggests that this area was probably slightly restricted at some time during Traverse history. A third possibility may be found by comparison to Upper Cambrian and Middle

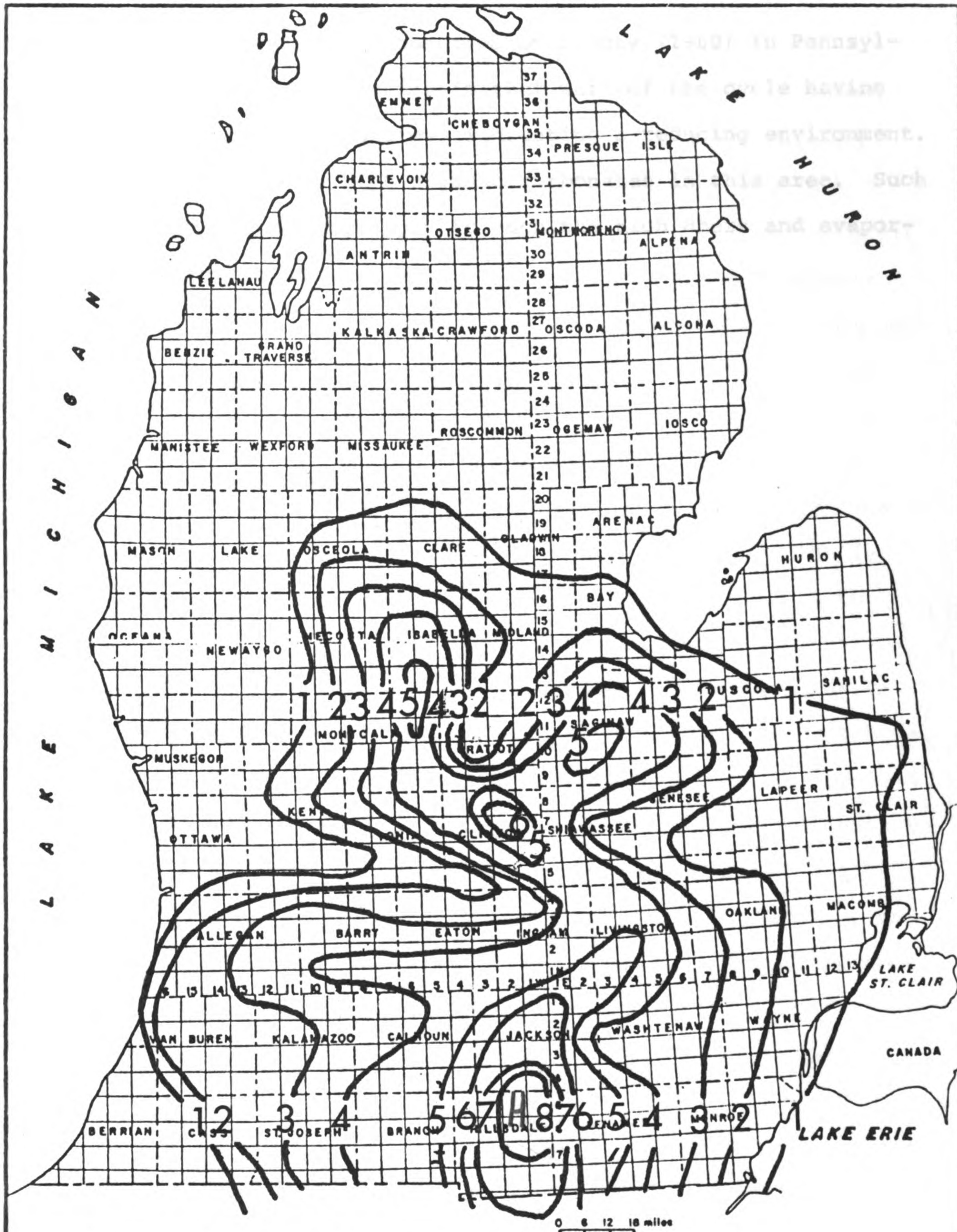

Figure 14. Chert Percent Map

Ordovician cycles as observed by Prouty (1960) in Pennsylvania where chert accurs in that unit of the cycle having dark, organic carbonates, indicating a reducing environment. The writer noted high organic carbonates in this area. Such an environment may apply to both the high chert and evaporites content here.

ENVIRONMENTAL INTERPRETATION

At the beginning of Traverse time the seas advanced over the Michigan Basin from the north or northwest as pointed out earlier. The depocenter existed in the general Saginaw Bay area as the thickest accumulation of sediment is found there, and a shelf-like, thick area existed throughout the northern portion of the southern peninsula. Reef development built up over some parts of this area as evidenced by abundant fossil debris in some of the wells in the northwest and in outcrops in the northeast. This area was probably a shallow, subsiding marine carbonate shelf. Limestone was deposited as the sea deepened to the north and the environment was favorable to the preservation of life forms as evidenced in the samples. The high dolomite content in the west suggests shallowing and some restriction. These dolomite isoliths are subparallel and possibly related genetically with the Wisconsin Arch. An alternative hypothesis suggest that a barrier, probably structural, is indicated by the relatively high dolomite and evaporite content on the west side of it, developing a restricted lagoonal area there. Isopachous thickening and thinning areas denote that some very slight diastrophism was taking place in the Basin at this time forecasting either the Acadian Orogeny or the later, Appalachian Orogeny; or perhaps owing to differential basinal settling. A clastic facies map indicates that the primary source area existed to the northeast, east and southeast, whether from afar or the eastern periphery.

Some clastics may have been derived also from a structurally low relief Canadian Shield to the north. Dolomite trends support a shallowing along the eastern rim of the Basin, perhaps on the Findlay Arch. In the northern, deeper water areas, precipitation of limestone predominated. Though clastics were entering the eastern and northern areas, rather pure limestone relative to dolomite, was deposited in this deeper, lower saline water area.

ECONOMIC IMPLICATIONS

Most of the hydrocarbon production associated with the Traverse Group has been discovered in southwest Michigan in the general vicinity of Van Buren, Allegan, Ottawa and Kent Counties. Jodry believes that some of this production is related to reef buildup on anticlines or his hypothesized West Michigan Barrier. Davies (1952) in a study of southwest Michigan, on the other hand, strongly advanced a structural relationship only, based on the definite lack of reef lithology in samples from producing wells. In either case, Traverse production in the southwest is usually found in the uppermost layer of the Traverse limestone where porosity is developed as a result of secondary (epigenetic) dolomitization and is overlain by a chert layer. In other areas of the state, production is found at the top or deeper in the Traverse limestone but usually from dolomitized layers. Cohee (1947) states that the best production from the Traverse has been obtained at places where limestone has been dolomitized. It has already been pointed out that dolomitization is apt to be most marked where cross-structures are associated with structural closure.

It has been noted that most of the hydrocarbon production from the Traverse Group is found in southwest Michigan, but by no means all of it. Many fields are located in the central and marginal areas out of the high regional dolomite area. Also since dolomitized production zones are often linear and found beneath layers of chert or shale and are associated with structures such as anticlines or inferred faults indicate that this dolomite is structural and epigenetic in origin rather than regional or diagenetic. Most authors concur that "structural" dolomitization stems from ascending ground waters up through fracture systems in association with damming affects produced by overlying impermeable layers such as shale or chert. If, in fact, the dolomite associated with the production zone in linear fields of the Traverse Group are structural, then this origin of structural dolomite could be postulated.

Though the Traverse Group was a much sought after target in the 1920's and 30's, other petroleum traps must exist. Further investigation along the cross-structures in Kent and southeast Montcalm County (Figs. 6 and 8) is warranted. The isopach map definitely indicates that faulting or folding has taken place along a northeast - southwest trend. The author suggests that the northeast extension of these structures be examined in more detail. The cross-structures located in Branch and Jackson Counties, which cross the Albion-Scipio field, suggest that a further search for hydrocarbons along such features be initiated not only in the Ordovician but in the Traverse Group above. Though it has been explored repeatedly, the Howell Anticline still remains one of the most attractive areas. The elusiveness of the big reservoir traps there can probably be associated with a complicated cross-structure relationship. In Lapeer County, T7N-R11W, an anticlinal thin or fault is shown in Figure 8. Though no structure as delineated from the structure map is seen to coincide with this isopach anomaly, it still remains a choice explorative area. It should be mentioned here, that the lack of structure associated with the above and heretofore mentioned traps is directly a result of the large contour interval on the structure map. A structure map with such a large interval will only define very large structures such as the Howell Anticline or the Mt. Pleasant-Porter structure. It must also be pointed out that these structures denoted on the isopach map formed during or later than Traverse time may have been destroyed, enchanced or at least moved slightly during more intense movement, possibly in Mississippian time. Therefore, smaller and more complicated closure can only be obtained from a more detailed mapping on a smaller scale and area such as a single township and range block. Other folds worth looking at exists in (1) T5N-3W through T6N-3W and 5N-3W (Fig. 8), (2) T6N and T7N-8W, and (3) 25N and 26N-10W and 11W. These areas indicate thinning taking place during Traverse Group deposition and petroleum traps could be associated with these. An excellent possibility exists in T17N and 18N-R6 west, exactly on the boundary separating the two range and township blocks. Here a structural east to west trending anticline (Fig. 5) coincides with an isopach thin or fold in Traverse time. If the later diastrophism which caused the east to west fold, denoted on the structure map, did not destroy the isopach thin or fold, which in all probability it did not, then this area holds future promise.

Though the major structural trends and the hydrocarbon accumulations associated with them have been discovered, new tools such as the gamma ray-neutron log and substantially more well control could enable more detailed mapping than ever before. A new innovation, which has possible potential as an exploration technique is ERTS-1 (LANDSAT) Imagery. By use of very high quality imagery, fracture trends (lineaments) can now be examined (Prouty, 1976). These and other techniques such as seismic velocity discrimination between dolomite and limestone can delineate the more subtle traps, thus reinstating the Traverse Group as a potential source for hydrocarbons. Production from fault zones not accompanied by anticlinal folds (Albion-Scipio Trend) is well recognized in Michigan. Thus techniques, as above, have considerable potential.

SUMMARY

It would appear that structural and isopach studies support the orientation of the known, major structural trends of the Michigan Basin. The various folds, the shape of the depocenter and structural center, doubly plunging anticlines and the Howell structure all coincide with the known structural trends of the Basin. Thinning over some of the anticlines suggest that some movement had taken place in the Basin as early as Traverse time; however, other major structures suggest post-Traverse structures was much stronger than the slight pulses taking place during Traverse time, whether the latter was caused by extrabasinal or intrabasinal stresses.

Sharp asymmetrical bending of isopach suggest lateral faulting in the southern, southwestern and southeastern parts of Michigan. These faults cross major structures where hydrocarbon production is well developed, such as the Albion-Scipio trend, suggesting a cross-structure relationship to these fields. A more pronounced dolomite development is believed to occur along areas where fractures meet, suggesting that hydrocarbon exploration along such cross-structures be instigated. Many of the present day oil and gas fields fall along the flexures diagnosed by the herein structure and isopach maps. Other possibilities for exploration are suggested along many of the linear isopach thins, but the future of Traverse Group production probably lies in sophisticated exploration techniques combined with detailed mapping on a small areal scale. The Traverse history of the Howell Anticline area is a mystery and will remain so until a further, more detailed, investigation can be instigated, Such a study is, in fact, underway by another graduate student at Michigan State.

The coincidence of regional dolomite and clastic content in eastern Michigan indicates a source to the east. Possible origins of this source could be related to either low peripheral lands or a rising eastern source area as indicated by the later Bedford-Berea sequence. The Findlay Arch appeared to be slightly higher than most structures around the Basin and together with a low-lying Algonquin Arch probably contributed some sediment to the Basin. A high clastic and dolomite content to the southwest indicates some shallowing of the seas in the vicinity of the Kankakee Arch. The high clastic build up there is probably related to the proximity to the Arch while the high limestone content suggests deeper water. On the west side of the state a low clastic but high dolomite development suggests the presence of a restricted area separated from the deeper sea to the east by an hypothesized west Michigan barrier, or shallowing produced by a slightly high, broad Wisconsin Arch. A linear north to south trending evaporite belt appears to be largely restricted to the west of this western Michigan structural or environmental barrier. Evaporation would be expected to be more effective in evaporite precipitation in this shallow environment.

An area of slight restriction, near the Findlay Arch, is evidenced by a high evaporite content there. Perhaps the environment there was conducive to abundant organic life which fostered a high chert content in this general area.

RECOMMENDATIONS FOR FUTURE STUDY

1) A more detailed examination of the abnormal thick and thin interval located over the present day Howell Anticline area would help to unravel this areas history as well as aid in the prediction of future Traverse petroleum here.

2) Detailed studies of existing Traverse fields would help discover the relationship of cross-structures to major structural trends aiding in future gas and oil exploration and add information on Basin fault patterns.

3) A closer look at the dolomite found in existing fields is warranted to ascertain its association to structure and its possibile origin.

Some interesting parallels can be drawn between Newhart's (1976) study of the carbonate facies of the Middle Ordovician and the Traverse Group. Both stratigraphic sections have the highest regional dolomite trend in a north to south direction, along western Michigan, indicating a close relationship to the Wisconsin Arch during the Ordovician and possibly the Devonian. Hydrocarbon production in both stratigraphic sections is primarily located in the south and southwest areas of Michigan. Newhart and earlier workers have postulated, for Ordovician fields, that magnesium rich waters ascended fracture systems and were dammed by an impervious seal above, the Utica Shale in this case.

The source of those dolomitizations fluids is believed to be artesion in nature from outcrops along the major positive elements flanking the Michigan Basin with high magnesium concentrations in the groundwater generated by its movement through older regional dolomite. This action probably took place after Devonian time as most of the structures are related to movement after this time. The writer speculates this same origin for Traverse structural dolomite, taking place probably at the same time with the shale-rich Traverse Formation and/or Antrim Shale providing the seal.

4) A closer examination of Traverse outcrops in eastern Wisconsin and well samples in western Michigan is needed to ascertain the origin of the regional dolomite found there. Is there a cause and effect relationship between this dolomite and the Wisconsin Arch or is it the result of a lagoonal environment?

5) One of the most perplexing problems associated with the Traverse Group is the widespread and common occurrence of chert, especially in the southern area of Michigan. The significance of this needs to be evaluated by more detailed study.

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APPENDICES

APPENDIX A

APPENDIX A

Location	Well Name	Elevation	Traverse Group Top	Dundee Top	Thickness
ALCONA					
22-26N-9E	Atchinson #1	721	858	1595	737
27-27N-6E	Quant #1	870.5	1283	2017	734
20-27N-8E	St. Haves #1	900	1037	1780	743
23-27N-9E	York #1	760	630	1358	728
30-28N-5E	Cranberry Ranch #1	922	1220	1990	770
10-26N-7E	Kohlman #1	829	1252	1952	700
ALLEGAN					
17-3N-11W	H. Edwards #2	800.5	1687	1985	298
21-3N-11W	Glusic Edwards #1	722.4	1731	2048	317
9-3N-15W	H. Veldhof #1	712.9	1413	1628	215
28-3N-15W	K. Bushee #1	709.5	1377	1595	218
5-4N 11W	H. Culp #1	814.6	1798	2082	284
15-2N-13W	J. & M. Rozeboom #1	745.9	1397	1694	297
3-4N-13W	Loew G-14	722	1580	1903	323
28-2N-13W	Perrigo M.F.G. Co. #1	618	1209	1496	287
ALPENA					
9-29N-5E	Turtle Lake Club #1	822	685	1425	740
ANTRIM					
19-32N-8W	Wolgamott #1	868	467	1182	715
27-29N-6W	Elkins #1-27	1308	1687	2476	789
35-31N-6W	Artie Morris Unit #1-35	1027	962	1747	785
31-31N-5W	L. H. White #1	892	858	1639	781
ARENAC					
11-18N-4E	Grashaw #1-A	625	1857	2689	832
5-19N-3E	St. Adams #1-A	767.5	2138	2958	820
7-19N-4E	Harry B. Weber #1	783.0	2025	2853	828
1-19N-6E	Chartier #1	589.0	2105	2908	803
22-19N-4E	Wood et al #2	723	1950	2786	836
BARRY					
23-1N-7W	E. Farley #1	848	1656	1971	315
30-1N-7W	Herrington #1	897	1690	2010	320
17-1N-8W	M. Puttman #1	978.8	1788	2094	306

Location	Well Name	Elevation	Traverse Group Top	Dundee Top	Thickness
BARRY					
22-3N-7W	Carl Bahs #1	896	1985	2336	351
20-4N-7W	Schiably #1	868.6	2094	2443	349
3-4N-8W	G. McClellon #1	868.8	2075	2437	362
20-4N-8W	J. M. Allerding #1	850.2	1983	2335	352
34-4N-10W	J. Janose #1	781	1788	2122	334
34-2N-9W	Hibbard #1	968	1765	2075	310
8-3N-9W	Kidder #1	796	1774	2097	323
BAY					
1-14N-4E	Schweitzer #5	589	2009	2706	697
2-16N-3E	Pomaville #1-2	644	2368	3135	767
29-18N-3E	A. B. McTincha #1	738	2227	3028	801
10-15N-3E	Edgar D. Solmtt #1	628	2344	3069	725
BERRIEN					
1-6S-19W	Schlutt #1-1	645.5	578	672	94
10-6S-17W	Thalmann #1	793	747	848	101
34-3S-17W	Warnan #1	663	850	474	124
8-8S-20W	Warren #1	645	357	467	110
BENZIE					
27-26N-13W	State-Inland #1-27	874	1302	2094	792
29-25N-15W	Mead #1-29	707	822	1580	758
12-25N-14W	Hazel Von Aken #1	858	1298	2086	788
BRANCH					
36-6S-5W	Paul Swain Unit #1	1050	1142	1337	195
29-6S-8W	Juday #1	862	932	1150	218
4-5S-6W	Pileri #1	969	1260	1493	233
CALHOUN					
12-1S-5W	Lena Lake Comm. #1	971.3	1836	2123	287
27-1S-5W	Cashman #1	951	1710	2003	293
7-2S-4W	Cruse #1	918	1617	1894	277
12-2S-5W	H. Fountain #1	912	1596	1880	284
14-3S-4W	Radee #1	1014	1535	1781	246
26-3S-7W	R. Case #1	933	1358	1618	260

Location	Well Name	Elevation	Traverse Group Top	Dundee Top	Thickness
CALHOUN					
1-4S-4W	Rosenaw #1-A	1021	1500	1730	230
26-2S-7W	J. Beeson #1	892	1435	1712	277
29-1S-7W	Wm. S. Fruin #1	843	1520	1810	290
CASS					
31-5S-13W	McKenzie #1	913.7	1032	1192	160
14-6S-14W	F. Kimmick #1	911.8	988	1146	158
26-7S-15W	Kaminski #1	835	650	798	148
15-8S-15W	Good #1	791	600	700	100
5-8S-16W	N. Beebe #1	746	550	585	35
CHARLEVOIX					
7-32N-4W	Romaniak #1	833.2	262	1003	741
15032N-6W	A. J. Valler #1	837	363	1146	783
7-32N-4W	T. Romaniak #1	833	260	1010	750
CLARE					
6-17N-4W	McKay #1	956	3195	3888	693
21-20N-4W	Yake #1	1211	3280	4033	753
8-20N-5W	Amstutz #1	1099	3027	3775	748
21-19N-6W	St. Redding #1	1047	3175	3860	685
1-18N-5W	Kirkpatrick #1	1275	3508	4195	687
20-18N-5W	D. W. Frackelton #A-1	1138	3340	4003	663
CLINTON					
13-7N-2W	Henning #1	754	2370	2796	426
26-8N-2W	N. R. Irrer #1	716	2373	2820	447
35-8N-4W	F. Watts #1	738.5	2510	2928	418
14-5N-3W	Errin & Arlin Zischke #1	825	2388	2771	383
11-7N-2W	W. L. Skutt #1	765	2400	2790	390
CRAWFORD					
6-25N-3W	St. Beaver Crk. #1	1262	2414	3203	789
20-26N-2W	McClintic #1	1186	2284	3090	806
8-28N-4W	State Frederic "B" 1-8	1276	1865	2648	783
32-25N-1W	R. E. Sheppards #1	1200	2202	2972	770
28-27N-1W	Martindale #1	1121	2008	2770	762
17-25N-4W	St. Beaver Creek #A-3	1241	2245	2935	690

Location	Well Name	Elevation	Traverse Group Top	Dundee Top	Thickness
EATON					
2-1N-6W	Palmer-Miller Comm. #1	934.7	1850	2170	320
18-2N-5W	Cline & LaMont #1	910	1931	2250	319
24-2N-4W	C. G. Woodworth #1	901	2058	2385	327
5-3N-4W	Woodworth El	862	2128	2503	375
GENESEE					
29-6N-7E	E. A. Everson #1	850	1712	2116	404
12-6N-8E	E. J. Coffee #1	915	1732	2148	416
4-9N-8E	Hutchinson #1	827	1945	2460	515
11-6N-7E	G. Gardam #1	878	1777	2172	395
GLADWIN					
19-17N-2W	St. Beaverton #A-2	748	3116	3846	730
6-18N-1W	Briggs #1	783	2988	3763	775
19-18N-1W	Bonninghausen #1	745	2968	3744	776
36-18N-1W	McMahon #1	728.5	2708	3487	779
4-18N-2W	Mills #1	842	3083	3818	735
10-18N-2W	M. H. Cady #1	888	3108	3829	721
14-18N-2W	Ogg #1	827	3033	3765	732
30-19N-2W	Watson #1	887	3058	3787	729
15-18N-1E	Heil #1	713.7	2750	3543	793
16-20N-1E	St. Clement #A-1	817	2723	3538	815
3-18N-1W	Baum #1 (P.L.)	769	2850	3585	735
15-18N-1W	Johnson et al #1 (P.L.)	749	2810	3575	765
22-18N-1W	State C-3 (P.L.)	737	2755	3521	766
19-17N-2E	State #A-8	724	2688	3445	757
12-19N-1W	State - Gladwin #1	766	2654	3429	775
GRAND TRAVERSE					
9-25N-10W	Mos et al #1-9	1041	1743	2542	799
17-25N-11W	Fos #1-17	1055	1766	2520	754
28-26N-11W	Burroughs et al #1-28	974	1490	2255	765
32-27N-12W	D. & M. Pattinson #1	872	1194	1993	799
22-27N-9W	Anstett et al #1	988	1660	2430	770

Location	Well Name	Elevation	Traverse Group Top	Dundee Top	Thickness
GRATIOT					
36-11N-3W	J. Davidson #2	766	2670	3182	512
23-10N-2W	Awdrey #1	705	2570	3073	503
13-11N-3W	Georig #1	768.7	2685	3258	573
2-11N-1W	N. Wenzel #1	696	2672	3238	566
5-10N-4W	Shuttlewarth #1	796.5	2726	3250	524
HILLSDALE					
3-5S-2W	Campenhaut #1	1077.2	1438	1645	207
19-5S-2W	D. Finegan #1	1118	1382	1594	212
21-8S-1W	Wehrle #1	893	822	972	150
29-7S-3W	Israel Grace #1	1053	1055	1235	180
16-7S-2W	U. & M. Scharp #1	1121	1222	1402	180
HURON					
10-15N-10E	Szidir #1	638.7	2000	2756	756
36-16N-12E	Scott #1	750	1925	2620	695
36-17N-10E	Schulze #1	625.5	2072	2828	756
21-18N-13E	P. & M. Wisiewski	680	1605	2301	696
27-16N-11E	A. Keller #1	656	2050	2806	756
INGHAM					
16-2N-2W	F. W. Harkness #1	902	2114	2427	313
13-1N-2E	Dave Basore #1	963	1425	1717	292
15-2N-1W	Laston #1	924	2175	2493	318
12-2N-E	Scripter #1	918	2178	2482	304
20-1N-2W	Camp Ingham Inc. #1	910	1972	2250	278
13-2N-1E	F. C. Anderson #1	912	2148	2462	314
22-4N-1W	Wm. Kirkpatrick	852	2325	2651	326
IONIA					
4-6N-8W	C. E. Burtle #1	707	2170	2588	418
34-7N-8W	Samuel Len Cate #1	765.1	2200	2622	422
21-7N-5W	Albright #1	763.6	2430	2868	438
15-5N-7W	Weldman #1	857	2184	2565	381
11-6N-6W	C. & C. Smith #1	784	2330	2752	422

Location	Well Name	Elevation	Traverse Group Top	Dundee Top	Thickness
IOSCO					
11-21N-5E	Provoast #1	730.2	2200	3008	808
29-21N-5E	Erickson #1	763	2356	3173	817
20-21N-6E	Nat. Gyp. Co. #1	646.5	2310	3133	823
28-23N-5E	Mott #1	863.5	2355	3140	785
3-22N-5E	Stork #1	818	2315	3084	769
ISABELLA					
17-14N-5W	Couser & Wardrop #1	878	3017	3650	633
1-14N-6W	Cook #A-1	876.5	3000	3631	631
25-14N-6W	Pendell #1	984	3105	3723	618
23-15N-6W	Woodin & Forbes #1	927.5	3070	3706	636
30-15N-6W	Latham #1	1033	3150	3776	626
17-16N-3W	Northwise Unit #2-W	794	2975	3680	705
26-16N-5W	O'Rourke #1	896.5	3230	3900	670
22-13N-4W	Terry Childs et. al. #1-22	798.6	3011	3619	608
18-15N-4W	House #1	875	3182	3797	615
JACKSON					
14-1S-3W	Schultz-Cannel Comm #1	933.7	1820	2078	258
36-1S-3W	Campbell #1	1019.5	1908	2177	269
27-2S-2W	N. H. Bonn #1	927	1716	1972	256
27-2S-3W	MacDonald Lett #1	999	1690	1948	258
32-3S-1W	H. Gumper #1	983.1	1547	1740	193
5-4S-2W	Barnes #1	1116	1517	1737	220
28-4S-3W	Owen #1	1098	1452	1682	230
26-3S-1E	G. Boone #1	955.9	1577	1795	218
18-4S-1W	Ray Ried #1	1040	1483	1685	202
KALAMAZOO					
15-1S-12W	Menasha Wooden Ware #1	780	1345	1597	252
31-3S-10W	R. Hayward #1	868	1160	1408	248
27-2S-9W	J. & L. Smith GG-1	986	1442	1710	268
KALKASKA					
10-25N-8W	St. Springfield #1	1123	2345	3115	770
11-28N-6W	St. Cold Springs #1	1271	1838	2634	796
21-25N-5W	St. Garfield #1-21	1231	2431	3180	749
28-28N-7W	Sherwood #1-28	1007	1535	2328	793
22-27N-6W	State-Excelsion #1-22	1178	1958	2753	795
27-25N-8W	Consumers Power Co. #1	1017	2294	3013	719

Location	Well Name	Elevation	Traverse Group Top	Dundee Top	Thickness
KENT					
3-5N-9W	Alto L. P. G. #3	811	2060	2438	378
12-6N-9W	L. P. G. #4	638.7	1987	2388	401
35-8N-9W	Francisco #1	859.6	2397	2830	433
9-10N-11W	Free #1	907	2440	2900	460
6-8N-9W	J. Len Haven #1	857	2422	2858	436
35-9N-10W	B. E. Goss	936	2488	2917	429
4-8N-9W	F. Donovan #1	877	2460	2897	1583
LAKE					
30-20N-12W	St. Newkirk #1	976	2378	3088	710
17-19N-11W	Ellsworth Twp. #1	1101	2674	3347	673
20-18N-12W	J. Gramalna #1	872	2500	3135	635
LAPEER					
17-6N-12E	J. Braidwood #1	913	1472	1815	343
6-6N-12E	E. Ulatowski #1	842	1468	1868	400
14-7N-11E	Bagley #1	926	1709	2080	371
10-8N-9E	I. Thom #GG-1	790.2	1889	2360	471
6-8N-10E	St. Mayfield #1	838.6	1911	2375	464
1-9N-10E	A. R. Mathews #1	797	1932	2428	496
21-9N-11E	Wilder #1	824.4	1847	2320	473
17-10N-10E	Lyon #1	827.5	1943	2458	515
28-10N-10E	H. Nowlin #1	780	1887	2388	501
22-9N-10E	Louis Bodwin #1	837	1905	2370	465
LENAWEE					
14-5S-4E	Allen #1	859	760	975	215
25-6S-2E	Drewyer #1	860	832	1040	208
4-8S-1E	Charles Beal #3	858	766	910	144
24-6S-3E	L. Oenius #1	800	780	980	200
LIVINGSTON					
35-3N-4E	McPherson #1	941.5	492	842	350
27-4N-3E	M. & D. Hendryx #1	921	1013	1296	283
14-1N-6E	Manuel Lopez #1	915	488	782	294
13-3N-5E	C. P. Cornell #1-13	943	852	1213	361
25-3N-5E	E. John Hills #1	993	953	1325	372
25-2N-5E	Bauer #1	964	550	945	395

Location	Well Name	Elevation	Traverse Group Top	Dundee Top	Thickness
MACOMB					
15-3N-14E	Wayne Moore #1	591	555	786	231
10-3N-14E	Henning St. #1	598	557	802	245
29-4N-13E	Payne & Gray #1	657	908	1162	254
36-4N-14E	Seifert #1	619	658	889	231
36-5N-12E	Lamphar #1	757	1050	1338	288
8-5N-13E	Ward #1	777	1135	1437	302
MANISTEE					
13-21N-17W	Gambs #1	606	918	1600	682
8-24N-13W	Northrup #1	896	1472	2240	768
10-24N-14W	Con. Paw. Co. #1	758	1130	1891	761
8-22N-15W	McCarthy #1-8	765	1185	1930	745
5-22N-13W	State-Dickson #1-5	1080	1923	2627	704
23-23N-14W	Nuikklala	765	1420	2125	705
MASON					
9-17N-15W	Healey #1	706	1832	2478	646
7-18N-17W	Disposal Well #40	649	1426	2052	626
14-18N-17W	Jacobson #3	694	1588	2218	630
23-20N-15W	State-Cartier #1-23	719	1791	2494	703
19-19N-17W	Peterson #3-19	661	1384	2042	658
17-18N-16W	Woodward #1	652	1644	2270	626
MECOSTA					
2-13N-10W	Whipple #1	968	2794	3353	559
8-13N-10W	Finch #1	929	2705	3245	540
36-14N-8W	Delong #1	1025	3068	3658	590
3-15N-7W	Phillips #1	1015.2	3162	3827	665
23-15N-8W	Darling #1	1056.3	3115	3750	635
5-15N-9W	Flanders & Wilkins #1	958	2831	3435	604
17-15N-8W	F. D. Helmer #1	1046	3164	3774	610
MIDLAND					
6-15N-1W	D. Segerlund #1	656	2950	3667	717
15-15N-2W	Middleton et. al. #1	678.5	3023	3718	695
21-13N-1W	Emery #1	683.7	2745	3363	618
13-15N-1W	C. & O. #2	645	2958	3683	725
10-16N-1E	Rider #1	692	2990	3769	779
1-16N-2E	Askevich #1	669	2580	3395	815
12-15N-2E	Draves et. al. #1-12	666	2898	3648	750

Location	Well Name	Elevation	Traverse Group Top	Dundee Top	Thickness
MISSAUKEE					
31-21N-6W	Mulder #1	1190	3168	3907	739
32-22N-7W	Stroh & McBain #2	1194	3213	3952	739
10-23N-6W	State-West Branch #1	1195	2678	3452	774
25-22N-7W	Jager #1-25	1184	3125	3867	742
35-22N-6W	Alderman & McCoy #2	1159	3080	3830	750
35-22N-6W	Buning #1	1170	3120	3830	710
MONTCALM					
9-10N-7W	Neilson #1	890.5	2767	3266	499
26-10N-7W	Goodnaugh #1	843	2678	3170	492
30-11N-8W	Christensen #1	928	2753	3258	505
5-11N-9W	Race #1	908.5	2741	3245	504
27-12N-6W	H. Graham #1	943	2920	3452	532
28-9N-6W	Foncett #1-28	823	2630	3107	477
14-11N-9W	Wm. R. Spence #1	932	2781	3260	479
MONTMORENCY					
5-30N-2E	L. Rosen et. al. State Briley #1-5	1216	1124	1866	742
21-31N-4E	C. A. Gain #1-21	784	492	1230	738
10-30N-3E	W. & I. Miller #1	928	870	1580	710
MUSKEGON					
21-9W-14W	Wunsch #1	673	1845	2248	403
15-10N-17W	McMahn #1	620.5	1625	2074	449
8-12N-16W	Wm. Eilers #1	660	1761	2257	496
14-11N-17W	A. Wickstrom #1	630	1705	2182	477
15-11N-15W	W. J. Smith & C. Hammil #1	686	1887	2322	435
NEWAYGO					
18-11N-12W	Nyhof & Dobbin #1	810.4	2343	2805	462
15-11N-13W	Seaman #1	803	2256	2745	489
26-12N-14W	Sheridan Twp. #1	738	2123	2612	489
26-13N-14W	Siersema #1	890.3	2283	2824	541
30-16N-11W	R. Camfield #1	1087	2858	3467	609
20-15N-14W	Walter-Rosilea Thompson #1	821	2083	2648	565
5-12N-12W	Sawyer #1	806	2350	2863	513

Location	Well Name	Elevation	Traverse Group Top	Dundee Top	Thickness
OAKLAND					
30-2N-8E	Beauthien #1	963	798	1105	307
35-4N-8E	Huntoon #1	1033	1323	1648	325
11-4N-11E	Eldridge #1	972.8	1276	1574	298
18-5N-10E	E. Lorence #1	1063	1630	1990	360
21-1N-7E	W. Smith #1	936	445	735	290
OCEANA					
7-13N-16W	R. & L. Mund #1	780	1929	2434	505
29-15N-17W	Gray #1	903	1930	2495	565
11-16N-16W	Skidmore #1	976	1933	2515	582
15-16N-16W	Hill #1	885	1841	2455	614
15-16N-17W	J. N. Griener #1	650.5	1572	2130	558
12-13N-17W	Huls #1	706	1830	2324	494
27-14N-17W	Spooner #1	943	2038	2541	503
OGEMAW					
4-24N-3E	St. Rose #1	1232.3	2212	2998	786
35-22N-3E	F. Buckingham #4	861	1667	2487	820
28-24N-2E	State Foster #1	1457	2155	2952	797
10-21N-1E	E. A. Lehman #1	936	2472	3313	841
29-23N-3E	Morrison #1	934	1880	2669	789
OSCEOLA					
29-17N-7W	Rountree #1	1115.5	3236	3924	688
5-17N-10W	LR-82-3	1087	2830	3456	626
32-18N-7W	Wimmer #1	1056.5	3218	3897	679
35-19N-8W	Yarhouse #1	1213.6	3350	4046	696
26-19N-10W	Lindell #1	1197	3005	3690	685
5-20N-7W	Matt Found. #1	1213	3243	3988	745
17-20N-8W	Kleinhesselink #1	1304.5	3343	4068	725
14-20N-9W	Johnson-Thomas #1	1586.1	3578	4303	725
19-20N-10W	Lindberg #1	1168.5	2942	3657	715
31-17N-9W	Con. Paw. Co. #1	1117	3024	3648	624
10-18N-9W	State-Cedar #B-1	1332	3276	3944	668
OSCODA					
12-25N-2E	U.S.A. #1-12	1133	2382	3180	798
16-28N-1E	Garland #1	1230	1991	2793	802
19-25N-3E	U.S.A. #1	1241	2220	3000	780

Location	Well Name	Elevation	Traverse Group Top	Dundee Top	Thickness
OTSEGO					
22-30N-2W	Kenney #1-22	1308	1611	2363	752
27-31N-1W	Marstrand #1-27	1027	934	1678	744
2-29N-4W	L. J. Savage et. al. #2-2	1309	1530	2311	781
34-30N-3W	AuSable #1	1285	1575	2333	758
OTTAWA					
32-6N-14W	Wyngarden #1	668	1578	1955	377
34-7N-13W	Fenske #4-A	645	1748	2134	386
21-8N-14W	Heckel St. #1	651.4	1790	2194	404
19-7N-15W	Wm. A. Berg #1	639	1534	1947	413
21-6N-14W	Ponstantine #1	652	1590	1954	364
ROSCOMMON					
8-22N-4W	Hogan #6	1137	2884	3685	801
17-22N-4W	Hogan #5	1142.4	2880	3653	773
23-24N-1W	U.S.A. #B-1	1168	2000	2797	797
28-22N-2W	Trustees of Estate of L. Meldrum, deceased	1180	2928	3722	794
19-21N-3W	State-Roscommon FG-4	1128	3137	3908	771
2-23N-2W	Salling Hansen Co. Tr. #1	1166	2578	3345	767
SAGINAW					
5-12N-6E	L. Elbers #1	595.5	2478	3113	635
33-11N-3E	R. Gage Coal Co. #1	587	2382	2912	530
5-11N-3E	Rockwell #1	603	2515	3058	543
ST. CLAIR					
11-3N-16E	Sharrow #B1-1	590	438	662	224
2-4N-15E	Lopapkicwicz #1	646.7	687	953	266
4-5N-15E	Stern #1	704.3	835	1130	295
7-6N-14E	Schmidt #1	792	1160	1483	323
5-7N-13E	Hull #1	789.5	1442	1822	380
11-7N-14E	Gleason #1	783.5	1220	1577	357
4-8N-16E	O'Conner #1	720.6	546	948	402
18-7N-16E	Collins #1-18	698	505	860	355

Location	Well Name	Elevation	Traverse Group Top	Dundee Top	Thickness
ST. JOSEPH					
15-7S-9W	R. Reed #1	864	866	1077	211
17-5S-9W	Krupp #1	873	1067	1313	246
27-6S-11W	Thunder #1	817	820	1015	195
13-6S-11W	Dunworth #1	865	942	1163	221
SANILAC					
31-9N-15E	Kappler #1	767.6	1295	1688	393
2-10N-15W	Trowhill #1	761.3	990	1470	480
9-10N-16E	Keglovitz #1	771.6	927	1378	451
25-11N-12E	Ode #1	771	1940	2453	513
7-11N-14E	Mica #1	785.7	1628	2187	559
7-11N-16E	Essenmacher #1	805.5	1106	1611	505
9-12N-13E	Uiswell #1	783.6	1576	2168	592
12-12N-14E	Detary #1	762	1363	1933	570
28-14N-12E	Linderman #1	786	1950	2634	684
34-13N-15E	E. Mosure #1	778.6	1094	1648	554
26-9N-15E	Marshall #1	748	660	1073	413
SHIAWASSEE					
22-5N-2E	Dysinger #1	894.7	1978	2378	400
15-5N-3E	Schribner #1	870.7	1458	1857	399
12-8N-4E	Birchmeier #1	700	2110	2588	478
33-7N-3E	Brooks #1	809	1995	2410	415
TUSCOLA					
31-10N-8E	McCormick #1	770.5	1877	2385	508
8-13N-9E	Sattleberg #1	667.8	2112	2760	648
16-13N-11E	Novesta Twp. #1	727	1973	2595	622
12-14N-9E	Dancey #1	653.8	2009	2718	709
32-14N-8E	Downing #1	607	1998	2672	674
4-13N-9E	J. Timko #1	662	2109	2756	647
VAN BUREN					
34-4S-14W	Kern #1	911	1065	1245	180
24-2S-15W	T. A. Curtis #1	708	1028	1220	192
8-1S-14W	Pease #1	734	1178	1412	234
35-2S-16W	Ament & Webster #1	768	1033	1195	162

Location	Well Name	Elevation	Traverse Group Top	Dundee Top	Thickness
WASHTENAW					
16-4S-5E	Schowacko #GG-1	862.5	409	597	188
24-3S-7E	Wabash R.R.G. #1	691.6	130	357	227
25-2S-3E	Goers #1	937	1028	1274	246
26-2S-7E	Jorgensen #1	768	424	642	218
22-1S-3E	Warner & Slocum #1	954.5	1280	1540	260
12-1S-7E	Butler-Ansel-Strok #2	936	397	652	255
28-1S-5E	Brassow #1	946	1222	1471	249
22-2S-3E	J. Merkel #1	998	1185	1465	280
WESFORD					
28-21N-9W	Davidson #1	1323	3182	3900	718
23-21N-11W	St. Henderson #1-23	1336	3048	3702	654
32-22N-9W	Lesson & Sours #1	1303	3066	3791	725
9-22N-10W	Commers Sons Cypress Co. #1	1411	2910	3621	711
20-24N-9W	St. Liberty #A-1	1014	2377	3142	765
2-24N-12W	Kellogg #1-2	1089	1890	2631	741
1-22N-9W	Andrews #1	1310	3030	3746	716

APPENDIX B

APPENDIX B

County	Location	Name of Well	LS/Dol	Clastic Ratio	Evaporite %	Quartz %	Ryrite %	Chert %
Alcona	10-26N-7E	Kohlman #1	31.06	2.9	0	0	0	0
Allegan	28-2N-13W	Perrigo M.F.G., Co. #1	5.19	10.4	.68	0	.13	3.06
Alpena	9-29N-5E	Turtle Lake Club #1	890.6	2.06	0	.0018	0	0
Antrim	31-31N-5W	L. H. White #1	0	2.78	.84	3.36	0	.56
Arenac	22-19N-4E	Wood et. al. #2	46.05	1.25	0	0	0	.22
Barry	8-3N-9W	Kidder #1	111.29	4.86	0	0	0	6.34
Bay	10-15N-3E	Edgar D. Solmtt #1	46.05	1.25	0	0	0	.22
Berien	8-8S-20W	Warren #1	3.12	18.39	.5	1.16	.3	0
Calhoun	29-1S-7W	Wm. S. Fruin #1	0	5.88	0	0	0	3.41
Cass	15-8S-15W	Good #1	8.82	4.1	0	0	.65	.13
Cass	5-8S-16W	N. Beebe #1	29.75	1.36	0	0	2.89	0
Charlevoix	7-32N-4W	T. Romaniak #1	12.4	2.55	.0112	.00017	.0027	0
Clare	20-18N-5W	D. W. Frackelton #A-1	410.7	6.73	0	0	.0008	1.3
Clinton	11-7N-2W	W. L. Skutt #1	21.7	3.07	0	.0007	0	7.67
Crawford	17-25N-4W	St. Beaver Creek #A-3	84.86	1.96	0	0	0	0
Eaton	5-3N-4W	Woodworth #1	16.52	5.14	0	0	.05	3.04
Genesee	11-6N-7E	G. Gardann #1	15.43	1.7	0	0	0	1.62
Gladwin	12-19N-1W	State-Gladwin #1	38.9	1.9	0	0	0	0
Gratiot	36-11N-3W	J. Davidson #2	31.85	5.62	.0005	0	.0011	2.43
Hillsdale	16-7S-2W	V. & M. Scharp #1	3.56	2.13	0	0	0	7.72
Huron	27-16N-11E	A. Keller #1	21.18	.88	0	0	.03	.08
Ingham	22-4N-1W	Wm. Kirkpatrick	153.95	3.26	.38	0	0	2.32
Ionia	11-6N-6W	C. & C. Smith #1	16.1	23.13	0	0	0	1.83
Iosco	3-22N-5E	Stork #1	20	1.22	0	0	0	.7
Isabella	18-15N-4W	House #1	0	1.72	0	0	0	4.0
Jackson	18-4S-1W	Ray Ried #1	4.98	2.56	1.69	0	0	8.34
Kalamazoo	27-2S-9W	J. & L. Smith GG-1	22.3	6.77	.18	0	0	3.35
Kalkaska	27-25N-8W	Consumers Power Co. #1	535.05	11.39	0	0	.0007	1.8
Kent	4-8N-9W	F. Donovan #1	0	20.1	.11	1.56	0	2.47
Lake	20-18N-12W	J. Gramalva #1	6.66	4.42	.0058	.041	.002	0
Lapeer	22-9N-10E	L. Bodiven #1	26.6	.78	0	0	0	1.9

County	Location	Name of Well	LS/Dol	Clastic Ratio	Evaporite %	Quartz %	Ryrite %	Chert %
Lenawee	24-6S-3E	L. Denius #1	1.75	1.68	0	0	.06	5.3
Livingston	25-2N-5E	Baver #1	2.11	1.2	0	0	.09	4.21
Macomb	15-3N-14E	W. Moore #1	0	1.19	0	0	.36	1.67
Manistee	23-23N-14W	Nuikklala #1	16.75	30.6	1.18	0	0	0
Mason	17-18N-16W	Woodward #1	2.19	4.88	.009	0	.00004	2.3
Mecosta	17-15N-8W	F. D. Helmer #1	0	6.76	1.43	0	0	0
Midland	6-15N-1W	D. Segerlund #1	21.38	2.78	0	0	0	1.56
Missaukee	35-22N-6W	Buning #1	4.049	4.4	1.55	.04	0	.33
Montcalm	14-11N-9W	Wm. R. Spence #1	0	54.6	0	0	0	1.59
Montmorency	10-30N-3W	W. & I. Miller #1	45.9	9.85	.0018	0	0	0
Muskegon	15-11N-15W	W. J. Smith & C. Hamill #1	3.54	16.078	0	0	0	0
Newaygo	5-12N-12W	Sawyer #1	13.26	65.78	0	.13	0	0
Oakland	21-1N-7E	W. Smith #1	4.9	1.45	0	1.02	.79	3.11
Oceana	27-14N-17W	Spooner #1	1.18	13.83	.0732	0	.0011	.09
Ogemaw	29-23N-3E	Morrison #1	13.04	1.8	0	.15	0	.85
Osceola	10-18N-9W	State-Cedar #B-1	40.9	3.12	1.72	0	0	1.8
Oscoda	19-25N-3E	U.S.A. #1	0	2.44	0	0	0	.17
Otsego	34-30N-3W	AuSable #1	108.15	2.23	.0022	.0022	.0009	0
Ottawa	21-6N-14W	Ponstontine #1	271.5	11.9	0	1.19	14.68	.93
Roscommon	2-23N-2W	Salling Hansing Co. TN. H 1	3.29	1.92	0	0	0	0
Saginaw	5-11N-3E	Rockwell #1	12.40	1.715	0	0	0	4.4
St. Clair	18-7N-16E	Collins #1-18	0	.66	0	0	0	.44
St. Joseph	13-6S-11W	Dunworth #1	47	6.35	0	0	.02	3.7
Sanilac	26-9N-15E	Marshall #1	37.4	.614	0	0	.005	1.83
Shiawassee	33-7N-3E	Brooks #1	42	3.48	.006	0	0	2.98
Tuscola	4-13N-9E	J. Timko #1	41.52	.7856	0	0	.001	.55
Van Buren	35-2S-16W	Ament & Webster	6.79	11	0	0	0	2.34
Washtenaw	22-2S-3E	J. Merkel #1	5.32	2.55	0	0	0	3.98
Wexford	1-22N-9W	Andrews #1	3.8	3.78	0	0	0	1.6

APPENDIX C

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Location	Well Name	Elevation	Traverse Group Top	Dundee Top	Thickness
LIVINGSTON					
18-2N-5E	Lounsberry #1-18	923.6	637	1288	651
8-2N-5E	White #1-8	960	678	1108	430
17-2N-5E	Lounsberry #1-17	926	620	1185	565
13-3N-5E	Chanay P. Cornell #1-13	943	852	1212	360
7-2N-5E	Kuhns #6-7	913	640	1178	538
8-2N-5E	White #2-8	941	634	1151	517
12-2N-4E	Gates #1-12	916	620	1038	418