A QUANTITATIVE SEDIMENTARY ANALYSIS OF THE MIDDLE DEVONIAN TRAVERSE GROUP IN THE MICHIGAN BASIN

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Roy M. Ross, Jr.

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A QUANTITATIVE SEDIMENTARY ANALYSIS OF THE MIDDLE DEVONIAN TRAVERSE GROUP IN THE MICHIGAN BASIN

By

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A THESIS

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ABSTRACT

The lateral variation of sedimentary deposits is indicative of the different processes at work and the source areas of the detrital material at the time of deposition. In this investigation thirty-three wells, representing complete vertical sections of the Traverse group of the Michigan basin, were quantitatively analyzed to determine their respective lithologic character.

Numerical ratios obtained from this investigation were utilized to construct the various lithofacies maps which accompany this report. The clastic ratio map is a graphic comparison of the detrital sediments, derived from the erosion of the pre-existing rock, with the nonclastic material derived by organic and inorganic precipitation. The sand-shale ratio map compares the coarse to the fine clastic material. The construction of the evaporite ratio map is based upon the weight of the evaporite material compared to the weight of the remaining chemical precipitates. The quartz-chert map depicts the percent of quartz to the percent of chert found in each sample and is in effect representative of the contrast between the primary and secondary sediments.

The lithofacies maps were superimposed over the isopach map to aid in their interpretation. A study of the resulting patterns helped to reconstruct tectonic conditions that existed in mid-Devonian time.

This sedimentary analysis indicated that during the deposition of the Traverse group in the Michigan basin, there were no major crustal disturbances within the region. It was shown the structural features defining the limits of the basin were stable and lowlying, and the bulk of the sediments making up the Traverse group entered the basin from the northeast.

ACKNOWLEDGMENTS

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INTRODUCTION

Description of the Michigan Basin

Until 1926, before the beginning of extensive oil and gas development in the Lower Peninsula of Michigan, little was known of the details of the subsurface geology. This part of Michigan is masked by the thickest deposit of glacial material in the United States. During the last thirty years many wells, together with test drillings and coring operations, have yielded much information about the Michigan basin.

Pirtle (1932) had this to say about the Michigan basin:

> The Michigan basin is a broad structural and sedimentary basin probably originating in Precambrian time. It is slightly rectangular in form, trending northwest and southeast, with its deepest point near the center of the southern peninsula of Michigan. It extends approximately 450 miles east and west, and almost the same distance north and south. The rocks dip toward the center at a rate of 30-35 feet per mile. Its sedimentary and structural history is closely related to the large positive elements of the Cincinnati, Kankakee, and Wisconsin arches. Folds within the Michigan basin have a persistent northwest-southeast parallel trend and may be traced through a distance of 40-60 miles. Their origin is believed to be closely related to the early history of the basin itself, being controlled by trends of folding or lines of structural weakness which existed in the basement rocks.

If the glacial drift in this area were stripped away, the sequence of stratigraphic units filling the Michigan basin would crop out as more or less concentric bands with the youngest system (Pennsylvanian) being innermost and the oldest (Cambrian and Ordovician) located most distant from the center. These systems might be compared with a nest of shallow dishes or saucers.

Pirtle (1932) enumerates the structures bounding the basin are the Wisconsin arch in the west, the two limbs of the Cincinnati arch in the south, the Kankakee arch to the southwest, and the Findlay arch to the southeast. The northern boundary is the Canadian Shield, and the eastern boundary is the Algonquin arch.

The material written by Smith (1912), Pirtle (1932), and Newcombe (1933) describing the basin, its relationship to surrounding areas, and time of origin are mainly in accord. These have previously been stated. Green (1957) in a recent paper re-evaluates some of the time-honored concepts. He states that the regional aspect of the Michigan basin structure resulted from subsidence within the basin itself, rather than from uplift about it. This subsidence, he feels, began in post-Niagaran Silurian time. Green (1957) writes that many of the major structural features discussed in literature will not withstand the test of careful examination. The "Kankakee arch" is cited by Green (1957) as an example of a term that should be dropped because no structural connection ever existed between the Wisconsin and Cincinnati arches.

It is left to the reader as to which of these conflicting concepts he wishes to accept, because both have merit. The author, for this investigation and its conclusions, has chosen to follow the beliefs of Smith, Pirtle, and Newcombe.

Sedimentary Facies and Lithofacies

The principle of facies and facies changes has been recognized by stratigraphers for many years, but only in the last decade has more serious consideration been given this concept.

Moore (1949) states, "Sedimentary facies are areally segregated parts of differing nature belonging to any genetically related body of sedimentary deposits." He further states, "The term lithofacies denotes the collective character of any sedimentary rock which furnish record of its depositional environment."

The "collective character" of a sedimentary rock or "lithofacies" can perhaps be clarified by an illustration. Within the limits of a certain area a formation may be limestone. In an adjoining area this same formation grades into a shale, and beyond this area the shale grades into a sandstone. The lithofacies of this formation is limestone in the first area, shale in the second, and sandstone in the third. The study of lithofacies by means of facies changes in a formation is helpful in determining the original depositional environment.

Purpose

The purpose of this paper is to determine the depositional environment within the Michigan basin during Middle Devonian time. This will be determined by the construction and interpretation of lithofacies maps of the Traverse group.

The author intends that a detailed investigation will contribute to the understanding of the tectonic environment which existed at the time of deposition of this well-defined stratigraphic unit.

Other similar investigations have previously been conducted on formations from the Lower and Middle Devonian series. The Traverse group, representing the Middle Devonian series, was selected for analysis so that these investigations might be continued and a detailed picture of all Devonian sediments and their source areas can be constructed.

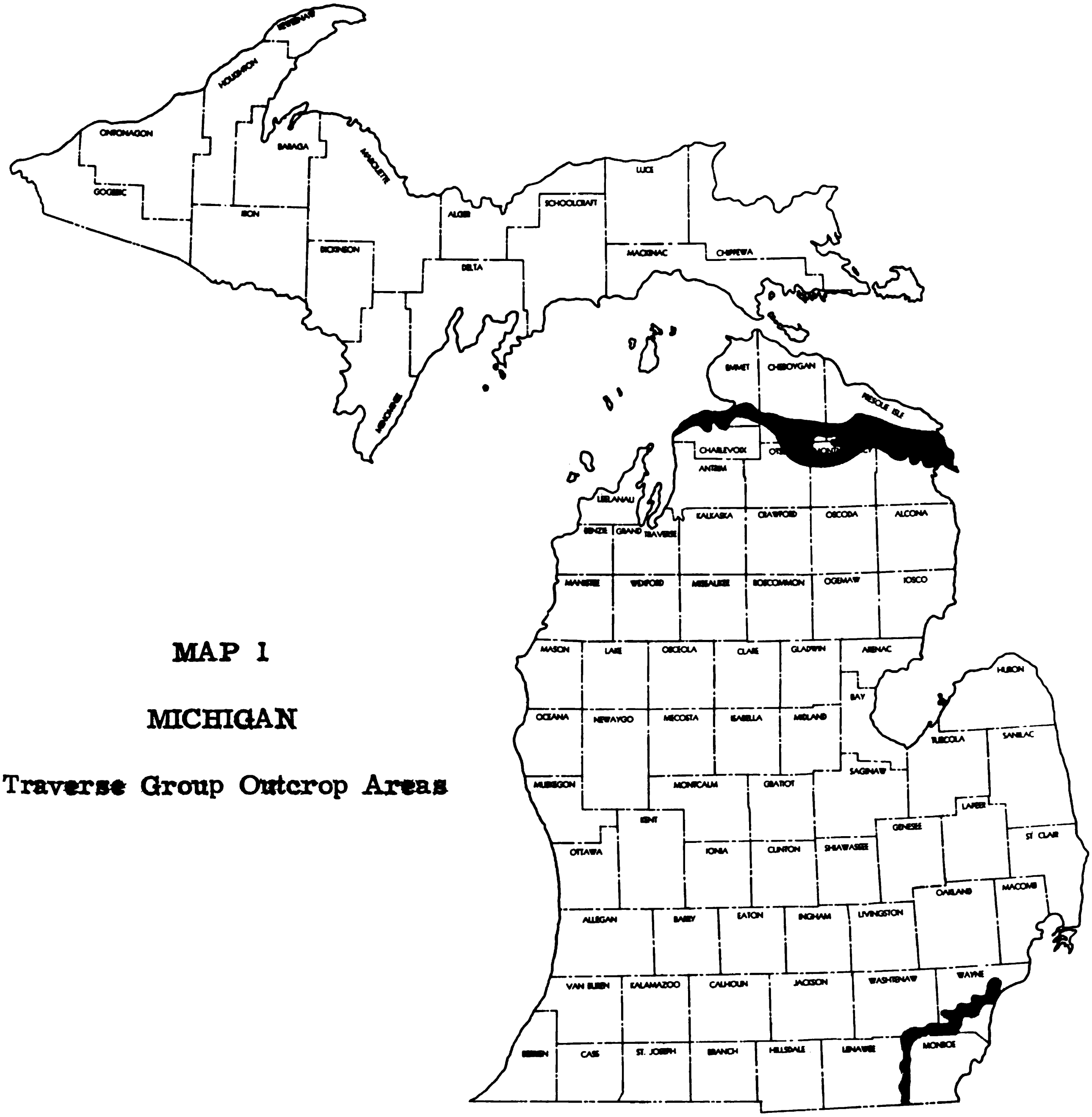
SAMPLE SELECTION AND DISTRIBUTION

Stratigraphy and Lithology of the Middle Devonian Traverse Group

The Traverse group is present over a large part of the Michigan basin. It crops out (see Map 1) at the surface in the northernmost counties of the southern peninsula of Michigan. The rocks of this age crop out beneath glacial drift along the northern flank of the Kankakee arch in Indiana and along the Findlay arch in northwest Ohio and southeast Michigan.

The Traverse group, which has been correlated with the Hamilton group of New York State on the basis of certain faunal elements, consists of gray to buff limestone, gray shaly limestone, and shale. Many of the limestone beds are cherty, fossiliferous, and contain abundant corals. In western Michigan some anhydrite has been found in the lower part. In the localities where the Traverse group attains maximum thickness the upper part is predominately shale and the lower part is shale and shaly limestone.

By grouping similar lithologic characteristics, the Traverse group has been divided into units as a means of correlation. Many formations can be distinguished over a large area, but because of



MAP 1

MICHIGAN

Traverse Group Outcrop Areas

lateral gradation from east to west, and thinning in the south, certain formations cannot be differentiated throughout the state. The formations making up the Traverse group will be discussed in order of age from the oldest to the youngest.

A generalized column of the Middle Devonian formations in the Michigan basin is shown in Table I. Special emphasis has been placed on the Traverse group.

The Bell shale is the lowest formation of the Traverse group. It rests on the Rogers City limestone. In the absence of the Rogers City limestone the Bell shale overlies the Dundee limestone. The Bell shale extends south from the outcrop area (Map 1), but is absent in the southern and southwestern part of the state. The shale is calcareous, fossiliferous in part, and generally includes a few thin beds of limestone.

The Rockport Quarry limestone, in the north part of the Lower Peninsula of Michigan, is a gray or brownish limestone with some interbedded shale. South from the center of the basin it becomes very argillaceous and shaly. The Rockport Quarry limestone is absent in southeast Michigan, and the Silica formation, which has been correlated with the Ferron Point formation, lies directly upon the mid-Devonian Dundee limestone.

TABLE I

GENERALIZED MIDDLE DEVONIAN COLUMN IN MICHIGAN
(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] Gorbut[2] Kohler[2]	Alpena[3]
			Newton Creek[3]
			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 I (Continued)

Thickness (feet)	Lithology
8	Brown fossiliferous limestone overlain with dolomite
13-40	Limestone interbedded with shale
70	Shale alternating with sublithographic limestone
45	Shale thinly interbedded with limestone
20	Biohermal limestone with thin shale members
79	Pure to argillaceous limestone
25	Dark limestone
116	Dark limestone
37	Calcareous shale and thin shaly limestone
40	Dark limestone with some interbedded shale
80	Calcareous and fossiliferous shale with thin beds of limestone

The Ferron Point formation in the northern and eastern part of the basin is a calcareous shale and thin, shaly limestone. It grades to the west into an argillaceous, brown limestone and, in some places, to a pure limestone.

The Genshaw formation exposures are gray and brown limestones and shale. In eastern Michigan the limestone becomes more shaly, and in the western part of the state the formation is almost a pure limestone, but with some interbedded argillaceous members. There is a dark to black limestone included in the Genshaw formation called the Killians member.

The Newton Creek limestone is dark brown and can be differentiated, in the outcrop area, from the light gray or brownish gray Alpena limestone which overlies it. In well cuttings the contact between the Newton Creek limestone and the Alpena limestone is very difficult to distinguish.

The Alpena limestone formation is light gray and brownish gray where it crops out at the northern rim of the Michigan basin. It grades from a pure to a very argillaceous limestone. There are many bioherms throughout this formation; in some places chert is also found.

The Four Mile Dam formation is a brownish gray biohermal limestone containing several shale members. It becomes very cherty as it is traced south from the northern outcrop area. In the southern part of Michigan it cannot be distinguished from the underlying Alpena limestone.

The Norway Point formation is a calcareous, gray shale with thin interbeds of limestone in the northern and eastern part of the basin. In western Michigan it becomes an argillaceous limestone.

The Potter Farm formation in the outcrop area is a blue to gray shale alternating with sublithographic or argillaceous limestone. This formation has a limited lateral extent.

The Thunder Bay limestone is a light gray limestone interbedded with shale at its outcrop area on the southern cape of Thunder Bay. In the eastern part of the state this formation is for the greater part a shale; in the southeastern part of Michigan it is a cherty argillaceous limestone. It grades to a pure limestone to the west.

The Squaw Bay limestone crops out in Alpena County. The outcrops are brown, fossiliferous limestone overlain by a brown to brownish gray dolomite containing many solution cavities. In the center of the basin it is mainly a brown crystalline limestone, dolomitic limestone, or dolomite. The Squaw Bay limestone is overlain by the Antrim shale. The Antrim shale is black carbonaceous shale with several thin, gray shale members in the lower part. In

northern and northwestern Michigan the Squaw Bay is overlain by gray shale and argillaceous limestone of the Antrim shale. In the southwestern and southeastern part of the Lower Peninsula where the Squaw Bay limestone is absent the gray and brown argillaceous limestone found at the base of the Antrim shale overlies the Thunder Bay limestone.

Cohee (1947), in a diagrammatic cross-section extending east-west across southern Michigan, indicated a wedge of gray shale and gray and brown limestone underlain by black shale in the basal part of the Antrim in the area of Ingham County. At the western end of this cross-section in Allegan County this lower black shale is absent.

Selection of the Top and Bottom of the Traverse Group

The contact between the Bell shale and the Rogers City limestone was selected as a marker for the lower limit of the Traverse group. In the absence of the Rogers City limestone the contact between the Dundee limestone and the Bell shale was used for the lower marker. In the southeastern part of the state, where the Bell shale and the Rockport Quarry limestone are absent, the contact between the Silica formation, which has been correlated with the Ferron Point formation, and the top of the Dundee limestone was selected as the base of the Traverse group. The contact between the Rogers City limestone or the Dundee limestone and the overlying basal member of the Traverse group, was for the most part well defined.

The contact of the top of the Squaw Bay limestone and the base of the Antrim shale was used as the marker in selecting the upper limit of the Traverse group in the northern and central basin areas. Where the Squaw Bay limestone was absent in southwestern Michigan the contact between the Thunder Bay limestone and the Antrim shale was used for the marker horizon. With very few exceptions the contact between the uppermost formation of the Traverse group and the base of the Antrim shale was very distinct. In the south-central part of the basin three wells showed what might be considered as a transititional zone between these two formations.

Requirements for Selecting Wells

Cable-tool and rotary-tool methods are used in drilling for oil and gas in the Lower Peninsula of Michigan. Krumbein and Sloww (1951) compared the samples taken during drilling by each method.

They stated that because ''cable-tool wells require the casing and cementing of caving formations and artesian aquifiers the samples taken from this type of well are relatively pure, with

only a minor amount of material knocked off the bore by the passage of tools and bailer."

This is not the case, however, in wells drilled by rotary-tool methods. Krumbein and Sloss (1951) state, "In rotary-tool drilling the rotation of the drill pipe and each removal and introduction of the tools cause a certain amount of caving from the side of the bore. Therefore, rotary samples taken from a given drilling interval contain not only cuttings from the strata represented, but also fragments from any horizon drilled below the lowest casing point."

The proper spacing of control points used for the construction of the lithofacies maps was important. If the wells were widely dispersed the results would be vague and meaningless. On the other hand, if control points were very closely spaced the complexities introduced by local anomalies would obscure the regional interpretation.

Another requirement was that only wells representing a complete stratigraphic section of the Traverse group should be used.

Selection of Wells

Whenever possible samples were taken from wells drilled by cable-tool methods. The author attempted to select wells properly spaced to give the most accurate results. Each well chosen passed through at least a part of the Antrim shale and penetrated the Rogers City or Dundee limestone. In this manner the sampling of a complete section of the Traverse group was assured.

Table II lists the wells used in this investigation. It includes the location, the operator, the permit number, and the thickness of the sampled section.

Map 2 shows the locations of the wells listed in Table II.

TABLE II

WELL DESCRIPTIONS

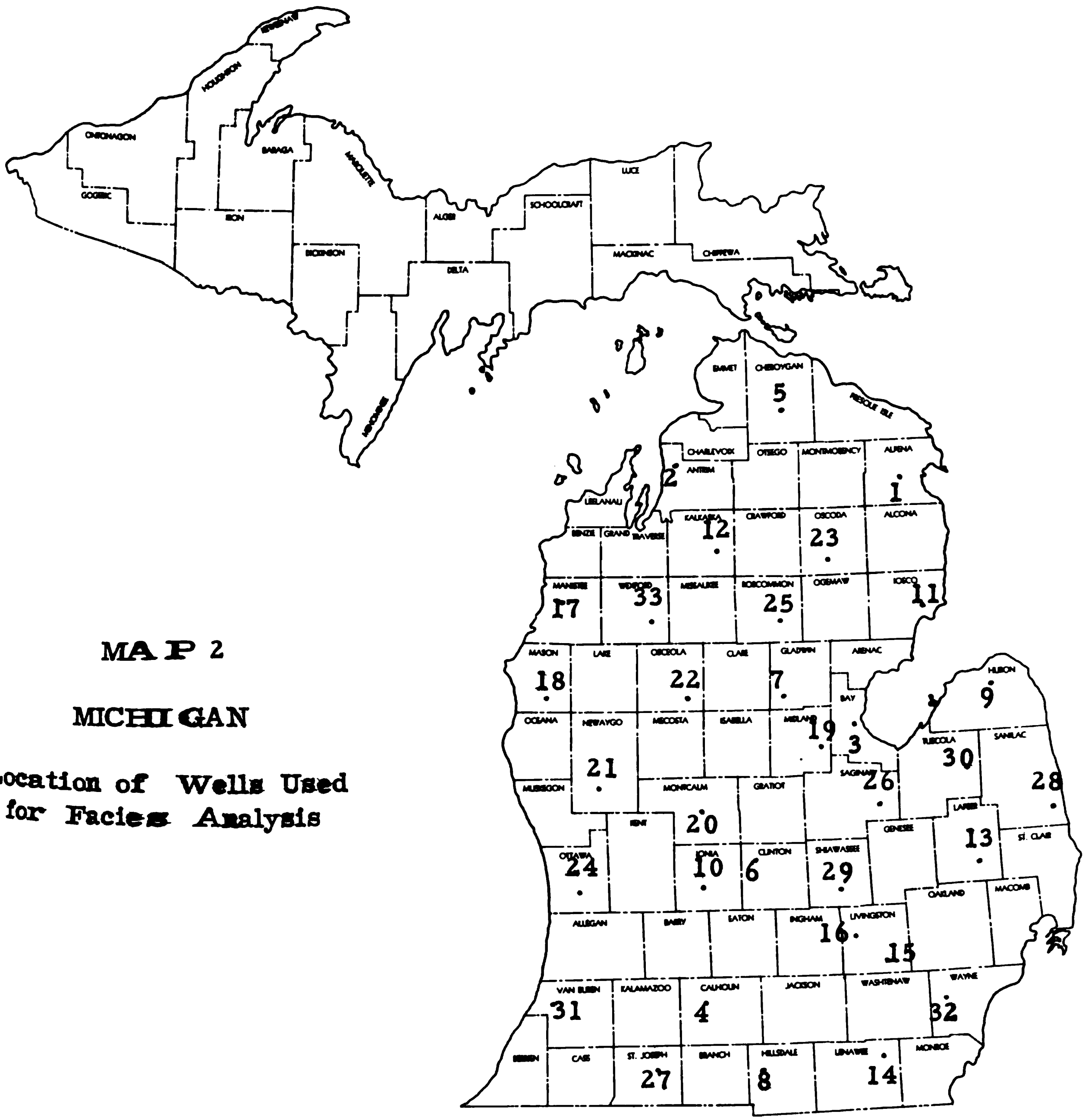
Well No.	County and Township	Operator and Permit Number	Sec.	Twp.	Rg.	Thickness of Section (feet)
1	Alpena Wilson	Notman and Aubin No. 576	25	30N	6E	772
2	Antrim Central Lake	Naph-Sol Refining No. 17180	14	31N	8W	785
3	Bay Kawkawlin	Gulf Refining Co. No. 10551	34	15N	4E	700
4	Calhoun Pennfield	Verona Crude Oil and Gas Co. No. 4768	29	1S	7W	265
5	Cheboygan Ellis	Scott Drilling, Inc. No. 19422	7	34N	2W	660
6	Clinton Lebanon	Parson Brothers Co. No. 19272	27	8N	4W	410
7	Gladwin Beaverton	Gordon Drilling Co. No. 19585	2	17N	2W	730
8	Hillsdale Lithfield	D. B. Lesh Drilling Co. No. 18594	7	5S	4W	220
9	Huron Hume	Collins and Cline Drilling Co. No. 18019	12	18N	12E	708
10	Ionia Berlin	Terry-Dale-Michigan Co. No. 3154	12	6N	7W	349

TABLE II (Continued)

Well No.	County and Township	Operator and Permit Number	Sec.	Twp.	Rg.	Thick-ness of Section (feet)
11	Iosco Baldwin	Bay W. Matlock No. 12163	1	22N	8E	723
12	Kalkaska Bear Lake	Mogul Oil Co. No. 15121	17	26N	5W	770
13	Lapeer Attica	Don Shape Drilling Co. No. 17786	14	7N	11E	360
14	Lenawee Clinton	Michigan Oil and Gas Drilling Co. No. 20036	14	5S	4E	175
15	Livingston Genoa	I. C. Chamness No. 11818	25	2N	5E	339
16	Livingston Handy	Panhandle Eastern Pipe Line Co. No. 10990	11	3N	3E	319
17	Manistee Pleasanton	Carter Oil Co. No. 17709	35	24N	15W	730
18	Mason Eden	Superior Oil Co. No. 18905	25	17N	16W	550
19	Midland Midland	Dow Chemical Co. Fee No. 8	21	14N	2E	650
20	Montcalm Douglas	Gordon Drilling Co. No. 20075	3	11N	7W	450
21	Newaygo Garfield	Sun Oil Co. No. 13816	11	12N	13W	480

TABLE II (Continued)

Well No.	County and Township	Operator and Permit Number	Sec.	Twp.	Rg.	Thickness of Section (feet)
22	Osceola Orient	Sohio Petroleum Co. No. 15489	11	17N	7W	627
23	Oscoda Big Creek	E. V. Hilliard No. 17517	26	25N	2E	756
24	Ottawa Olive	Muskegon Oil Corp. No. 3678	35	6N	15W	390
25	Roscommon Backus	Sun Oil Co. No. 18973	28	22N	2W	765
26	Saginaw Taymouth	Dow Chemical Co. B.D. No. 98	14	10N	5E	540
27	St. Joseph Nottawa	Ford Oil Co. and Basin Oil Co. No. 19599	7	6S	10W	196
28	Sanilac Lexington	Wm. M. Joy and O. J. Tomczyk No. 18305	35	10N	16E	411
29	Shiawassee Perry	Panhandle Eastern Pipeline Co. No. 16738	23	5N	2E	350
30	Tuscola Novesta	Shell Oil Co., Inc. No. 10968	16	13N	11E	627
31	Van Buren Bangor	Whitehill and Drury Drilling Co. No. 5229	35	2S	16W	203
32	Wayne Canton	Max Spidel No. 19634	6	2S	8E	328
33	Wexford Selma	Turner Drilling Co. No. 10245	30	22N	10N	693



MAP 2

MICHIGAN

Location of Wells Used for Facies Analysis

LABORATORY PROCEDURE

Sampling Method

The samples used for each of the thirty-three wells were obtained from the Michigan Geological Survey, Lansing, Michigan.

The section representing the Traverse group was selected from each set of well samples. The vertical sections analyzed ranged from 175 feet to 785 feet in thickness. This vertical section of each well was represented by three to six trays, each containing twenty-five vials. Each vial contained a sample of the cuttings taken from a drilling interval of usually 5 to 10 feet.

Wentworth (1926) states it is hardly advisable to collect less than about 125 grams of any sedimentary sample for mechanical analysis regardless of its grain size. To adhere to this minimum sample of 125 grams an arbitrary weight of sample to be taken from each vial was determined. The arbitrary weight of sample per vertical foot of section was not constant from well to well, but in every case it was constant throughout each individual well.

It was the intention of the author, wherever possible, to take a more generous sample than the minimum suggested. However, in some of the wells due to the restricted vertical range or to the small amount of cuttings in the vials, a total sample of somewhat less than 125 grams was analyzed.

The composite sample taken from each well was contaminated with small fragments of iron from the well casing and the drill bit. Before a final weighing could be made it was necessary to remove these particles of iron with the aid of a powerful electromagnet. The sample was then placed in a 400-milliliter breaker of known weight.

Removal of Water-Soluble Salts

Wiegner (1927) states that an appreciable amount of soluble salts in a solution may seriously hinder dispersion of the small particles and will increase the rate of coagulation. The author is not mainly concerned with dispersion, but is interested in the procedure used by Wiegner (1927) to remove these soluble salts so that the determined data might be used later to compute evaporite ratios for each well.

The procedure followed was to boil the sample for one hour in 200 milliliters of tap water. This caused the ionic particles to go into solution so they could be removed by siphoning.

Ten milliliters of clear solution were siphoned off after the solution had settled. The salinity of the solution was checked by adding several small crystals of silver nitrate. The resulting precipitate was compared with that formed in a similar amount of tap water treated in the same way. If the precipitate formed in the solution was greater than that formed from tap water, the sample was decanted and boiled again in clear water.

With few exceptions two treatments were sufficient to remove the water-soluble salts. The sample was washed several times by adding water, stirring, allowing the mixture to settle, then siphoning off the clear solution. The remaining sample was dried and weighed. The amount of water solubles removed was determined by subtracting the weight of the treated sample from that of the original sample.

Removal of Acid Solubles

The remaining nonclastic material was removed from the sample by a series of treatments with hydrochloric acid.

The first treatment was to add slowly a 25 percent solution of hydrochloric acid to the sample until effervescence had ceased. The sample was allowed to settle and the supernatant liquid was siphoned off. The second and third treatments were the same as the first, but using 50 to 100 percent hydrochloric acids respectively.

Before the final acid was decanted the sample was heated in a sand bath for 30 minutes to insure that the reaction was complete and all carbonates had been removed.

The sample was then washed by allowing it to settle, drawing off the clear solution, adding tap water, stirring, and again allowing the material to settle. This process was repeated until the wash water did not affect blue litmus paper. The residue was dried and weighed.

The weight of the acid solubles was calculated by subtracting this weight from the weight of the sample after the removal of the water-soluble salts.

Disaggregation

The remaining clastic material had been, for the most part, broken up by the previous treatments. However, small bits of shale were observed in many of the samples. It was determined that disaggregation was necessary to facilitate easy sieving.

Disaggregation is defined by Krumbein and Pettijohn (1938) as "the breaking-down of aggregates into smaller clusters or into individual grains." They suggested many ways to accomplish this, but only the method used by the author will be discussed here.

Each sample was boiled slowly for two hours in 125 milliliters of solution prepared by adding one gram of potassium hydroxide (KOH) to one milliliter of water. At the end of this time the sample was allowed to cool and solidify. The remainder of the disaggregation procedure will be discussed under the heading "Sieving."

Sieving

The clastic and sand-shale ratios used in this investigation required that the weight of the shale in each sample be determined. To accomplish this it was necessary to separate the sand from the silt and clay particles which were the original components of the shale.

Wentworth (1922) states that very fine sand will be retained on a sieve having an opening of 1/16 millimeters and that silt and clay particles will pass through. Krumbein and Pettijohn (1938) show that the 230 mesh Tyler sieve corresponds with the Wentworth grade scale of 1/16 millimeters.

The disaggregated sample, solidified in the potassium hydroxide (KOH) solution, was washed with a gentle stream of warm tap water. The neutralized overflow from the beaker was passed through a 230 mesh Tyler sieve. The sand particles were retained on the sieve; the silt and clay-size particles were discarded. Any small bits of shale which failed to disaggregate were so softened that they were easily broken up by gently rubbing them between the fingers.

After drying and weighing, this fine sand was saved for microscopic analysis.

The weight of the silt and clay fraction was determined by subtracting the weight of the sand fraction from the weight of the sample before disaggregation.

Mounting and Analyzing the Sand Grains

The sand saved from the acid and water treatments was screened with the aid of 60 and 100 mesh Tyler sieves. This break-down facilitated easy mounting on microscopic slides of that portion retained on the 100 mesh sieve.

The mounted material was considered as representative of the entire sand fraction of each well. The percentage of quartz and chert was determined by a grain count.

Accuracy of the Data

The samples were contaminated by cavings from the shale lying above the Traverse group. These particles were removed whenever possible before beginning work. The transfer of the sample from one container to another was avoided at every opportunity, thus keeping sample loss at a minimum. Each sample was treated and handled in exactly the same manner so any errors in procedure or technique would be constant throughout the investigation and thus be minimized. One well sample was discarded during analysis owing to spillage and the subsequent loss of material.

Results of the Laboratory Analyses

Table III represents the data obtained by the quantitative analyses of samples from thirty-three wells. These data were used to compute the ratios shown in Table IV. The quartz-chert ratio was determined by grain count.

TABLE III

SUMMARY OF QUANTITATIVE ANALYSIS

Well No.	Sample Weight	Water Solubles	Acid Solubles	Sand Fraction	Silt and Clay Fraction
1	102.800	0.109	67.027	0.206	35.458
2	156.203	0.504	128.784	0.911	26.004
3	136.771	0.734	62.747	5.205	68.085
4	28.666	0.275	22.730	0.160	2.501
5	127.069	1.050	100.750	0.712	24.557
6	82.911	0.291	20.925	3.014	58.681
7	74.636	0.476	36.038	0.573	37.549
8	89.607	0.482	57.276	1.855	29.994
9	122.647	0.482	54.703	0.083	67.379
10	107.973	0.826	86.995	0.985	19.167
11	139.723	1.456	68.220	1.935	68.112
12	133.692	1.480	97.273	0.412	34.527
13	143.858	0.669	43.109	2.147	97.933
14	66.020	0.113	40.273	0.466	25.168
15	98.115	0.439	65.656	0.947	31.073
16	102.816	0.635	72.447	0.393	29.341
17	151.285	1.330	121.921	0.755	27.279
18	121.586	0.826	98.585	0.404	21.771
19	125.187	0.735	64.561	Lost	Lost
20	88.701	0.402	35.229	3.980	49.090
21	95.534	0.368	70.827	0.850	23.489
22	128.898	1.050	97.103	0.454	30.291
23	152.526	1.630	95.443	0.575	54.878
24	74.162	0.012	62.973	0.135	11.042
25	148.593	0.455	37.033	0.484	111.621
26	108.591	0.629	47.748	2.632	57.582
27	123.698	0.693	89.041	3.540	30.424
28	108.362	0.194	64.504	0.146	43.518
29	141.767	1.101	88.090	0.551	52.025
30	123.496	0.586	63.735	9.499	49.676
31	20.066	0.055	17.620	0.112	2.279
32	57.597	0.094	39.079	0.138	18.268
33	140.479	1.780	112.151	0.272	26.276

LITHOLOGIC INTERPRETATION

Methods of Analysis

Because facies changes are lateral variations in a rock unit, the most effective way of portraying them is by maps.

Krumbein (1952) states that facies maps have been made for fifty years, but their modern development awaited the introduction of numerical data into stratigraphy and sedimentation. It is too general to say a stratigraphic section consists of several hundred feet of sand and shale. An exact and detailed description is needed for a stratigraphic unit to permit the development of facies maps.

The expression of subsurface data as a numerical value has been accomplished by using the principles set forth by Krumbein and Sloss (1951), and Krumbein (1952). These papers state, "An adequate expression is achieved by a quantitative approach in which each lithologic component is given a value according to the thickness of stratigraphic section in which is is represented. Then the relationship between any two lithotypes in a stratigraphic interval at a given point may be expressed as a ratio."

The most fundamental lithologic ratio is the clastic and nonclastic ratio. It is expressed by the formula:

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

An equal amount of clastic and nonclastic sediments would be indicated by a ratio of one. A ratio of greater than one would indicate the predominance of clastics over the nonclastics; the predominance of nonclastics over clastics would be a ratio of less than one.

A sand-shale ratio is another way of expressing the variation in the coarse and fine clastic material. The sand-shale ratio was computed by using the formula:

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

A section consisting of an equal amount of sandstone and shale would have a ratio of one. An increasing amount of sand would cause the sand-shale ratio to rise towards infinity; with an increasing amount of shale the ratio approaches zero.

An evaporite ratio was the third ratio used by the author. It showed the variation within the nonclastic material, and was computed by the use of the following formula:

$$\text{Evaporite Ratio} = \frac{\text{Evaporites}}{\text{Limestones + Dolomites}}$$

The significance of the evaporite ratio is open to doubt. It is very probable that portions of the water-soluble salts were removed from the samples by the drilling muds and also by washing of the samples before they were placed in their vials.

The quartz-chert ratios were an attempt to express variation in the primary and secondary silica fraction. The formula used was:

$$\text{Quartz-Chert} = \frac{\text{Percent Quartz}}{\text{Percent Chert}}$$

The procedure used for this computation is discussed under the heading "Mounting and Analyzing the Sand Grains."

Table IV lists the lithologic ratios for each well. These ratios were obtained from the data given in Table III.

Facies Map Construction

Facies maps were constructed by plotting the appropriate ratio at its proper location on a base map. Points with equal ratios were joined by a continuous line. The spacing between lithofacies lines was selected using an arithmetic interval.

Krumbein (1952) states ratio maps are usually drawn on an isopach map to give a simultaneous picture of total thickness and lithologic character of the stratigraphic unit being analyzed.

In order that the maps would not become overly congested, the isopach map and the ratio maps were drawn separately on

TABLE IV

LITHOLOGIC RATIOS

Well Number	Clastic Ratio	Sand-Shale Ratio	Evaporite Ratio	Quartz-Chert Ratio
1	0.53	0.006	0.0165	3.56
2	0.21	0.035	0.0039	9.73
3	1.16	0.077	0.0117	2.12
4	0.15	0.064	0.0121	0.25
5	0.25	0.029	0.0102	11.84
6	2.91	0.051	0.0139	0.92
7	1.05	0.015	0.0132	0.42
8	0.55	0.062	0.0084	8.23
9	1.22	0.001	0.0088	0.16
10	0.23	0.051	0.0095	0.62
11	1.07	0.028	0.0213	0.02
12	0.35	0.012	0.0152	7.90
13	2.28	0.022	0.0155	0.04
14	0.64	0.019	0.0028	8.97
15	0.48	0.030	0.0065	2.96
16	0.41	0.013	0.0088	1.54
17	0.23	0.028	0.0109	0.16
18	0.22	0.019	0.0084	1.17
19	Lost	Lost	0.0114	Lost
20	1.49	0.081	0.0114	0.43
21	0.34	0.036	0.0052	5.51
22	0.31	0.015	0.0108	0.52
23	0.57	0.010	0.0171	3.05
24	0.18	0.001	0.0019	0.25
25	2.90	0.004	0.0123	0.34
26	1.25	0.046	0.0132	0.60
27	0.38	0.116	0.0078	0.50
28	0.67	0.003	0.0030	8.05
29	0.59	0.011	0.0125	5.31
30	0.92	0.191	0.0092	4.45
31	0.14	0.049	0.0031	3.88
32	0.47	0.008	0.0024	10.82
33	0.23	0.010	0.0159	5.45

semitransparent paper. These maps may now be superimposed over one another in any manner desired.

Maps 4, 5, 6, 7, and 8 are the sand-shale ratio, clastic ratio, quartz-chert ratio, isopach, and the evaporite ratio maps, respectively.

Methods of Geological Interpretation

Owing to the recent increase of interest in facies maps a need for systematic principles of interpretation has arisen.

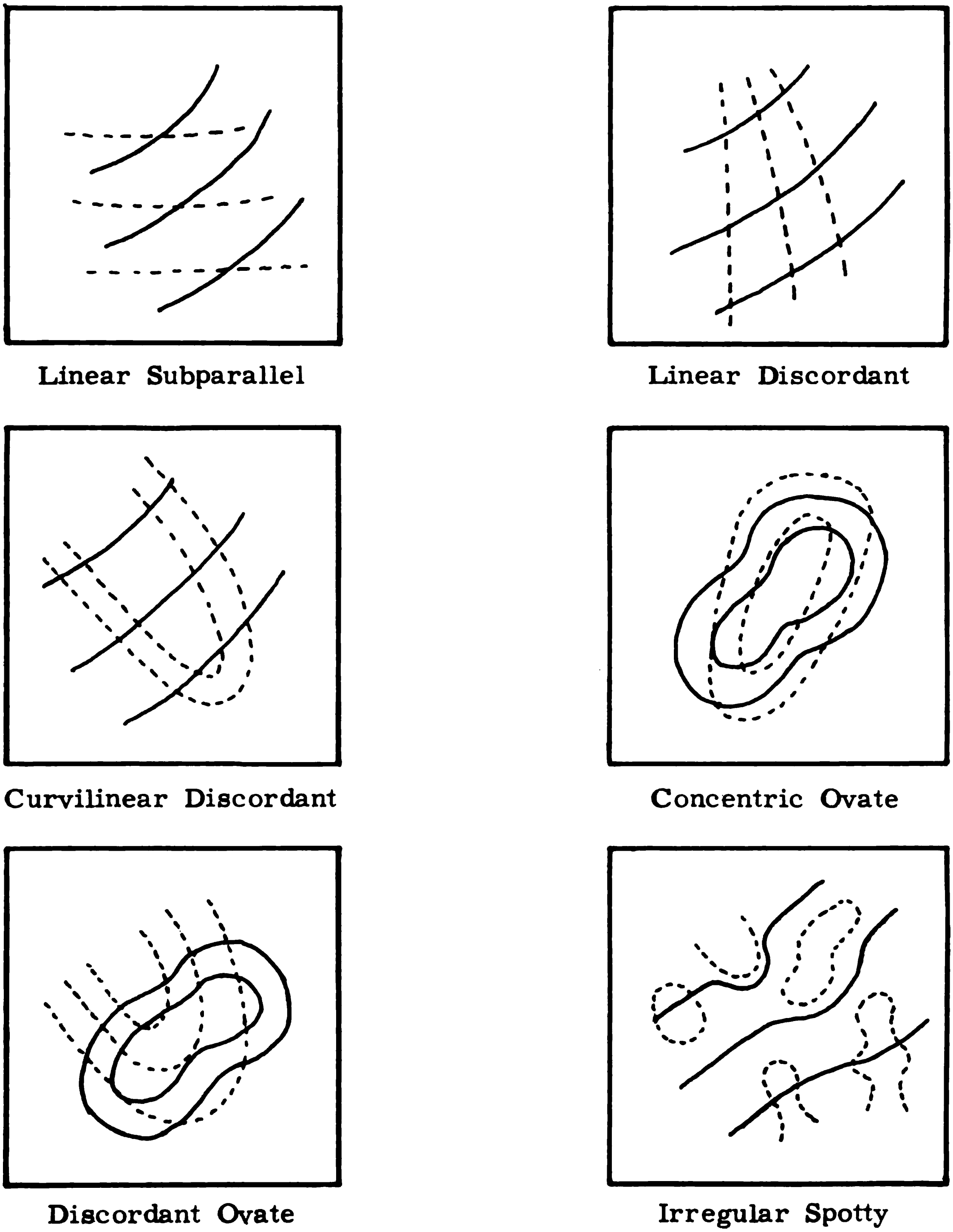
Krumbein (1952) brought forth such a set of principles. His method of interpretation is based upon the relation between isopach and lithofacies lines. He discussed six existing relations. These are illustrated in Figure I. The distinction between the linear and ovate patterns is partly one of map scale.

According to Krumbein (1952), the linear subparallel pattern may occur under conditions where clastic sediments are spread over a subsiding area; the curvilinear discordant pattern may arise when a local concentration of clastics is poured into a subsiding area, as in a delta; the concentric ovate pattern is characteristic of evaporites in an intracratonic basin; and the irregular spotty pattern occurs near the edges of sheet sands.

Krumbein (1952) states that three of the patterns are associated with intracratonic basin conditions such as found in the Michigan

FIGURE I

Relationships between Isopachs (Solid) and
Facies Lines (after Krumbein, 1952)



basin. The curvilinear discordant pattern would be indicative of a nearby orogenic or a nearby epeirogenic source. The concentric ovate pattern would show a distant orogenic, a nearby orogenic, or a nearby epeirogenic source of sedimentary material. The discordant ovate pattern results from either a nearby orogenic or a nearby epeirogenic source.

Utilizing the methods set forth by Krumbein (1952), the author will present an interpretation of the facies maps.

Errors Involved in Interpretation

In using composite samples of such a thick stratigraphic unit as the Traverse, there is a possibility of minor irregularities being hidden; however, the broad intrabasinal features should not be concealed.

Postdepositional erosion may greatly disturb the relation between facies and isopach maps. It was for this reason the author was cautious to analyze only those samples which were taken from a complete section.

Geographical Interpretation

The facies maps were interpreted separately by placing each over the isopach map. The patterns (Figure I), used as a basis for this interpretation, are located by counties. To aid the reader in following the discussion, a map of counties (Map 3) is included in the pocket.

The clastic ratio map. A deltaic pattern of high clastic ratios is shown on this map. This trilobate depositional pattern originates in the region of the present-day Saginaw Bay. The distinct lobes are located in the eastern Thumb area, the northcentral and the southcentral area of the southern peninsula.

The facies lines of the northern lobe, when related to the contour lines of the isopach map, show a curvilinear discordant pattern. This pattern, located in Crawford, Roscommon, Ogemaw, Gladwin, Arenac, and Bay counties, is indicative of a nearby orogenic source area.

The projection of the deltaic pattern into the southcentral portion of the state also shows a curvilinear discordant pattern. This suggests that Midland, Isabella, Montcalm, Gratiot, Saginaw, Ionia, Clinton, and Shiawassee counties are located near an orogenic source area.

The curvilinear discordant pattern of the southeastern lobe is seen in Tuscola, Sanilac, Genesee, Lapeer, St. Clair, Oakland, and Macomb counties. A nearby orogenic source area is again indicated.

Krumbein (1952) states that "the curvilinear discordant pattern may arise when a local concentration of clastic is poured into a subsiding area, as in a delta."

The lobate pattern broadens to the north, northwest, west, south, and southeast. In the areas about the periphery the pattern observed ranges between a linear discordant and a broad curvilinear discordant pattern. This pattern could result from the spread of clastic sediments over a subsiding basin in decreasing amounts away from the source area. The numerical value of the clastic ratio lines would tend to decrease because of an increasing amount of lime deposited.

The following is a summary of the major structural trends determined from the clastic ratio map:

1. The trilobate deltaic pattern in the central and east part of the basin indicated a nearby source of sedimentary material located northeast of the basin.

2. The depositional pattern shown in the counties located about the northern, southern, and western margins of the state indicates a depositional environment far from the source area to the east.

<u>The sand-shale ratio map.</u> At no place do the many sand-shale ratios used to construct this sand-shale map exceed 0.190. This indicates a predominance of fine clastic material.

A sharp, elongate, ridgelike structure extended east to west across the central portion of the state. The lithofacies lines have been closed about its east end. This may or may not be the case but was assumed, owing to a lack of control to the east.

At the west end of this ridge, in Montcalm, southern Newaygo, southern Mecosta, northern Kent, and northern Ionia counties, a curvilinear discordant pattern was shown. The facies lines opened to the east and closed to the west. This pattern indicated a nearby orogenic source of clastic material to the east.

The highest sand-shale ratio determined was in Tuscola County. The curvilinear discordant pattern was shown in Tuscola, southwestern Bay, eastern Saginaw, southern Huron, and northern Lapeer counties. The lithofacies lines in this area opened to the east and extended into an area where control was lacking. This suggests a local concentration of clastics derived from a nearby orogenic source located east of the basin.

Another area of moderately high ratios was shown in the southwestern part of Michigan. This high was located in Berrien, Cass, St. Joseph, Branch, Calhoun, southwestern Kalamazoo, and western Hillsdale counties. The direction of the facies lines and the curvilinear discordant pattern indicated a nearby source area to the southwest.

The remaining area of significance was located in the northwestern part of the state. A broad discordant ovate pattern was spread in a wide band, from northeast to southwest through southern Cheboygan, southeastern Antrim, and northwestern Grand Traverse counties. This suggested either a nearby orogenic or epeirogenic source of material. The indications for this were very weak, but the lithofacies lines showed that the sediments came from the northwest.

The dominant structures shown on the sand-shale ratio map are summarized as follows:

1. A ridgelike structure with its axis extending east from Montcalm County through Sanilac County indicated a source area a short distance to the east.

2. A nearby orogenic source was determined southwest of the basin.

3. A possible source area of sedimentary material was located to the northwest of the basin.

The quartz-chert ratio map. The construction of this ratio map was an attempt by the author to differentiate the areas of offshore and nearshore depositional environments by comparing the amount of primary quartz to secondary chert found in the Traverse group of the Michigan basin.

Tarr (1926) states that in restricted shallow seas, the relative amount of chert would be greater in the calm offshore areas than in the areas of disturbance associated with the nearshore environments.

The silica fraction made up a very small amount of the total clastic material found in the Traverse group, but the quartz-chert comparison of this fraction further substantiated areas of low relief associated with the margin of the basin during mid-Devonian time.

An area of high quartz-chert ratios is located in the southeastern part of the state, in Hillsdale, Lenawee, Washtenaw, Wayne, Oakland, Macomb, and St. Clair counties. To the northwest this area of high quartz-chert ratios grades into an area of predominant chert, which extends northeast-southwest across the Lower Peninsula from Iosco County to St. Joseph County. The facies lines outlining the predominant quartz area show a curvilinear discordant pattern opening to the southeast. This indicated a nearby source area in that direction.

Another area with a relatively large amount of quartz extends into the upper part of the basin from the north. This area is located in Kalkaska, Crawford, Antrim, Otsego, northeast Grand Traverse, northern Missaukee, southern Charlevoix, Cheboygan, and Presque Isle counties.

Increasing amounts of chert are indicated to the south by the series of decreasing ratios surrounding this area. This region of dominant chert is located along a line from Iosco, through Mecosta, and extended to Mason counties. The source area responsible for this quartz anomaly is situated to the north of the southern peninsula.

The major structures indicated by the quartz-chert ratio map are as follows:

1. A nearby orogenic source area was indicated to the southeast of the Lower Peninsula.

2. A source of sedimentary material was located to the north.

3. A distant or a low-lying source area was shown west of the basin.

4. The sediments of the central and eastern part of the basin revealed an offshore environment favorable for the deposition of chert.

<u>The evaporite ratio map.</u> The evaporite ratios were, without exception, very small. It was previously stated that owing to drilling methods and washing of the samples before they were stored, some of the water-soluble salts would be removed from the samples before analysis. These facts make the validity of the evaporite ratio map questionable.

The area of high evaporite ratios was shown by a wide belt entering the southern peninsula from the northeast. In the area of Gladwin County this pattern divided into two arms. One broad arm extended south to the northern boundaries of Eaton, Ingham, Livingston, and Oakland counties, and the other, more narrow arm, terminated to the west in Mason and Manistee counties.

In the southern, southeastern, and southwestern part of the state bounding this high evaporite area, the lithofacies lines, when related to the isopach lines, showed a curvilinear discordant pattern. This pattern suggested that this portion of the state was closely associated with an orogenic source area.

The northwest boundary of the high evaporite area extended through Benzie, Grand Traverse, Antrim, Otsego, Cheboygan, and Presque Isle counties. The very broad discordant ovate pattern indicated a nearby orogenic or epeirogenic source area of low relief to the northwest.

The following is a summary of the prominent structures indicated by the evaporite lithofacies map:

1. In the central and northeast part of the state there was an environment favorable for the deposition of water-soluble salts.

2. A source of sediments bounds the basin to the southwest, south, and southeast.

3. A lowlying source area was indicated northwest of the southern peninsula.

REGIONAL TECTONICS

Structural Relations of the Michigan Basin

The major structures which defined the limits of the Michigan basin were formed long before Middle Devonian time.

The Precambrian Laurentian Shield confined the basin to the north. The structure limiting the western extent of the basin was the Wisconsin dome. The formation of this dome is attributed to an uplift which took place in early Ordovician time (Eardley, 1951).

Another important structure isolating the basin was the Cincinnati dome, which extends in a general southern direction from Ontario, Canada, to northern Alabama (Pirtle, 1932). The Cincinnati dome, thought to have been formed in Ordovician time, divides into two branches in the north--the Kankakee arch extending to the west-northwest, and the other, the Findlay arch, to the north-northeast. These arches were the structures which defined the southwest, south, and southeast limit of the basin.

The Kankakee arch which connected the Wisconsin and Cincinnati structures was perhaps more closely related to the Wisconsin dome. It was possibly a southeast extension of the structure located to the west of the basin.

The Findlay arch, the right arm of the Cincinnati dome, which extended to the northeast, connected with the Canadian Shield (Eardley, 1951). In the vicinity of Lake St. Clair this arch was broken by a low saddle called the Chatham sag. This gap between the Michigan basin and the Appalachian geosyncline may have been important in the faunal history of these two regions.

The author will now attempt a correlation of the lithofacies maps with the regional structure during mid-Devonian time.

Structural Interpretations in Relation to Tectonics

The various structures indicated by this investigation differ to a certain extent from map to map. Less variation was expected between the clastic and sand-shale ratio maps than between the evaporite and the quartz-chert ratio maps. The clastic and sand-shale ratio maps located the source areas of the detrital material entering the basin. The quartz-chert ratio map indicated the deep water areas within the basin, while the evaporite ratio map showed the areas of final evaporation of the intrabasinal sea. These last two maps, each in its own way, indicated the same general area within the basin.

The deltaic pattern of the clastic ratio map indicated the entrance of detrital material into the basin from a nearby orogenic source area northeast of the Lower Peninsula. The trilobate outline of this pattern showed there may have been a distribution of the clastic particles by current action.

The decreasing clastic ratios in the areas removed from this central and eastern high indicated a gradation from predominant clastic to predominant nonclastic sediments. The nonclastic high ratio area in the north, west, and southern margin of the state indicated a more stable environmental condition, and thus, a lesser degree of subsidence than in the central and eastern part of the basin which received the major amount of detrital material. The clastic ratio map indicated the structural features surrounding the basin, and bordering the dominant nonclastic area, added a relatively small amount of the clastics to the Traverse group.

The conclusions drawn by the author and based upon the facts determined from the clastic ratio map are as follows:

1. The major portion of the clastic material had its source in the region northeast of the Lower Peninsula.

2. Most of the detrital material entered the basin near the present-day Saginaw Bay and was possibly distributed in a dendritic

pattern by stream action. These sediments diminished outward from the east-central area.

3. The dominant nonclastics of the Traverse group in the north, west, and southern margins of the Michigan basin depicted a more stable condition, with less subsidence, than the central and eastern area with its higher clastic ratios.

4. The Canadian Shield to the north, the Wisconsin dome to the west, and the Kankakee arch to the southwest were relatively stable and lowlying during deposition of the Traverse group.

5. The Findlay arch, to the southeast, stood slightly higher than the other structures surrounding the basin.

The sand-shale ratio map, for the main part, substantiated the conclusions determined from the clastic ratio map. The sand-shale ratios were all low, which showed the detrital material poured into the basin was primarily clay and silt with only a minor amount of sand deposited. The great amount of silt and clay of the Traverse denoted the predetermined lowlying structures bounding the basin.

A narrow ridgelike structure extended across the state from Sanilac to Montcalm counties. The sand-shale ratios, decreasing from east to west, indicated the eastern section of this ridge was nearer the source area than the more distant western end.

Another area of significant ratios was located in the southwest part of the state. The Kankakee arch was thought to be the possible source area for this region.

An area in the northwestern part of the state furnished a small amount of sand to the basin.

The summary of conclusions based on the sand-shale ratios follows:

1. The small fraction of sand in the Traverse group sediments indicated the tectonic features about the basin had little relief during mid-Devonian time.

2. A ridgelike pattern of high sand ratios, along which the ratios decreased across the central portion of the state from east to west, showed a source of clastic material to the east of the basin.

3. The Kankakee arch in the southwest, though of low relief, was a minor source of clastic material during Traverse time.

4. The Laurentian Shield, northwest of the state, was a source area of minor importance for Traverse sediments.

5. The Wisconsin dome and the Findlay arch were extremely low in relief at this time.

The quartz-chert ratio map and the evaporite ratio map, which depict the location of maximum depth in the basin, were not always in agreement. It was the author's belief that the quartz-chert ratio map was the more valid.

The offshore conditions which favored the formation of chert and the precipitation of salts were shown on the two maps as a wide area from Saginaw Bay to Alpena County. This area extended southwest and in the northcentral part of the state divided into two arms. The narrow arm continued into Mason and Manistee counties; the broader arm extended south into the central part of the basin. Both maps showed a shallow, nearshore depositional environment in the southwestern, southern, and eastern part of the state.

This was to be expected when both the isopach map of the Traverse group and the regional tectonics of mid-Devonian time were considered. An interesting observation was that across the northern part of the state, the areas having the thickest sediments also had the greatest amounts of chert and evaporites. An area of low evaporites and high quartz-chert ratios in the northern and northwestern part of the state indicated a nearshore condition and a nearby area of low relief. This fact contradicts the premise that deep waters mean more chert. The writer contributed this departure to possibly a slower rate of subsidence in this portion of the basin.

Tectonic Aspect

During the deposition of the Traverse group in the Michigan basin there were no major crustal disturbances within the region. Deposition began and ended quietly.

The structural features defining the limits of the basin were stable and lowlying. Periods of elevation and depression occured, but these were restricted within the basin.

The bulk of sediments making up the Traverse group entered the basin from the northeast and were derived from a structural feature of relatively low relief.

CONCLUSIONS

Eardley (1951), among others, states the Findlay arch, broken by the Chatham sag, extended northeastward from the Cincinnati dome to the Canadian Shield. The results of this investigation revealed nothing which would prove or disprove the existence of the Chatham sag during Traverse time, but it did disprove Eardley's statement regarding the northern extent of the Findlay arch. The author feels this sedimentary analysis proves that the Findlay arch did not extend northeast far enough to connect the Laurentian highlands with the Cincinnati dome at the time the Traverse sediments were deposited. The northeast part of the Findlay arch was either nonexistent or submerged during Traverse time and thus permitted sedimentary material to enter the basin from the northeast.

Pohl (1930) stated the sediments comprising the Traverse group originated to the north of the basin. The result of this investigation does not support Pohl's conclusions.

The author feels that lithofacies analyses of other formations from the Michigan basin would be extremely valuable in the understanding of the tectonics and depositional environments associated with the sediments within the state of Michigan.

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Map 4
Map 5
Map 6
Map 7
Map 8

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