A MECHANICAL AND CHEMICAL ANALYSIS OF THE MIDDLE DEVONIAN DETROIT RIVER GROUP ABOVE THE SYLVANIA IN THE MICHIGAN BASIN

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ABSTRACT

This sedimentary lithofacies study was undertaken to show the environmental, depositional, and tectonic conditions existing during the deposition of the "Upper Detroit River" sediments. Composite samples representing the complete "Upper Detroit River" section were obtained from twenty-six wells located in the Lower Peninsula of Michigan. These samples were acidized, disaggregated, and sieved to determine their lithologic character.

Facies maps were then constructed from the numerical data obtained from the mechanical and chemical analysis. The clastic ratio map indicates the variations between the clastic and nonclastic material; the sand-shale ratio map shows the variations in the clastic material, the evaporite ratio map depicts the relation between the evaporites and carbonates, the Mg/Ca ratio map indicates

the variations in the carbonates, and the anhydrite percentage map locates the depositional areas of anhydrite.

The lithofacies maps were interpreted by studying the patterns formed when an isopach map is superimposed on the various ratio maps. The information acquired from this investigation aided in reconstructing the geologic history of "Upper Detroit River" time.

This sedimentary facies analysis indicates that during "Upper Detroit River" time, the basin received clastic sediments from four source areas, the north, west, southwest, and southeast. Deposition began and ended quietly and there were no major crustal disturbances in or around the basin. It was shown that although the structural features surrounding the basin were stable and lowlying, they were emergent for periods of time due to subsidence within the basin.

CONTENTS

ILLUSTRATIONS

A MECHANICAL AND CHEMICAL ANALYSIS OF THE MIDDLE DEVONIAN DETROIT RIVER GROUP ABOVE THE SYLVANIA IN THE MICHIGAN BASIN

INTRODUCTION

Description of the Michigan Basin

Due to the extensive cover of Pleistocene glacial deposits, little subsurface information concerning the Michigan basin was available until extensive oil and gas exploration was undertaken some thirty-five years ago. This subsurface information along with outcrop studies have added greatly to our present knowledge of the basin.

The Paleozoic strata form an elliptical pattern in the basin with the major axis trending northeast-southwest. Sediments were deposited in the shallow marine seas occupying the Michigan basin during Paleozoic time. These range in age from the younger Pennsylvanian, deposited in the center, to the older Ordovician and Cambrian sediments found at the periphery of the basin.

Newcombe (1933) described the areal extent of the Michigan basin in this manner:

The area comprising the Michigan basin includes about 106,700 square miles and stretches from Fort Wayne, Indiana, on the south, to Whitefish point, near Sault Ste. Marie, Michigan, on the north and from west to east about 370 miles.

In the center of the basin, which coincides with the geographic center of the Lower Peninsula of Michigan, the Paleozoic sediments attain a thickness of approximately 15,000 feet.

Pirtle (1932) described the structures bounding the Michigan basin as follows: The Wisconsin arch to the west, the two limbs of the Cincinnati arch in the south, the Kankakee arch in the southeast, the Canadian Shield to the north, and the Algonquin arch, an extension of the Findlay arch, to the east. Pirtle further states that the development of the Michigan basin is due to uplift around the rim and that the northwest-trending folds in the east-central portion of the basin are related to the pre-existing Precambrian zones of weakness. Folds within the Paleozoic sediments of southwest Michigan trend northeast and are related to the Kankakee arch.

Green (1957), in discussing the structure and geologic history of the basin, made the following statements which are not in accord with those presented by Pirtle (1932): "The structural development of the Michigan Basin has resulted from the subsidence of the basin during post-Niagaran Silurian time rather than uplift around the rim. . . . the term 'Kankakee arch' found in earlier literature should be dropped, as no structural connection between the Wisconsin and the Cincinnati arches is indicated. In place of the Kankakee arch, Green (1957) suggested that the southwest boundary of the Michigan basin be the Francesville arch, which lies between the Wisconsin and Cincinnati arches, and is not structurally related to either.

It is left to the reader to choose between the ideas of Green and those of Pirtle, but in either event both authors presented the same general picture of the Michigan basin. A negative area rimmed by positive features, receiving sediments throughout the Paleozoic era.

Facies Analysis

Moore (1949) defines sedimentary facies as "any areally restricted part of a designated stratigraphic unit which exhibits characteristics significantly different from those of other parts of the unit involved."

Three types of facies, namely lithofacies, biofacies, and tectofacies have been defined. Moore (1949) defines lithofacies as "groups of strata demonstrably different in lithologic aspect from laterally equivalent rocks." Krumbein and Sloss (1951) describes biofacies as "lateral variations in the biologic aspect of a

stratigraphic unit" and tectofacies as "laterally varying tectonic aspects of a stratigraphic unit."

The results of various facies analyses may be expressed as contours on maps. Lithofacies and biofacies maps express variations in the sedimentary environment, and tectofacies maps show tectonic variations in the stratigraphic unit.

Purpose of Study

The purpose of this study is to determine the depositional and environmental conditions which prevailed in the Michigan basin during "Upper Detroit River" time. This information will be gained by mechanical and chemical analysis of samples taken from twenty-six selected wells. The data obtained will form the basis for the construction and interpretation of lithofacies maps.

Similar investigations have been carried out on other Devonian formations from the Michigan basin. It is the desire of the author that the information gained from this report will shed additional light on the picture of the Devonian sedimentation in the Michigan basin.

WELL SELECTION AND DISTRIBUTION

Stratigraphy of the Analyzed Section

The section analyzed includes the Lucas and Amherstburg formations of the Detroit River Group. Table I shows the generalized Devonian section in the Michigan basin. The lower formation of the Detroit River Group, the Sylvania sandstone, was not included in the analysis because of its entirely different lithologic type. Krumbein (1952) states that when dealing with radically different sections in lithofacies studies it is best to divide the interval into two or more parts for separate analysis. Throughout the remainder of this paper the term "Upper Detroit River" will be used to refer to the section analyzed, the Lucas and Amherstburg formations.

The Detroit River Group, sometimes called the "Middle Monroe," has been tentatively correlated with the Onondaga of New York, the Ulsterian of Ontario, and the Columbus limestone (Ulsterian) of Ohio. These correlations are based on both faunal and lithologic elements.

TABLE I

GENERALIZED DEVONIAN COLUMN OF MICHIGAN

Series	Group	Formation	Name of Unit	Thickness(')	Descriptions	Remarks
MIDDLE			TRAVERSE	100-875	Limestone & shale	Bell shale at base Erosional unconformity
MIDDLE			ROGERS CITY	0-125	Brown limestone	Absent in SW Michigan
MIDDLE			DUNDEE	0-460	Mostly limestone	Absent in SW Michigan Erosional unconformity
MIDDLE	DETROIT RIVER GROUP	LUCAS FM.		68-1124	Dolomite, anhydrite & salt	
MIDDLE	DETROIT RIVER GROUP	LUCAS FM.	Richfield	0-80	Dolomite with sandstone	Subsurface only. Mainly in central & S. Michigan Erosional unconformity
MIDDLE	DETROIT RIVER GROUP	AMHERSTBURG FM.		0-150	Dark limestone & dolomite	
MIDDLE	DETROIT RIVER GROUP	AMHERSTBURG FM.	Filer Lentil	0-100	Sandstone	Erratic distribution; thickest in W. Michigan
MIDDLE	DETROIT RIVER GROUP	AMHERSTBURG FM.		0-200	Dark black limestone or dolomite	
MIDDLE	DETROIT RIVER GROUP	AMHERSTBURG FM.	Sylvania	0-300	Sandstone with dolomite & chert	Only in eastern Michigan Erosional unconformity
LOWER			BOIS BLANC	0-1000	Cherty limestone or dolomite	Absent in SE & SW Michigan Erosional unconformity
LOWER			GARDEN ISLAND	0-30	Dolomite	Patchy distribution

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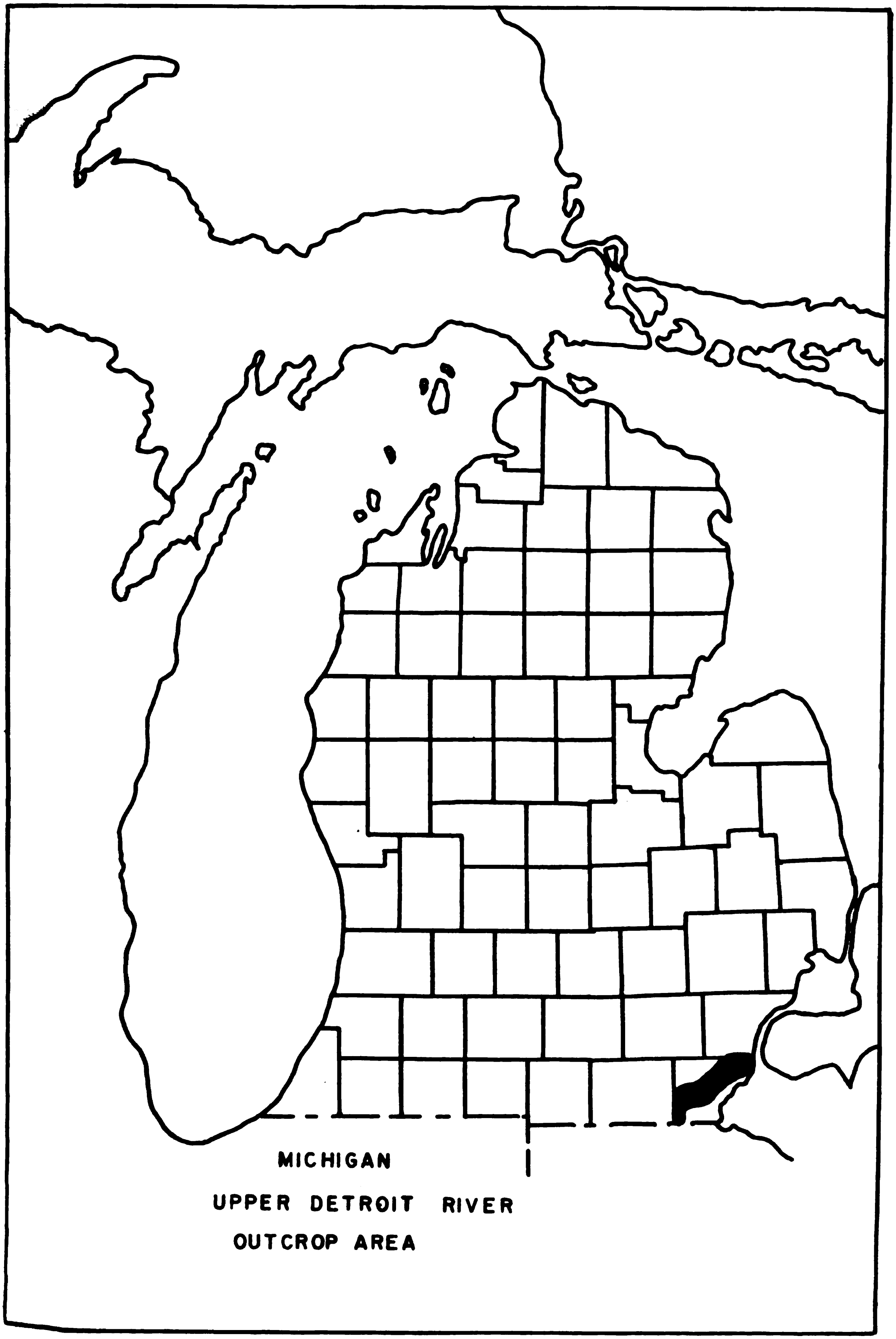
The Upper Detroit River underlies most of the Lower Peninsula of Michigan and crops out (Map I) between Detroit and Monroe (Michigan) and in the vicinity of Sylvania, Ohio. The section varies in thickness from a few hundred feet to 1,300 feet; the thickest section is located in the center of the basin in Clare County.

A committee from the Michigan Geological Society (1948) described the Upper Detroit River as:

> . . . typically fine-grained gray to buff thin-bedded dolomite with abundant carbonaceous partings and with some limestone members mainly in the upper part, anhydrite throughout: an evaporite series of dolomite, anhydrite, and several beds of salt are in the middle part in central Michigan, where the formation is thickest: sandstone sandy dolomite and chert in the lower part, and some black limestone members.

The Lucas formation ranges from 20 to 1,125 feet in thickness. It is a light-colored dolomite which includes a thick evaporite section. Dolomite, anhydrite, salt, limestone, and sandstone, named in order of abundance, make up the formation. The upper member, the Anderdon dolomite, is found above the Lucas in outcrop but cannot be traced in the subsurface section. The Richfield member at the base of the Lucas is a porous dolomite with lenticular sandy phases. These sandstone lenses are sometimes referred to as the "Freer sandstone." The Richfield can be recognized in subsurface only within a 50-mile radius of Roscommon County.

MAP I



The Amherstburg formation found in all parts of the Lower Peninsula except in the southeast and southwest corners ranges in thickness from 0 to 450 feet. In the north and east parts of the Lower Peninsula the Amherstburg, except for local sandstones, is composed of dark brown to black limestones with subordinant amounts of dolomite, but in the south and west portions dolomite predominates. The "Filer" sandstone lentil, which is found in the middle of the formation, ranges in thickness from 0 to 100 feet. It is found in a belt three counties wide extending in an east-west direction from Saginaw Bay to Lake Michigan.

Selection of the Top and Bottom of the Upper Detroit River

The top of the Upper Detroit River underlies the Dundee formation except in southwest Michigan, but where the Dundee is absent the Upper Detroit River is overlain by the Traverse group. The criteria used for picking the contact between the Dundee or Traverse and the top of the Lucas are the following: lack of anhydrite in the Dundee and Traverse; the absence of sand and chert at the top of the Lucas; and in general, the carbonate section at the top of the Lucas is lighter in color than the overlying formations.

The Upper Detroit River overlies three different formations: the Sylvania sandstone, Bois Blanc cherty limestone, and the Silurian Bass Island formation found in the southwest.

The contact between the Amherstburg and the Sylvania sandstone in some places is gradational, but in most cases the contact could be picked easily by the increase of sand in the upper carbonate section of the Sylvania formation. Where the underlying Sylvania is absent the contact between the Amherstburg and the Bois Blanc is gradational. The top of the Bois Blanc and the bottom of the Amherstburg is limestone. The contact between the two formations was established by comparing the dark brown to black carbonates found at the bottom of the Amherstburg to lighter carbonates in the Bois Blanc. The obvious lithologic differences between the Bass Island, when overlain by the Amherstburg, was either yellow, gray, or bluish dolomite or light green shale, as compared to the dark brown to black limestone or dolomite of the Amherstburg formation.

Selection of Wells

The following four criteria were used to pick the wells for this investigation: (1) Every well penetrated the complete Upper Detroit River section. (2) Whenever possible, samples obtained by cable tool methods were used to insure more accuracy and less contamination. (3) To insure a more reliable Mg/Ca ratio, exploratory wells were analyzed in place of field well. Tinkelpaugh (1957) stated that samples taken from field wells producing from porous dolomites give abnormally high Mg/Ca ratios. Of the twenty-six wells studied only three were field wells. (4) The last criterion was to pick wells that were properly spaced to insure adequate control. Well spacing in a regional lithofacies study should be far enough apart to show broad regional trends in lithology. Close well spacing can confuse and disorganize the general regional pattern by overemphasizing local irregularities (Krumbein, 1952).

Table II lists and describes the wells used in this investigation.

Map 2 gives the location of the analyzed wells.

Map 3, a county reference map, is included for the convenience of the reader.

TABLE II

WELL DESCRIPTIONS

Well No.	County and Township	Driller and Farm	Land Description	Thickness of Section (feet)
1	Shiawassee Perry	Panhandle Eastern S. Nemcik #1	23-5N-2E	400
2	Lapeer Attica	Brazos Oil and Gas G. Smith #1	14-7N-11E	505
3	Midland Midland	Dow Chemical Co. Fee #8	21-14N-2E	700
4	Sanilac Lexington	M. Joy and Black John Tomczyk #1	35-10N-16E	361
5	Livingston Genoa	Panhandle Eastern G. Baver #1	25-2N-5E	258
6	Muskegon Montague	Taggart Brothers Gas C. W. Nelson #1	20-12N-17W	320
7	Wayne Plymouth	Basin Oil Co. E. Raetzel #1	22-1S-8E	250
8	Huron Rubicon	Pure Oil Co. J. Stapleton #1	22-17N-15E	486
9	Tuscola Novesta	Shell Oil Co. F. Woiden #1	16-13N-11E	493
10	Van Buren Bangor	Little Four Oil Co. J. Getz #1	23-2S-16W	208
11	Mason Hamlin	Brazos Oil and Gas Genson and Wheaton #1	26-19N-18W	790
12	Antrim Central Lake	Ohio Oil Co. H. Chamberlain #1	14-31N-8W	665
13	Hillsdale Scipio	Clifford A. Perry Fern House Knecht #1	10-5S-R3W	264

TABLE II (Continued)

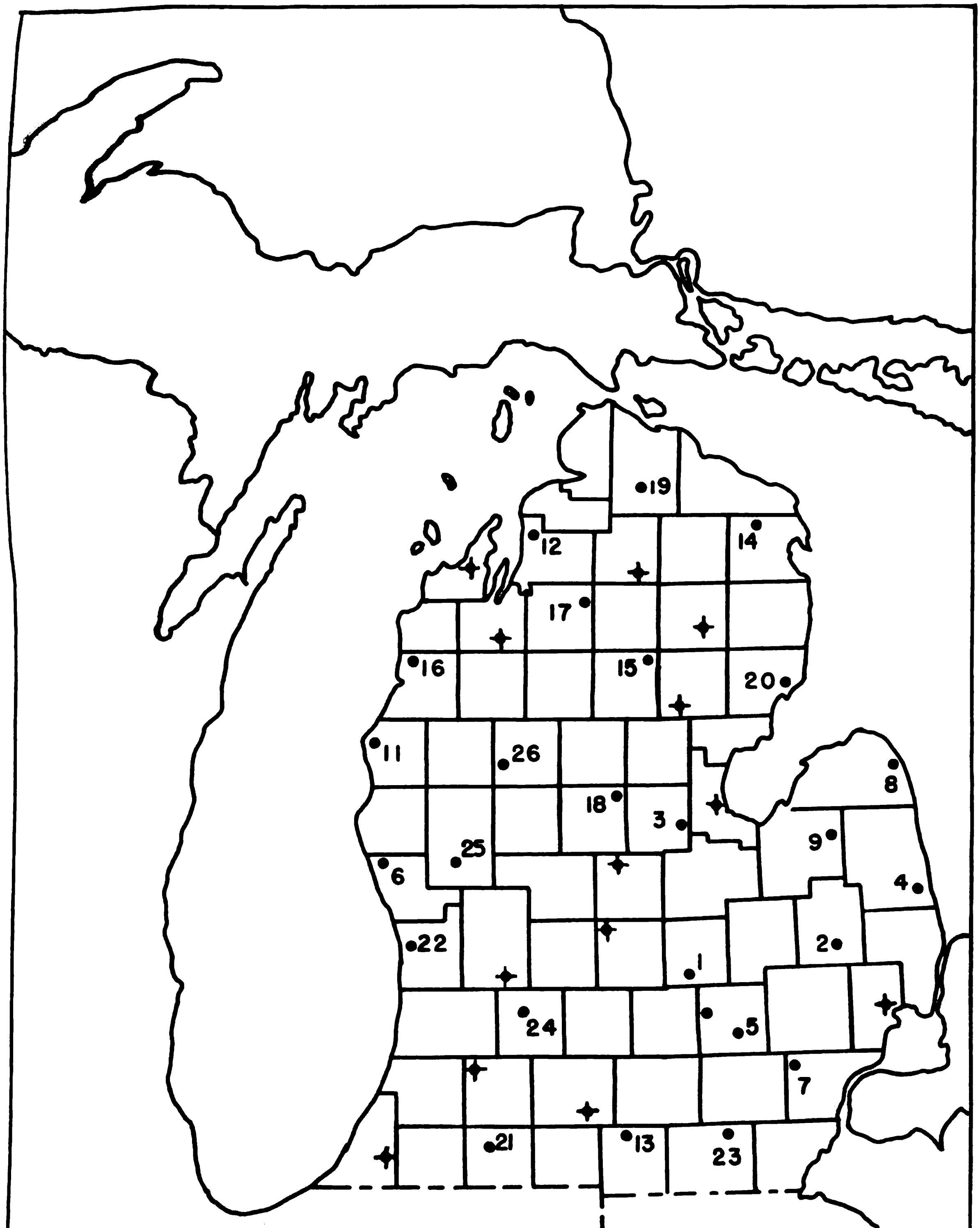
Well No.	County and Township	Driller and Farm	Land Description	Thickness of Section (feet)
14	Alpena Long Rapids	C. W. Teater Nevins #1	18-32N-6E	690
15	Roscommon Au Sable	J. O. Mutch E. B. Hollwell #1	2-24N-1W	935
16	Manistee Pleasanton	Carter Oil Co. F. Crook #1	35-24N-15W	855
17	Kalkaska Clearwater	John Neyer State-Clrwtr. #1	27-27N-5W	1,275
18	Isabella Wise	Cities Service Methner #B-1	33-16N-3W	1,115
19	Cheboygan Ellis	Roosevelt Oil Co. Ormsbee #1	1-34N-2W	317
20	Iosco Baldwin	Ray W. Matlock J. C. Johnson #1	1-22N-8E	660
21	St. Joseph Lock Port	Ora A. Avery S. Dunworth #1	13-6S-11W	156
22	Ottawa Grand Haven	Voorhees Drilling Reible #1	36-7N-16W	180
23	Lenawee Clinton	Voorhees Drilling Irving Grove #1	8-5S-4E	250
24	Barry Rutland	Sun Oil Co. W. L. Kidder #1	8-T3N-9W	414
25	Newaygo Garfield	Sun Oil Co. Glen Bradley #4	11-T12N-13W	570
26	Osceola Lincoln	OHW Oil Co. P. N. Stedman #3	29-18N-10W	1,290

TABLE II (Continued)

DESCRIPTION OF ADDITIONAL WELLS USED FOR ISOPACH CONTROL

County	State Permit	Land Description	Thickness (feet)
Calhoun	18542	6-4S-5W	310
Grand Traverse	18512	9-25N-10W	1,160
Kalamazoo		32-1S-12W	230
Kent	9166	30-7S-12W	405
Clinton	19272	27-8N-4W	800
Gratiot	5067	24-12N-3W	620
Berrien	13879	2-7S-17W	140
Leelanau	10103	5-29N-12W	710
Oscoda	11995	30-25N-3E	1,200
Otsego	16920	15-29N-2W	950
Bay	10551	34-15N-4E	780

MAP 2



• LOCATION OF WELLS USED FOR FACIES ANALYSIS

✦ LOCATION OF ADDITIONAL WELLS USED FOR ISOPACH CONTROL

LABORATORY PROCEDURE

Sampling Methods

Samples for the twenty-six wells were obtained from either the Michigan Geological Survey or the Gulf sample collection at Michigan State University.

Wells were selected which had a complete Upper Detroit River section; tops and bottom of the formations were picked on their lithologic characteristics.

The Upper Detroit River was represented by four to ten trays of twenty-five vials each containing ten grams of sample. The number of samples selected varied from well to well. This variation was caused by: (1) the difference in the sample interval of each sample set, which was usually from two to ten feet; (2) the variation in the formation thickness which ranged from 200 feet to 1,300 feet.

Wentworth (1926) states that in making a mechanical analysis of sedimentary samples about a 125-gram sample should be used. To achieve this sample weight a weight-per-foot factor was determined for each of the wells studied. This varied from well to well due to the different sample interval and vertical range, but was a constant in each individual well.

In most cases it was possible to form a composite sample of 125 grams or more, but in a few wells, due to small formational thickness and the need to conserve the initial sample for future use, less than 125 grams were removed for analysis.

Before the final weighing the sample was cleared of drilling "junk" by an electromagnet. The sample was then placed in a weighed 400-milliliter beaker and ready for the following treatments.

Removal of Water Solubles

Wiegner (1927) outlined a method by which soluble salts may be removed from a sample by treatment with water. The method involved boiling the sample in water to cause the ionic particles to go into solution.

The sample was immersed in 250 milliliters of tap water and allowed to boil for approximately two hours. After the suspended material settled a 10-milliliter sample of the clear water was pipetted off and placed in a test tube. The salinity of which water was compared with an equal amount of tap water by the addition of a few crystals of silver nitrate to each. If the amount of precipitate formed was greater in the sample than in the tap water, the boiling procedure was repeated until the sample precipitate matched or was less than the tap water standard.

The clear solution was siphoned off, the sample washed in tap water, dried, and weighed. The difference in weight before and after the treatment gave the amount of water solubles present.

Removal of Carbonates

The removal of calcium carbonate and dolomite was carried out in the following manner.

About 200 milliliters of a 25-percent solution of hydrochloric acid was slowly added to the sample. After effervescence ceased the solution was allowed to settle. A 10-milliliter sample of the supernatant liquid was pipetted off for future testing of Mg/Ca ratios. The remaining supernatant liquid was then siphoned off.

The process was repeated with hydrochloric acids at 50-percent and 100-percent strengths. The three acid treatments were used to retard the violent reaction that would result from an initial treatment with 100-percent strength acid.

After the 100-percent acid treatment the sample was heated in a sand bath for one hour to remove the less soluble carbonates. The Mg/Ca sample was removed as before, and water added to facilitate settling. The clear solution was siphoned off and the sample washed with water until neutralized.

Disaggregation

Although the Upper Detroit River is predominately dolomite, limestone, anhydrite, and salt, small amounts of shale were noted in the sample after acid treatment. In order to facilitate sieving, the shale particles were disaggregated.

Krumbein and Pettijohn (1938) define disaggregation as ''the breaking down of aggregates into smaller clusters or into individual grains.''

The method of disaggregation used was suggested by Krumbein and Pettijohn (1938); Cooke (1956) discussed this method in detail.

The sample was treated with a supersaturated solution of potassium hydroxide (KOH) and allowed to boil for six hours. Inspection and a little experimenting showed that this was ample time to disaggregate the shale. After washing with water to neutralize the potassium hydroxide the sample was ready for sieving.

Sieving

In order to compute sand-shale and clastic ratios it was necessary to separate the silt and clay particles from the remainder of the sample.

According to Wentworth's (1922) Partical Classification Table, fine sand will be retained on a sieve having a mesh opening of 1/16 millimeter. This mesh size corresponds to a 230 Tyler Sieve.

The washed disaggregated sample was wet-sieved by passing a light stream of water over the sample which flushed the silt and clay material through the 230 Tyler Sieve leaving fine sand and larger material on the sieve.

After drying and weighing, the amount of the silt and clay fraction was determined by the difference in weight before and after disaggregation and sieving.

Removal of Anhydrite

Inspection of the sample contained on the sieve showed it to be a mixture of anhydrite and fine sand. The anhydrite seemed to be little affected by the previous processes, as the fragments were, for the most part, angular and showed little evidence of solution by the acid and water treatments.

As all samples were treated in a like manner, the author felt that the anhydrite content in each sample, if plotted on a base map in the form of a percentage, would give a good indication of its areal distribution.

Concentrated nitric acid removed the anhydrite from the sand fraction in the remaining sample. About 150 milliliters of concentrated nitric acid (HNO_3) was added slowly to the sample. When effervescence ceased the sample was allowed to boil on a sand bath for one hour to make sure all the anhydrite was dissolved.

The sample was allowed to cool, then washed with water until the nitric acid was neutralized. The weight of the anhydrite fraction was determined by drying and weighing the remaining sand.

The weight of the sand fraction was recorded for computing the sand-shale and clastic ratios.

Magnesium/Calcium Analysis

For the Mg/Ca analysis the author used the formulas and laboratory techniques developed by Jodry (1955). The following are excerpts from Jodry's report to show how he accomplished his titration analysis.

Jodry (1955) stated, ''In its simplest form, the formula for determining the Mg/Ca ratio for a given sample may be expressed as follows:

$$\frac{\text{Percent MgO}}{\text{Percent CaO}} = \frac{\text{D-B}}{1.39\text{B}}$$

B = Milliliters of Versenate solution used in titration, with Murexide as indicator.

D = Milliliters of Versenate solution used in titration, with F 241 as indicator.

This basic formula permits the ratio computation without use of a specific weight of sample (1.000 grams in the original formula) and without standardizing the versenate solution near the strength described only because these proportions give an optimum reaction without waste of reagents."

As stated before under "Removal of Carbonates," after acid treatments by 25-percent, 50-percent, and 100-percent strength acids, a 10-milliliter sample from each was saved for the Mg/Ca determination.

The three 10-milliliter samples were mixed with 200 milliliters of distilled water; the solution thus formed the sample to be tested in the following manner to obtain the Mg/Ca ratio.

Jodry (1955) states:

Determination of Calcium

Reagents

Versenate solution. Dissolve 4 grams of disodium salt of (ethylenedinitrilo) tetraacetic acid in 1 liter of water. Standardize this solution against a standard calcium solution with Versenate in the manner described below.

Standard calcium solution. Dissolve 2.500 grams of reagentgrade calcium carbonate in approximately 5 milliliters of

1-to-1 hydrochloric acid (warm gently if necessary) and dilute to exactly 1 liter with water. This solution contains 1 milligram of calcium per milliliter.

Potassium hydroxide. Use a 20-percent aqueous solution.

Calcium indicator powder. Mix thoroughly 40 grams of powdered potassium sulfate and 0.2 gram of Murexide.

Titration

1. Pipette a 10-milliliter aliquot of the solution to be analyzed into a 200-milliliter porcelain dish, then add approximately 20 milliliters of water, 1 milliliter of potassium hydroxide, and a tiny scoop (20 to 30 mg.) of calcium indicator powder.

2. Stir the solution and titrate with the standardized Versenate. The end point is reached when the color of the solution changes from pink to violet.

Determination of Magnesium

Reagents

Versenate solution. Prepare as above.

Buffer solution. Dissolve 60 grams of ammonium chloride in approximately 200 milliliters of water; add 570 milliliters of concentrated ammonium hydroxide, and dilute to 1 liter with water.

Potassium cyanide. Prepare a 10-percent aqueous solution.

F 241 indicator. Dissolve 0.15 gram of Eriochrome Black T-(F 241) and 0.5 gram of sodium borate in 25 milliliters of methanol.

Titration

1. Pipette a 10-milliliter aliquot of the solution to be analyzed into a 200-milliliter porcelain dish, then add 25 milliliters of water, 2 to 3 milliliters of buffer solution, a few drops of potassium cyanide solution and 8 drops of F 241 indicator.

2. Stir, and titrate with the Versenate solution. The end point is reached when the color of the solution changes from winered to clear blue.

By substituting the values gained by titration into the formula

$\frac{MgO}{CaO} = \frac{D-B}{1.39B}$ the Mg/Ca ratios were obtained.

Accuracy of the Data

By transferring samples only when necessary and using pipetting techniques instead of filtering methods, sample loss was held to a minimum.

Each sample was handled and treated in the same manner so any errors that were inherent to the laboratory procedure were constant in all samples, thus minimizing their effect.

In regard to the accuracy of the Mg/Ca data, Jodry (1955) states tha reasonable care in this analysis should give values for CaO and MgO within 0.5 percent accuracy.

Results of Laboratory Analysis

Table III shows the results of the laboratory analysis. These data were used to compute the ratios shown in the following section, and the results are given in Table IV.

TABLE III

QUANTITATIVE ANALYSIS

Well No.	Sample Weight	Water Solubles	Acid Solubles HCl	Acid Solubles HNO_3	Sand Fraction	Silt and Clay Fraction
1	119.777	0.592	89.372	6.593	0.459	32.319
2	124.578	0.773	78.734	8.212	1.408	43.663
3	133.819	0.969	95.880	13.142	2.543	34.426
4	123.958	0.737	109.581	5.494	1.898	11.736
5	125.200	1.771	94.878	9.077	0.467	28.084
6	121.540	0.923	85.454	15.590	1.903	33.240
7	130.602	0.494	116.467	3.230	1.017	12.624
8	120.209	0.784	109.392	8.539	0.209	9.811
9	127.358	0.192	85.941	11.365	0.759	40.465
10	107.209	0.928	47.440	6.233	2.155	56.686
11	93.570	3.937	60.753	8.667	14.710	14.171
12	108.982	0.312	83.198	10.019	1.515	23.858
13	123.429	0.615	105.156	3.675	1.979	15.678
14	103.179	0.916	82.102	6.223	0.788	19.474
15	116.670	15.285	83.367	7.220	1.279	16.738
16	115.061	0.352	75.037	15.919	2.633	37.042
17	125.143	15.630	89.362	7.469	1.558	18.602
18	130.534	0.230	94.288	16.212	3.148	32.867
19	113.185	0.751	84.231	0.119	2.627	25.576
20	81.685	1.263	70.558	2.705	0.788	9.076
21	103.443	1.516	85.833	9.373	4.111	12.982
22	124.888	0.505	104.505	11.947	3.092	16.787
23	124.469	0.217	114.157	5.186	2.949	7.136
24	122.528	1.346	91.545	7.037	2.585	20.016
25	65.123	0.682	42.493	1.843	1.425	18.681
26	121.759	3.436	81.025	3.738	7.426	26.124

TABLE IV

LITHOLOGIC RATIOS

Sample Number	Sand-Shale Ratio	Clatic Ratio	Evaporite Ratio	Mg/Ca Ratio	Anhydrite Percentage
1	0.053	0.354	0.083	0.591	5.504
2	0.033	0.514	0.114	0.305	6.592
3	0.074	0.336	0.147	0.435	9.821
4	0.162	0.117	0.057	0.347	4.434
5	0.017	0.270	0.114	0.708	7.250
6	0.057	0.345	0.193	0.659	12.827
7	0.081	0.113	0.035	0.605	2.473
8	0.021	0.084	0.085	0.528	7.107
9	0.019	0.423	0.134	0.360	8.924
10	0.038	1.007	0.150	0.935	5.814
11	1.04	0.393	0.207	0.720	9.263
12	0.064	0.271	0.124	0.261	9.193
13	0.124	0.161	0.041	0.577	2.971
14	0.035	0.226	0.087	-----	6.031
15	0.076	0.170	0.269	-----	6.188
16	0.071	0.431	0.216	0.599	13.835
17	0.084	0.179	0.258	0.240	5.968
18	0.096	0.325	0.174	0.270	12.420
19	0.103	0.331	0.010	0.077	0.105
20	0.087	0.132	0.048	0.419	3.312
21	0.317	0.178	0.115	0.634	9.061
22	0.184	0.169	0.119	0.667	9.566
23	0.413	0.084	0.047	0.685	4.166
24	0.129	0.226	0.092	0.625	5.743
25	0.076	0.447	0.059	0.626	2.830
26	0.284	0.381	0.089	0.445	3.070

LITHOLOGIC INTERPRETATIONS

Lithologic Ratios

By its very nature, the areal extent and variation of lithology in geologic sections are best portrayed on a lithofacies map. Most lithofacies maps are based on numerical data which can be expressed as percentage, thicknesses of various lithologies, or as lithologic ratios. The writer used ratio and percentage maps in preparing the lithofacies maps for this report.

Krumbein (1952) states: "The ratio method is based on the use of the end-member concept which contrasts the relations among end-members present. In essence the ratios yield easily visualized values of numerator type rock per foot of denominator type rock." The following are the ratios used by the author in this investigation.

The clastic ratio is expressed by the formula:

$$\text{Clastic Ratio} = \frac{\text{Conglomerates} + \text{Sandstone} + \text{Shale}}{\text{Limestones} + \text{Dolomites} + \text{Evaporites}}$$

A ratio of "one" would represent equal amounts of clastic and nonclastic material. A ratio greater than one indicates a greater amount of clastic than nonclastic material; values less than one indicate more nonclastic than clastic material.

Variations in clastic material are represented by the sand-shale ratio. The formula for this ratio is computed as follows:

$$\text{Sand-Shale Ratio} = \frac{\text{Conglomerate + Sandstone}}{\text{Silt + Clay}}$$

A formation containing only sandstone is expressed by a sand-shale ratio of infinity; a formation containing only shale has a ratio of zero.

In order to show variation within nonclastic material an evaporite ratio is used and computed in this manner:

$$\text{Evaporite Ratio} = \frac{\text{Evaporite}}{\text{Limestone + Dolomite}}$$

A section containing an equal amount of evaporite and limestone is represented by a ratio of one. With an increasing amount of evaporites the ratio approaches infinity; an increase in carbonates will produce a ratio which approaches zero.

Due to drilling techniques and the washing of samples prior to their use in this investigation, there was loss of the more soluble evaporites such as salt. The writer feels an evaporite ratio can still be of value in this investigation if the inaccuracies caused by this evaporite loss are kept in mind when interpreting the evaporite facies map.

A magnesium/calcium ratio showed the variations in the carbonate material in the formation. The general formula for this ratio can be represented by:

$$\text{Mg/Ca Ratio} = \frac{\%\ \text{Mg}}{\%\ \text{Ca}}$$

The use of this formula produces a ratio that varies between zero and one for limestones and dolomites. With an increase of dolomite over limestone the ratio approaches one; an increase of limestone over dolomite produces a ratio which approaches zero.

A percentage anhydrite facies map was constructed to point out the depositional areas of the relatively large amounts of anhydrite found in the Upper Detroit River. The anhydrite percentages were obtained by the formula:

$$\text{Anhydrite Percentage} = \frac{\text{Weight of Anhydrite}}{\text{Weight of Total Sample}}$$

From the above formula it is easily seen the higher the anhydrite content the higher the anhydrite percentage.

Table IV lists the ratio or percentage values for each of the wells analyzed.

Construction of Facies Maps

To construct facies maps of lithologic ratios or percentages the numerical data found in Table IV were plotted at each well location on a base map of Michigan.

Isopleth lines of equal ratio or percentage values were then drawn connecting points of equal value. The isopleth spacing was based on arithmetic rather than geometric intervals.

The Isopach map was constructed on semitransparent paper; the ratio maps were drawn on opaque paper. Using this method the isopach map may be superimposed on the various facies maps when using Krumbein's (1952) method of lithofacies interpretation.

Maps 4, 5, 6, 7, 8, and 9, found in the "pocket" of this report, are the isopach, clastic, sand-shale, evaporite, Mg/Ca, and anhydrite lithofacies maps, respectively.

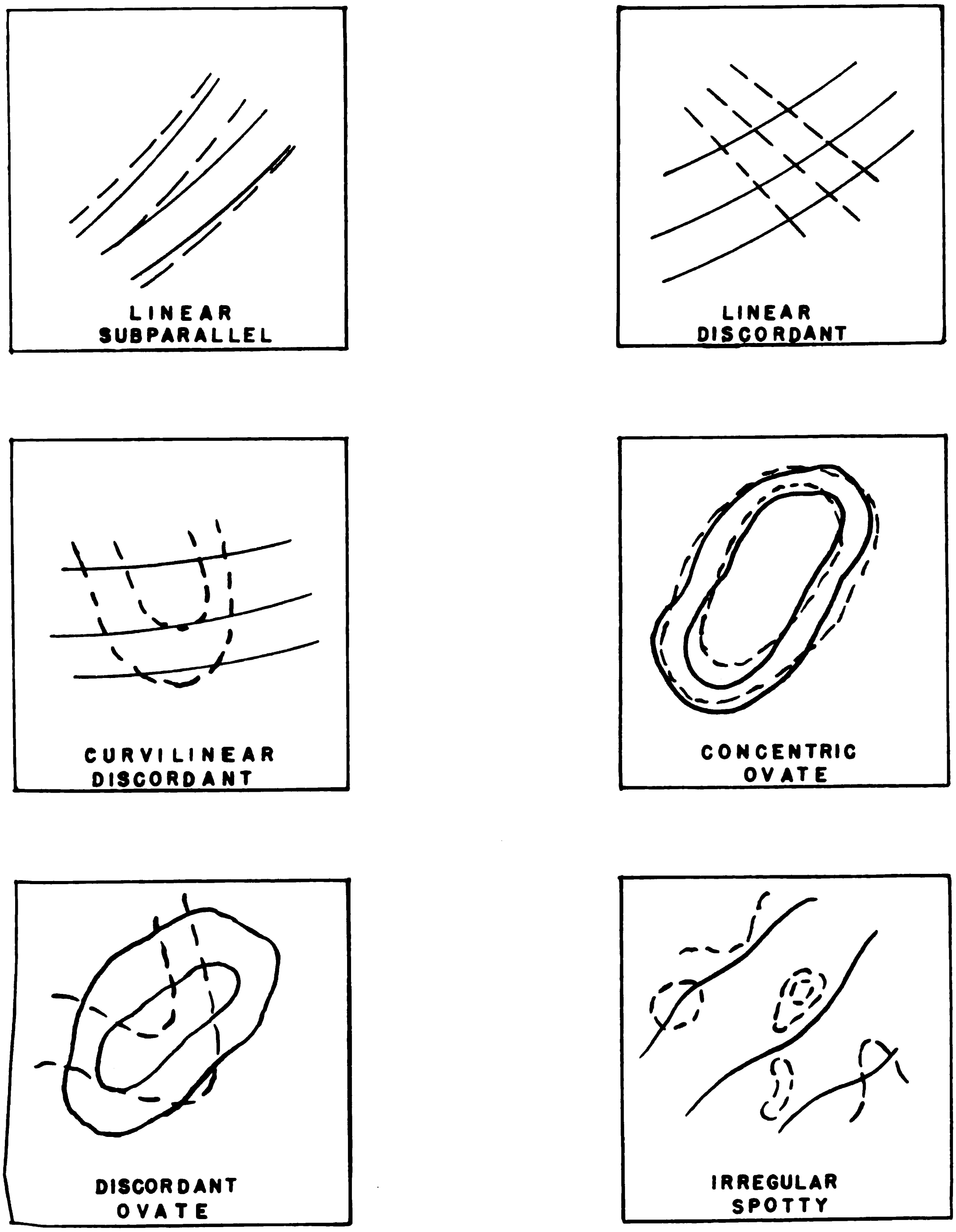
Methods of Geologic Interpretation

To aid in the interpretation of facies mape Krumbein (1952) proposed a systematic method. This method of interpretation is based on the relation between isopleth and isopach lines. By superimposing the isopach map on the lithofacies map, Krumbein found the six types of patterns as shown in Figure I.

FIGURE I

RELATIONS OF ISOPACHS (SOLID) AND FACIES LINES

KRUMBEIN (1952)



Describing some of the patterns, Krumbein (1952) states:

> The linear sub-parallel pattern may occur under conditions where clastic sediments are spread over a subsiding area in decreasing amount away from the sources, so that the clastic ratio lines tend to decrease as the isopachs increase because of increasing lime deposition. The curvilinear discordant pattern may arise when a local concentration of clastics is poured into a subsiding area, such as a delta. Here the clastic ratio lines may project farther into the basin than normally. The concentric ovate pattern is characteristic of evaporites in an intracratonic basin. The irregular spotty pattern occurs near the deteriorating edges of sheet sands, where the accumulation becomes patchy or spotty.

Krumbein also states that three of the patterns are normally associated with intracratonic basin conditions, such as found in the Michigan basin. The interpretation of these patterns indicate and locate the tectonics which controlled sedimentary deposition. The three patterns are:

1. Curvilinear discordant patterns--indicate either a nearby orogenic or epeirogenic source.
2. Concentric-ovate patterns--infer either a nearby orogenic or epeirogenic source or a distant orogenic source.
3. Discordant-ovate patterns--indicate either a nearby orogenic or nearby epeiorgenic source.

Using Krumbein's (1952) methods of facies analysis, the writer presents the following interpretations of the facies maps constructed from this investigation.

Lithofacies Interpretations

The clastic ratio map. This map indicates the Michigan basin received clastic sediments from four sources during Upper Detroit River time. The highest clastic concentration is in the southwest section of the state, in Berrien, Van Buren, and Cass counties. Applying Krumbein's facies analysis techniques, a combination of linear subparallel to curvilinear discordant patterns are noted. These patterns indicate clastic sediments derived from a nearby orogenic or epeirogenic source spreading over a subsiding area. This spreading, coupled with the fact that the clastic ratios are decreasing in value to the northeast, indicates a possible source area to the southwest.

High clastic ratios are found in the southeast section of the state in Lapeer, Macomb, and Saint Clair counties. The clastic isopleth lines open to the southeast and close to the northwest. They decrease in value towards the center of the basin. A curvilinear discordant pattern is noted in the southeast which indicates a nearby orogenic source.

A third clastic high is in the western part of the Lower Peninsula in Mason and Manistee counties. The isopleth lines open to the west and close to the southeast, and show a decrease in clastics in a general southeast trend. This trend, along with a curvilinear discordant pattern, indicates a source area to the west or northwest.

A fourth area of moderately high clastic ratios is found in the north section of the state, with its center in southern Cheboygan County. A source area to the north is indicated by a curvilinear discordant pattern and a decrease in clastics to the south.

A summary of the inferred structural features determined from the clastic ratio map is:

1. A broad ridge of clastic material extending in a northeast direction from Saint Clair County to Clare County. The trend of this ridge indicates a source area to the southwest, possibly the Findlay arch.

2. A ridge of high clastic content originates at the west side of the Lower Peninsula in Mason and Manistee counties and trends southeast to Barry County. Its location and development indicate a source area to the west or northwest, possibly from the Wisconsin dome.

3. A broad clastic ridge, in the north part of the state, showing a curvilinear discordant pattern with a south trend, indicates a Canadian Shield source area.

4. A shelf area having a rapid decrease in clastic material to the northeast is in the southwest section of the state. Subparallel

discordant to curvilinear discordant patterns, with a decrease in clastic material northeast, indicate a source area to the southwest, possibly the Kankakee arch.

The sand-shale map. Inspection of the sand-shale ratio values on the map indicates three different relations exist between the sand and shale deposition. In the west part of the state the ratio value of 1.004 indicates equal amounts of sand and fine clastic material were deposited. In the north a low ratio of 0.100 indicates a preponderance of fine clastic material. Ratio values of 0.300 to 0.400 found in a band following the southern border of the state from Saint Clair County to Allegan and Ottawa counties indicate moderate amounts of sand compared to fine clastic material.

The highest sand-shale ratio is in Mason County. The sand fraction decreases to the southeast with the isopleth lines closing to the east and opening to the west. This feature extends in a belt three counties wide from Mason County in the west to Clinton and Shiawassee counties. The curvilinear discordant pattern covering this area indicates a nearby epeirogenic source to the west or northwest.

Another area of moderately high ratios is located in the north part of the Lower Peninsula extending from Charlevoix and lower

Cheboygan counties to Iosco County. The lithofacies lines close to the south and open to the north. The curvilinear discordant patterns and the decrease in sand to the southeast indicates a nearby epeirogenic source area to the north or northwest.

There is also a band of moderately high ratios found in the southern part of the state. These ratios decrease in value toward the center of the basin. A linear subparallel pattern in this area indicates a possible subsiding shelf area with an epeirogenic source to the southwest, south, and southeast.

A summary of the features indicated by the sand-shale facies map:

1. There is a ridgelike feature of high sand-shale ratios striking southeast from Mason County to Clinton County; the source area is to the west or northwest.

2. A south to southwest trending ridge in the northern portion of the state indicates a possible source from the Canadian Shield.

3. A band of moderate sand-shale ratios paralleling the southern border of Michigan indicates the sediments were derived from the southwest, south, and southeast.

4. Variations in the sand-shale ratios indicate the structural features surrounding the basin during Upper Detroit River time did

not have equal relief. The higher sand content in the west-central portion of the state indicates the Wisconsin dome area had slightly higher relief than the other tectonic features bordering the basin during the deposition of the Upper Detroit River sediments.

The evaporite ratio map. The highest concentration of evaporites is in Roscommon County near the geographical center of the basin. The evaporite ratios decrease in value from this high and delineate an ovate pattern extending from Otsego County in the north to Kent County in the south, and from Saginaw Bay in the east to a position in Lake Michigan west of Mason County. The concentric ovate pattern found in this area indicates the deposition of evaporites in an intracratonic basin.

A bar or ridgelike feature of low evaporite values is surrounded by an area of higher ratios in Newaygo and Osceola counties. This pattern indicates a topographic high in a restricted evaporite basin.

A minor evaporite high is in the southwest part of the state in Berrien, Van Buren, and Cass counties. This feature trends northeast-southwest and decreases in evaporite content to the northeast. A curvilinear discordant pattern suggests a nearby epeirogenic source, possibly to the southwest.

Another moderate evaporite high in Genesee and Lapeer counties in the Thumb Area of Michigan is elliptical in shape and trends northeast-southwest. A curvilinear discordant pattern indicates a nearby epeirogenic source.

A summary of the structural features represented by the evaporite ratio map are:

1. A large evaporite basin is located in the northern half of the Lower Peninsula.

2. A ridgelike feature in Newaygo and Osceola counties strikes northeast. This feature indicates a topographic high not suitable for evaporite deposition. An alternative explanation might be nondeposition due to the inflow of fresh water. The writer rejected this last hypothesis because the high evaporite ratios which completely isolate the area give no indication of a fresh water inlet.

3. A minor evaporite high in the southwest section of the state indicates possible local conditions favorable for the deposition of evaporites.

4. A third evaporite high located in the Thumb Area of Michigan also indicates local conditions favorable for the deposition of evaporites. Conditions which could cause local evaporite deposition are local subsidence, topographically low areas, and high

concentrations of evapororite salts due to isolation from a source of fresh water.

The anhydrite percentage map. An oval-shaped anhydrite concentration in Clare County, the center of the Michigan basin, covers an area which includes the northeast, central, southeast, and southwest parts of the Lower Peninsula. This ovate pattern, with decreasing anhydrite values toward the periphery, indicates a restricted evaporite basin in an intracratonic depositional area.

A barrier or ridgelike feature indicated by low anhydrite values surrounded by higher anhydrite concentration is found in Newaygo, Osceola, and Missaukee counties. This feature trends northeast-southwest and corresponds to a similar feature shown on the evaporite ratio map.

Two areas having high anhydrite concentrations, separated by an area with lower anhydrite values, are located near the shore of the present Lake Michigan in the west-central part of the state. One of the anhydrite highs is in Manistee County; the other, in Oceana County. The area of low anhydrite concentration separating the two highs is in Mason County. A pattern of this type indicates a possible coalescing of two lagoonal areas favorable to anhydrite deposition.

A triangular-shaped area in Calhoun, Jackson, and Eaton counties, containing low anhydrite percentages surrounded by higher anhydrite concentrations, indicates a topographic high or shelf area in an evaporite depositing environment.

A deltaic pattern of low anhydrite concentration is centered in Cheboygan County. The isopleth lines closing to the south and opening to the north have increasing anhydrite values toward the center of the basin. This depositional pattern may indicate an inflow of fresh marine water from the north which lowered the anhydrite concentration in the area.

The features indicated by the anhydrite facies map are:

1. An oval-shaped pattern with a high anhydrite concentration in Clare County covers all but the north, northwest, and west-central parts of the Lower Peninsula. This ovate pattern is indicative of evaporite deposition in an intracratonic basin.

2. A ridgelike feature in west-central Michigan is indicated by low anhydrite concentration.

3. Two coalescing lagoonal areas of high anhydrite concentration, located in the west-central part of the state, extend into the area now occupied by Lake Michigan. The location of these lagoonal areas indicates the western limit of the Michigan basin was farther

west than the present-day Lake Michigan shore line during Upper Detroit River time.

4. Low anhydrite concentrations indicate a topographic high, possibly a shelf area, in south-central Michigan.

5. A deltaic feature of low anhydrite concentration in northern Michigan indicates a possible inflow of fresh marine water from the north.

6. A general picture of the Michigan basin during the deposition of the Upper Detroit River evaporite sequence is not that of a smoothly sloping basin, but one containing local relief or raised places, which tends to retard the deposition of evaporite in these areas.

The magnesium/calcium ratio map. According to Briggs (1957) and Landes (1951), the normal sequence of carbonate and evaporite precipitation in a marine environment is: limestone followed by dolomite, gypsum, anhydrite, and halite. Chilingar and Bissell (1957) state that a high magnesium content in a carbonate rock indicates shallow and warm water conditions, and a high calcium content can be interpreted as a gradual subsiding or deepening in a depositional area.

Examination of the Mg/Ca ratio map indicates that north of a line running diagonally across the state from Benzie County to Macomb County, limestone is more abundant than dolomite, whereas south of this line the ratios indicate a higher percentage of dolomite.

Thie depositional pattern indicates shallow water shelf conditions in the southwest part of the state. North of a line extending from Benzie to Macomb counties, the increase of limestone over dolomite indicates deeper water conditions. This may be caused by greater subsidence of the Michigan basin in this area during Upper Detroit River time.

REGIONAL TECTONICS AND CONCLUSIONS

Structures Related to the Michigan Basin

The structural features which led to the development of the Michigan basin were in existence long before Middle Devonian time. The Precambrian Shield complex confined the basin in the north. The Wisconsin dome, which was developed by uplift in Ordovician time, bordered the basin to the west (Eardley, 1951).

According to Pirtle (1932) and other investigators, the southeast, south, and southwest limits of the basin were defined by the Findlay and Kankakee arches.

The Findlay arch strikes northeast from central Ohio to southwest Ontario, and is related in age to the Cincinnati dome formed during Ordovician time. A gap in the Findlay arch, the Chatham sag, located in the vicinity of Lake Saint Clair, was a connecting link between the Appalachian Geosyncline and the Michigan basin for periods of time during their development (Landes, 1951).

The Kankakee arch extends northwest from northwest Indiana to southeast Wisconsin. This connection between the Wisconsin and

Cincinnati domes is believed to be more closely related to the Wisconsin dome in age (Pirtle, 1932).

Keeping in mind the geological setting prior to Middle Devonian time, and using the formation gained from the interpretation of the lithofacies maps, the following tectonic and sedimentary relations were indicated during the deposition of the Upper Detroit River sediments.

Sedimentary and Tectonic Interpretations

Clastic ratio map. The clastic material deposited in the Michigan basin was not supplied by one area, but was derived from four areas surrounding the basin. This indicates the Michigan basin was a topographic depression, surrounded by topographically higher areas, for some times during development of Upper Detroit River sediments.

The highest clastic values were found in southwest Michigan, indicating a source area to the southwest.

The area of lowest clastic accumulation was in Cheboygan County; and the sediments were derived from the north. Source areas for the two intermediate clastic accumulations in southeast and west-central Michigan are northwest and southeast, respectively.

It is interesting to note that the Chatham sag and the source of the clastic material found in southeast Michigan coincide. This may indicate the Chatham sag was emergent at times during Upper Detroit River deposition.

A summary of conclusions gained from the clastic ratio map are:

1. The basin received clastic sediments from four different sources in Upper Detroit River time--the Wisconsin dome, Kankakee arch, Findlay arch, and the Canadian Shield, located in the west, southwest, southeast, and north, respectively.

2. The four areas of clastic accumulation did not receive equal amounts of clastic material, indicating the structural features bounding the basin varied in relief.

3. The Chatham sag was emergent from time to time during the basin's development.

Sand-shale map. The variation between the sand-shale ratios in the four areas of clastic accumulation show that the sources which supplied these sediments were of unequal relief. The sand-shale ratios indicated the following:

1. The Wisconsin dome supplied the highest percentage of sand-size material and had a moderate relief.

2. The Findlay and Kankakee arches were relatively stable and low in relief.

3. The Canadian Shield supplied the least amount of coarse, clastic material and had little relief.

A summary of conclusions based on the sand-shale ratio map is:

1. The basin received clastic sediments from four sources during Upper Detroit River time.

2. The Findlay arch, Kankakee arch, and the Canadian Shield area were relatively stable and low-lying.

3. The Wisconsin dome had moderate relief during Upper Detroit River time.

Evaporite ratio map. The evaporite ratios show the existence of a large evaporite basin in the geographic center of the Lower Peninsula.

Two small evaporite concentrations are found in southern Michigan: one located in the Thumb Area, the other in the southwest corner of the state.

The existence of a northeast-trending ridge in west-central Michigan is indicated by a concentration of low evaporite values enclosed within an area of higher evaporite ratios.

A summary of the conclusions based on the evaporite map is:

1. The relatively high evaporite concentrations which were precipitated in the basin indicate the structural features surrounding the basin were emergent for periods of time during the development of the Upper Detroit River group.

2. The thick evaporite section found in the center of the basin indicates subsidence was contemporaneous with deposition.

3. A barrier or ridgelike feature in west-central Michigan separates the central basin from a similar basin located farther to the west.

4. Two local depressions favorable to evaporite precipitation are found in southern Michigan--one in the Thumb Area, the other in the southwest corner of the state.

5. Local relief in the Michigan basin effected the precipitation of the evaporites during Upper Detroit River time.

Anhydrite percentage map. The center of a large oval-shaped anhydrite concentration was found in Clare County, the geographical center of the Michigan basin.

In west-central Michigan two coalescing lagoonal areas containing high anhydrite concentrations extend into an area now occupied by Lake Michigan.

A northeast-trending ridge in west-central Michigan corresponds to the one shown on the evaporite map.

A triangular area of low anhydrite values, in the south-central part of the state, reveals a topographic high not suited to anhydrite deposition.

A summary of the conclusions based on the anhydrite percentage map is:

1. The center of the evaporite sequence formed during Upper Detroit River time is located in the central portion of the Michigan basin.

2. A ridge or barrier in west-central Michigan separates the main evaporite basin in central Michigan from two coalescing evaporite basins found farther to the west.

3. The location of anhydrite basins in and on the shore of Lake Michigan indicates the western limit of the basin was farther west than the present Lake Michigan shore line during Upper Detroit River time.

<u>Magnesium/calcium ratio map</u>. The carbonates deposited north of a line extending from Benzie to Macomb counties are predominately limestones; south of this line dolomites predominate.

Summary of conclusions based on the Mg/Ca ratio map is:

1. The northeast and central portions of the Michigan basin were subsiding at a greater rate than the other sections of the basin during Upper Detroit River time.

2. The southwest section of the state was a shallow shelf area little affected by subsidence during Upper Detroit River time.

Conclusions

This investigation indicates the following environmental and tectonic features influenced the deposition of Upper Detroit River sediments.

1. The structural features surrounding the basin were stable and low-lying.

2. Clastic sediments entered the basin from four areas--the north, west, southeast, and southwest.

3. The Wisconsin dome was higher in relief than the other structural features bounding the basin.

4. There were no major crustal disturbances in or around the basin.

5. Deposition began and ended quietly with the encroachment of warm limestone-precipitating seas.

6. Subsidence and deposition of the thick evaporite series, particularly in the center of the basin, were contemporaneous.

7. The basin was restricted from other areas for periods of time due to the emergence of the positive structural features surrounding it.

8. The topographic features within the basin helped control the deposition of nonclastic material.

9. Lagoonal-type basins in west-central Michigan indicate the western limit of the Michigan basin was farther west than the present Lake Michigan shore line.

In studying the Traverse group (Upper Devonian), Jodry (1957) indicated the presence of a barrier in west-central Michigan which separated a large area of western Michigan from the main basin to the east. He indicates this barrier is related to pre-Devonian folding. The results of this investigation indicate that such a barrier existed during Upper Detroit River time.

Landes (1951) stated the gap in the Findlay arch (the Chatham sag) was emergent for periods of time during the development of the Detroit River group. The results of this study support this belief.

This investigation indicates the feasibility of using chemically derived Mg/Ca ratios in a regional sedimentary facies analysis. The writer feels more work along this line would result in a better understanding of the environmental conditions necessary for the precipitation of limestone and dolomite.

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Pocket has: 7 Maps
(Maps 3-9)