A MECHANICAL AND STATISTICAL ANALYSIS OF THE MIDDLE DEVONIAN ROGERS CITY - DUNDEE FORMATIONS IN MICHIGAN

By

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A THESIS

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ABSTRACT

Lateral variations of rock character suggest different sedimentary processes during their formation. In attempting to reconstruct the tectonic conditions existing during the deposition of the Rogers City and Dundee formations in the Michigan Basin, composite samples of twenty-five wells penetrating the complete system were analyzed with respect to their lithologic character.

Numerical pictures, in the form of lithofacies maps, were constructed from ratios relating the data. The clastic ratio compares the amount of land-derived sediments to the chemical precipitates and evaporites; the quartz-chert ratio shows the contrast between primary and secondary sediments; and the evaporite ratio relates the quantity of evaporite deposits to the chemically precipitated materials.

Lithofacies maps are relatively new in geologic literature, and their interpretation poses many problems. A study of the patterns formed by superimposing these facies maps on an isopach map of the Rogers City and Dundee formations was used to determine the possible tectonic conditions prevailing during the period of deposition.

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INTRODUCTION

History and Description of the Michigan Basin

Since the turn of this century subsurface exploration has been greatly intensified in Michigan. Prior to this time, these explorations had been a subject of great interest. Earlier subsurface exploration was impractical because parts of the Michigan Basin were overlain by glacial deposits that in places reach a thickness of nearly 1300 feet.

Dice (1955) completed a quantitative sedimentary study of the Devonian deposits in the Michigan Basin. In his investigation Dice covered a period that probably encompassed 40 million years. It is quite feasible that within such a time various geologic events may have occurred which, although insignificant to the Devonian system as a whole, may have been highly significant to a group or a member within the system.

The Devonian system in the Michigan Basin is composed of the following groups: Traverse, Casenovia, Detroit River, Onesquethaw and Deer Park.

The Casenovia group consists of two limestone formations, the Dundee and the Rogers City. The Dundee is the thicker of the two formations. Because the two formations are similar and very difficult to distinguish in the subsurface throughout most of Michigan, they are combined and referred to as the "Dundee" in this study.

The general outcrop pattern of the Paleozoic sediments in the Michigan Basin resemble concentric, elliptical rings with their major axes trending northeast. The younger Pennsylvanian sediments form the center ring and the older Paleozoic sediments in their outcrop pattern form the succeeding outer rings. The Ordovician and Cambrian sediments crop out irregularily in the upper peninsula of Michigan.

Newcombe (1933) described the areal extent of the Michigan Basin as an area comprising about 106,700 square miles. It extends north from Ft. Wayne, Indiana to Whitefish Point, near Sault Ste. Marie, Michigan. It extends east and west about 370 miles. The center of the sedimentary basin conforms approximately with the geographic center of the lower peninsula of Michigan.

According to Pirtle (1932) the Michigan Basin is bounded on the west by the Wisconsin Arch and on the north by pre-Cambrian rocks. Two diverging limbs from the Cincinnati Dome, the Kankakee and Findlay Arches, form the southwest and southeast boundaries, respectively. A continuation of the Findlay Arch, the so-called Algonquin Arch in Ontario, forms the eastern boundary.

Facies Analysis

Geologists refer to individual variations in the lithologic and biologic character of a sedimentary rock as "facies." Examples of these are "marine facies," "aeolian facies," and so forth. Geologists, similarly, agree that lateral or vertical changes of lithologic or faunal character are referred to as "facies changes."

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

Moore further defines two different types of facies: lithofacies and biofacies. Lithofacies are "groups of strata demonstrably different in lithologic aspect from laterally equivalent rocks." Biofacies are "laterally equivalent biotic assemblages differing in their biologic aspect."

Sloss, Krumbein and Dapples (1949) proposed a third type, tectofacies, which is best described as a "group of strata of different tectonic aspect from laterally equivalent strata."

A tectofacies map would show the laterally varying tectonic aspects on an areal basis, and permit delineation of the tectonic elements which comprised the framework of sedimentation. Therefore, such a tectofacies analysis would give minor variations in the sedimentary environment within the structure.

Krumbein and Sloss (1951) stated; "In the average case, lithofacies and biofacies maps of the same interval express similar trends and limits."

Purpose

The purpose of this investigation is to attempt to define the structures within the Michigan Basin by lithofacies and statistical analyses at the time of the deposition of the "Dundee" formation (middle Devonian).

The writer thinks that by quantitatively and statistically analyzing a well-defined formation, a general, but rather accurate and significant portrayal of the tectonic environment during that period of deposition may be inferred.

The "Dundee" was selected for this study because the complete section has been penetrated by numerous wells. It is hoped that the data obtained from this thesis may add evidence to the already determined structures, and further indicate features which have not been found through earlier research.

WELL SELECTION AND DISTRIBUTION

Stratigraphy of the Analyzed Section

The section analyzed in this report includes the Dundee and Rogers City formations. These two sections are stratigraphically located in the upper-middle Devonian section of the Michigan Basin.

The Dundee is a buff to light brown limestone, cherty limestone and dolomite, varying from approximately 50 to 460 feet in thickness. It is very thin or absent in southeastern Michigan.

The Rogers City is a brownish-buff dolomite limestone or dolomite which rarely exceeds a thickness of 100 feet. It is absent in southeast Michigan.

Porous zones are found in both formations. The porosity was probably caused by solution cavities in the limestone and dolomite, including cavities produced by dissolved fossils, corals and stylolites. The porous zones of the Dundee are similar in character to those of the Rogers City, but are probably somewhat less dolomitic.

Figure 1 is a generalized column of the Devonian section in the Michigan Basin

FIGURE I

GENERALIZED DEVONIAN COLUMN OF MICHIGAN

Series	Group	Formation	Name of Unit	Thickness(')	Descriptions	Remarks
UPPER			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

MODIFIED AFTER H.L. MARTIN

Selection of the Top and Bottom of the Dundee

The base of the Bell shale was selected as a marker for the upper limit of the "Dundee" formation. This shale forms the base of the overlying Traverse group. Because of its large areal extent the Bell shale is considered to be an excellent marker horizon.

In selecting the lower limit of the "Dundee" it was noted that the upper part of the underlying Detroit River group, known as the Lucas-Amderdon formation, contained a considerable amount of anhydrite.

The author feels that the soft, gray Bell shale above and the anhydrite-rich limestone and dolomite of the upper Detroit River group below, form well defined boundaries for the section analyzed in this study.

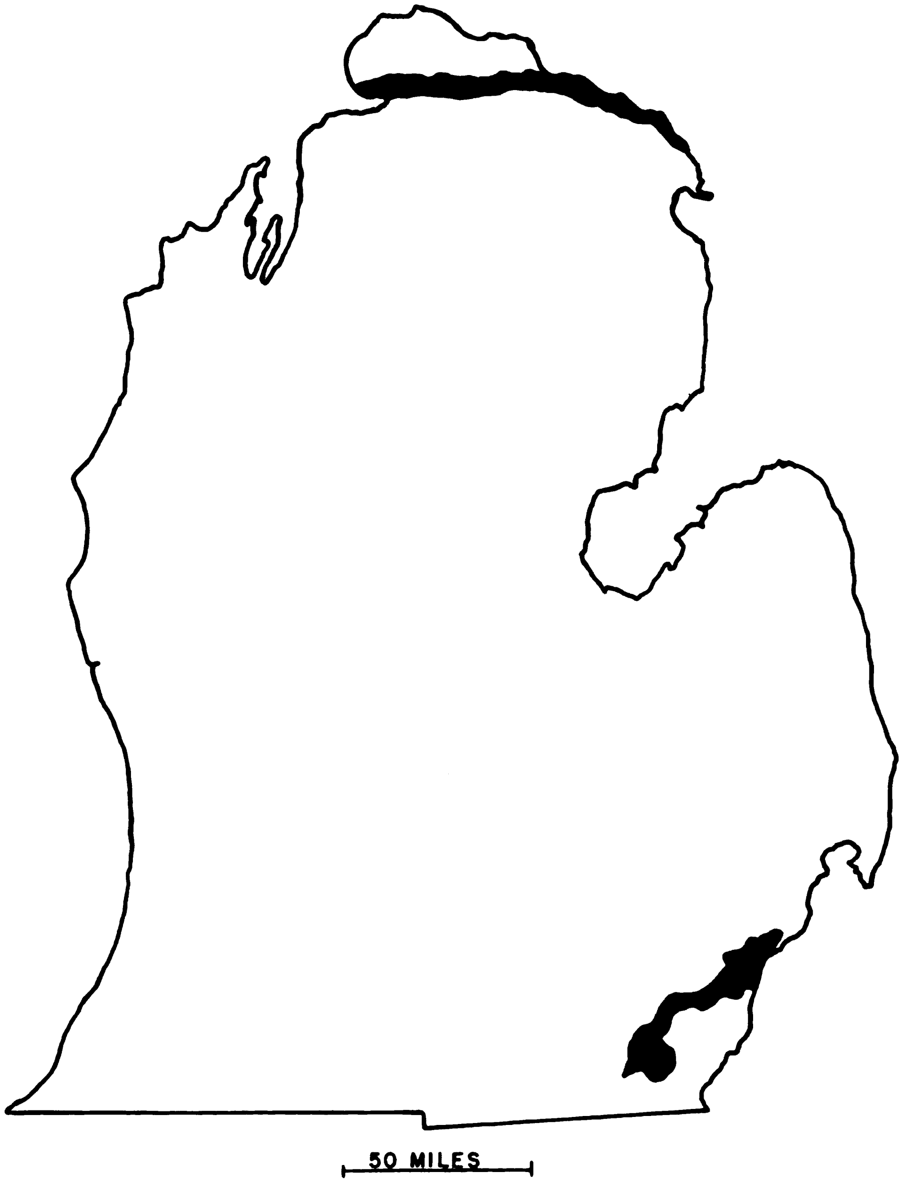
Selection of the Wells

Map I shows the outcrop pattern of the "Dundee" formation. No wells were selected which did not include the complete "Dundee" section.

Map II shows the location of the wells used in this investigation.

Table I shows the well number, location, thickness of the "Dundee" formation, land description, the driller and the farm owner. The well numbers that may be referred to from place to place throughout this analysis are the same numbers that are found in the first column of this table.

MAP I

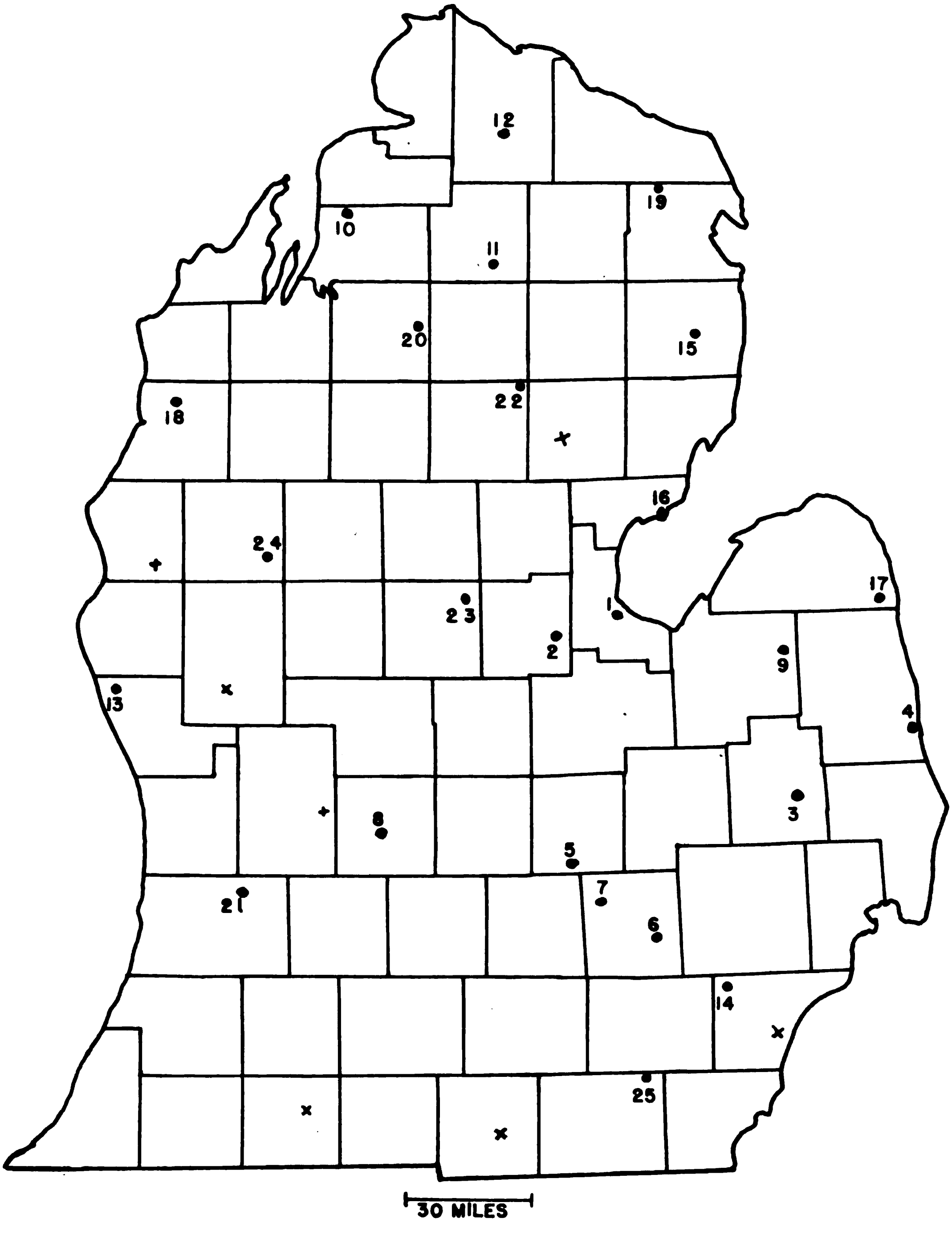


DUNDEE OUTCROP AREA

LOWER PENINSULA OF MICHIGAN

AFTER H.L. MARTIN

MAP II



WELL LOCATIONS AND NUMBERS
(+ — ISOPACH CONTROL WELLS)

TABLE I

WELL DESCRIPTIONS

Well Number	County & Township	Driller and Farm	Land Description	Thickness of Section
1	Bay Kawkawlin	Gulf Ref. Co. Salina #1	34-15N-4E	300'
2	Midland Midland	Dow Chem. Co. Fee #8	21-14N-2E	460'
3	Lapeer Attica	Brazos Oil & Gas G. Smith #1	14-7N-11	95'
4	Sanilac Lexington	McCoy and Black John Tomczyk #1	35-10N-16E	265'
5	Shiawassee Perry	Panhandle Eastern S. Nemcik Comm. #1	23-5N-2E	265'
6	Livingston Genoa	Panhandle Eastern G. Bauer #1	25-2N-5E	264'
7	Livingston Handy	Panhandle Eastern E.C. Addison #1	22-3N-3E	239'
8	Ionia Berlin	Terry-Dale-Mich. Tew #1	12-6N-7W	139'
9	Tuscola Novesta	Shell Oil Co. Woiden #1	16-13N-11E	210'
10	Antrim Central L.	Ohio Oil Co. Chamberlain #1	14-31N-8W	110'
11	Otsego Chester	Brazos Oil & Gas State-Chester HE#1	15-29N-2W	235'
12	Cheboygan Ellis	Roosevelt Oil Co. Ormsbee #1	1-34N-2W	187'
13	Muskegon Montague	Taggart Bros. Gas C.W.Nelson #1	20-12N-17W	250'
14	Wayne Plymouth	Basin Oil Co. E. Raetzel #1	22-1S-8E	170'

TABLE I (Cont'd)

Well Number	County & Township	Driller and Farm	Land Description	Thickness of Section
15	Alcona Millen	J.C.Arthurs, Inc. A. Kohlman #2	10-26N-7E	152'
16	Arenac Sims	Ward Oil Co. Daisy Petty #1	18-19N-7E	375'
17	Huron	Pure Oil Co. J. Stapleton #1	22-17N-15E	339'
18	Manistee	Carter Oil Co. Fred Crook #1	35-24N-15W	70'
19	Alpena Long Rapids	Alpena Exp. Co. Wilson #1	7-32N-6E	242'
20	Kalkaska	John Neyer State-Clrwtr. #1	27-27N-5W	300'
21	Allegan Dorr	Ford Oil Co. A. Scholten #1	30-4N-12W	278'
22	Roscommon Au Sable	J.O. Mutch E.B. Hollwell #1	2-24N-1W	276'
23	Isabella Wise	Cities Service Methner #B-1	33-16N-3W	260'
24	Lake Chase	C.A.Floto Special V. Warchell #1	4-17N-11W	190'
25	Lenawee Cambridge	J.O. Mutch C.L. Billmeyer #1	5-5S-2E	175'

LABORATORY PROCEDURE

Method of Sampling

Samples from the 25 wells used in this study were obtained from the Michigan Geologic Survey, Lansing, Michigan.

The wells were selected in order to get a general picture of the "Dundee" formation below the surface. Only the wells that contained the complete section were used. Wells drilled in an outcrop area or wells drilled in an area that had a formation lying uncomformably on the "Dundee", other than the Bell shale, were not used.

The "Dundee" formation was represented by two to six trays of well cuttings. The trays contained approximately 25, 10 gram vials. The difference in the number of trays is due to the varying thickness of the formation and the drilling intervals used by the drilling contractors. The interval at which the samples were taken varied from 2 to 15 feet with an average of 5 feet.

Wentworth (1926) states that in order to achieve best results in a mechanical analysis of materials that are sand size or smaller a sample of about 125 grams should be used. Since the vertical section studied ranged from 60 to 460 feet, in order to approach Wentworth's figure it was necessary to take a varying amount of sample per foot in the wells. However, the fact that in one well 1 gram per foot was taken and in another 0.3 gram per foot was taken should not detract from the value of the analysis because the analytical and statistical data used in this study are expressed as per cents or ratios.

A 400 milliliter beaker was cleaned, labeled and weighed for each well studied. Each vial was sampled according to the calculated figure that would give a composite sample of about 125 grams from each well.

Before final weighing a magnet was used on each of the composite samples to remove metal fragments that may have come from drilling bits or well casings.

To check the accurate weight of the samples, the thickness of the section, multiplied by the amount of sample taken per foot should equal the weight of the composite sample. In only one well did the error exceed one gram and this well was contaminated by drill bits or casing fragments, which were subsequently removed by the magnet. In this case the weight of the composite sample was 1.65 grams less than its computed value.

It was felt that the errors were not sufficient to cause any misinterpretation of the results.

Removal of Water Solubles

In order to facilitate disaggregation the samples should be free of electrolyte particles. Wiegner (1927) found that by boiling a water-immersed sample containing these electrolytes, the ionic particles were driven into solution and could be removed by siphoning or filtering.

Each sample was placed in 250 ml. of water and boiled for approximately 2 hours. After the fine material settled, 10 ml. of clear solution was withdrawn and placed into a test tube. The salinity was checked by adding a small crystal of silver nitrate. If the precipitate formed was denser than the one formed by placing a small crystal of silver nitrite in an equal amount of tap water, another boiling water treatment was necessary. This was repeated until the precipitate was equal to or less than that formed by the tap water.

Three or four treatments were necessary to remove the water-soluble salts. The remaining sample was filtered and washed thoroughly. After this treatment the sample was returned to its original beaker and allowed to dry on a warm sand bath.

The amount of water-soluble material was determined by substracting the weight of the sample and the beaker after it had been boiled and dried from the weight of the original composite sample and beaker.

The amount of fine particles left on the filter paper was determined by comparing the weight of the filter paper before and after it was used. This small smount, which averaged about 0.03 gram, was added to the clay fraction.

Removal of Acid-Solubles

Limestone, dolomite and perhaps a minor amount of anhydrite are the remaining non-clastic materials.

Due to the high percentage of acid-solubles in the "Dundee" there was danger of losing some material due to severe effervescence. To minimize this danger, acid of various strengths was added at three stages.

The first treatment, 100 ml. of 25% acid, was added slowly to the sample. Stirring the solution with a glass rod hastened the reaction. After the reaction ceased the solution was allowed to settle for several hours, and the supernatant liquid was siphoned.

The second and third treatments were similar to the first except that the strength of the acid was raised to 50 and 100 per-cents respectively. After the reaction of the 100% acid had ceased the sample was placed in a hot sand bath to remove the less soluble materials, such as anhydrite and dolomite.

After cooling and settling, the excess liquid was removed and the beaker was filled with water, which settled. The clear solution was then removed in order to check the acidity. This operation was repeated until there was no change in the blue litmus paper.

After neutralization, the beaker and the remaining sample were placed in a warm sand bath and dried. The difference in weight before and after the acid treatments denoted the amount of acid-solubles.

Disaggregation

Very little shale is present in the "Dundee" formation. Landes, Ehlers and Stanley (1945) noted that in an exposed section of the "Dundee" strata at Rogers City, Michigan, there was an eight inch band of shale near the base of the formation. This 8 inch band is very minor since the thickness of the section at this location exceeded 215 feet. However, to facilitate sieving, the author thought it best to disaggregate each sample.

Krumbein and Pettijohn(1928) define disaggregation as, "the breaking down of aggregates into smaller clusters or individuals."

Most of the shale present was broken down during the water and acid treatments. A few dark grey pieces which may have been indigenous or contaminants from the overlying Bell shale remained.

Cooke (1956) found that potassium hydroxide (KOH) was the best compound to use for disaggregation. A supersaturated solution was prepared. Care was taken not to add the KOH too rapidly, as a violent exothermal reaction could result. After boiling the supersaturated solution for 10 hours on two successive days the shale was disaggregated.

Sieving

Several water treatments were necessary to neutralize the KOH solution. The neutrality was determined when it no longer effected pink litmus paper.

Before attempting to sieve the sample just enough was was added to form a paste. This paste was rubbed with the fingers and allowed to soak in water for several hours.

The sample was then washed through a 230 mesh Tyler sieve. This mesh is small enough to retain the fine-grained sand particles but also large enough to permit the passage of the smaller silt and clay particles.

The solution carrying the silt and clay particles through the sieve was not saved. The reason will be explained later.

The sand retained by the 230 mesh sieve was dried and placed in small vials and saved for later microscopic analysis. This is known as the sand fraction. The weight of the sand fraction was not recorded. The reason for this, too, will be explained later.

Mounting and Analyzing the Sand Grains

The sand fraction saved from the disaggregation process was sieved through 80 and 100 mesh Tyler sieves. The fraction retained by the 100 mesh screen were believed to be ideal size for microscopic identification.

The grains were mounted on a glass slide with Canada balsam; a cover glass was placed over them. Each slide represented the entire well. The percentages of quartz and chert were estimated with the aid of a polarizing microscope.

Accuracy of the Data

It is possible that with the necessary handling of the samples, slight amounts of fine materials were lost. These losses were considered insignificant.

The "Dundee" samples were probably contaminated by cavings from the overlying Bell shale. Even though only slight amounts of cavings were present, however, it is very probable that they were equal to or greater than the total amount of shale indigenous to the entire "Dundee" section. For this reason the writer feels that to have attempted a sand-shale ratio would have been impractical and results erroneous. Therefore the amount of silt size particles sieved after the disaggregation was not recorded.

Results of the Quantitative Analysis

Table II represents the statistical summary of the quantitative analysis of the 25 wells.

The lithologic ratios expressed in Table III were computed according to the formulas presented in the following section.

Table II

Results of Quantitate Analysis

Well Number	Total Weight	Weight of Water Sols.	Pct. water Sols.x1000	Weight of Acid Sols.	Pct. Acid Soluables
1	120.783	.035	.274	115.683	95.77
2	118.569	.431	3.630	106.628	89.53
3	123.394	.068	.549	110.258	89.35
4	125.710	.452	3.600	109.884	87.41
5	129.185	.232	1.794	110.338	85.41
6	130.502	.011	.008	118.432	90.75
7	106.417	.555	5.215	93.688	88.04
8	111.428	.469	4.208	80.587	72.32
9	120.886	.015	.012	109.489	90.57
10	71.615	.419	5.712	65.668	91.70
11	131.562	.019	..144	127.952	97.26
12	118.777	.083	.697	116.171	97.80
13	123.258	.243	1.971	81.302	65.88
14	119.849	.162	1.352	113.010	94.13
15	115.329	.899	7.795	99.079	85.51
16	120.794	.032	.265	119.103	98.60
17	97.079	.171	1.761	94.418	97.23
18	120.760	.773	6.401	105.900	87.69
19	117.337	.109	.929	114.479	97.56
20	107.348	.513	4.778	102.882	95.84
21	112.951	.453	4.010	93.692	82.95
22	112.168	.021	.187	86.275	76.92
23	118.528	.254	2.143	96.748	81.63
24	126.008	.212	1.682	72.016	57.15
25	121.770	.212	1.741	103.079	84.65

Table III

Lithologic Ratios

Well Number	Evaporite Ratio x1000	Clastic Ratio	Quartz-Chert Ratio
1	.303	.048	.184
2	4.032	.110	.173
3	.617	.128	.176
4	4.113	.141	.217
5	2.102	.171	.094
6	.093	.102	.086
7	5.924	.130	.088
8	5.819	.375	.071
9	.137	.104	.200
10	6.380	.084	.032
11	.148	.028	.143
12	.713	.022	.105
13	2.992	.513	.091
14	1.433	.060	.200
15	9.073	.154	.294
16	.268	.014	.267
17	1.811	.263	.209
18	7.300	.132	.083
19	.952	.024	.158
20	4.986	.038	.054
21	4.835	.200	.051
22	.243	.300	.265
23	2.625	.222	.122
24	2.944	.745	.105
25	2.057	.180	.107

LITHOLOGIC VARIATIONS

Lithologic Ratios

The recent availability of data through drillings, cores and logs has increased the value of facies maps.

Krumbein and Sloss (1951) devised a system of ratios for mapping purposes:

> "Perhaps the most fundamental differentiation of stratigraphic units at a given point is into non-specific lithotopes based on a division into clastic and non-clastic elements in the stratigraphic section."

This is called the "clastic ratio" and to determine it the relative percentages of the clastic and non-clastic materials should be known.

$$\text{Clastic Ratio} = \frac{\text{Conglomerate+sandstone+shale}}{\text{limestone+dolomite+evaporite}}$$

A lithologic unit consisting entirely of sandstone would be represented by a clastic ratio of infinity, whereas that of an entire unit of limestone would be zero.

The other lithologic ratios expressed in Table III were computed as follows:

$$\text{Evaporite Ratio} = \frac{\text{evaporites}}{\text{limestone+dolomite}}$$

$$\text{Quartz-Chert Ratio} = \frac{\%\ \text{quartz}}{\%\ \text{chert}}$$

The evaporite ratio is used to illustrate variation within the non-clastic materials. There were very little evaporites in the "Dundee". Some of these may have been removed by waters used in the drilling of the wells; others may have been removed by subsequent solutions. Other evaporites may have been taken out of the samples when they were washed prior to being placed in the sample vials. For these reasons the significance of the evaporite ratio is questionable.

Figure 2 is intended to give a quick, reasonably accurate picture of the high percentage of non-clastics in the "Dundee" formation. It is interesting to note the homogeneity of the non-clastics in the "Dundee". The smaller, dashed triangle, which contains the results obtained from the 25 wells, comprises only about 4% of the entire triangle.

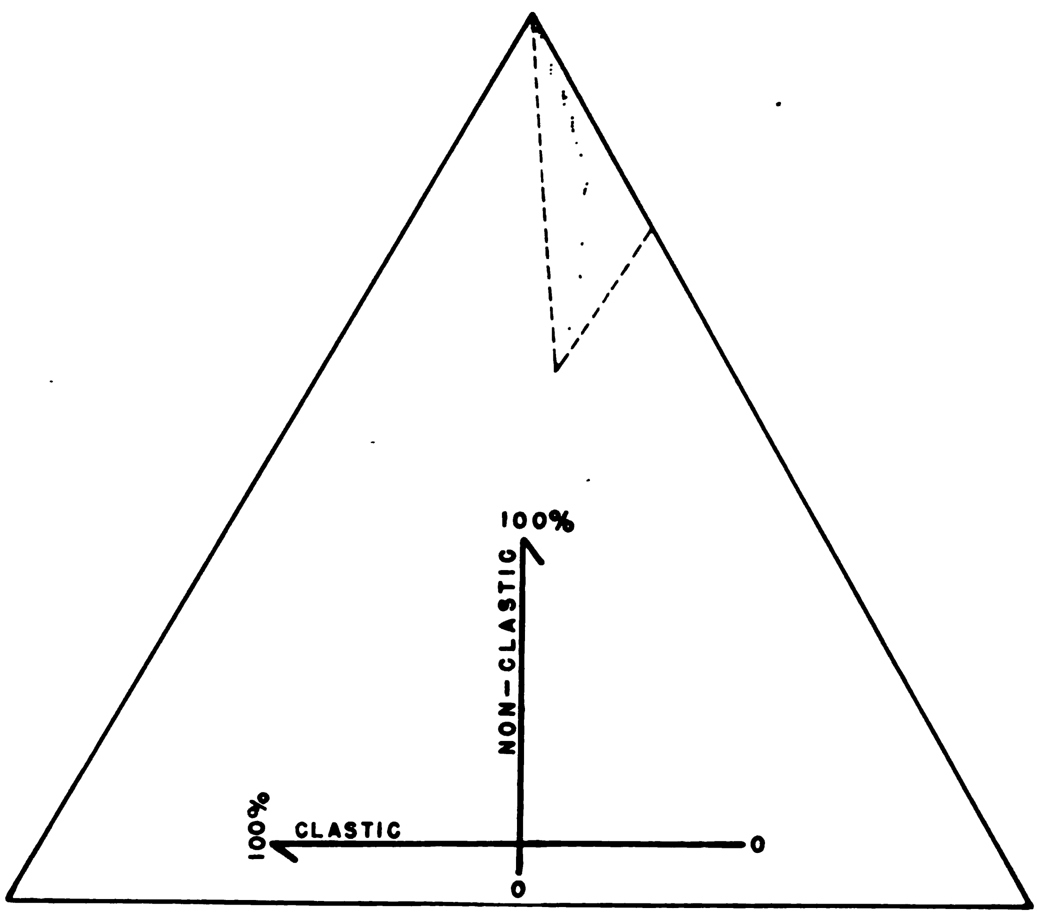
Figure 3 illustrates the quartz-chert and clastic ratios of the materials from all the samples analyzed.

Construction of the Facies Maps

To construct facies maps representing variations within a certain lithologic ratio, the ratios were plotted at their respective position on a good base map. Contour lines of equal ratio value were then drawn.

According to Krumbein (1952) the contour intervals may be plotted geometrically or arithmetically. The lines used in this study were plotted arithmetically.

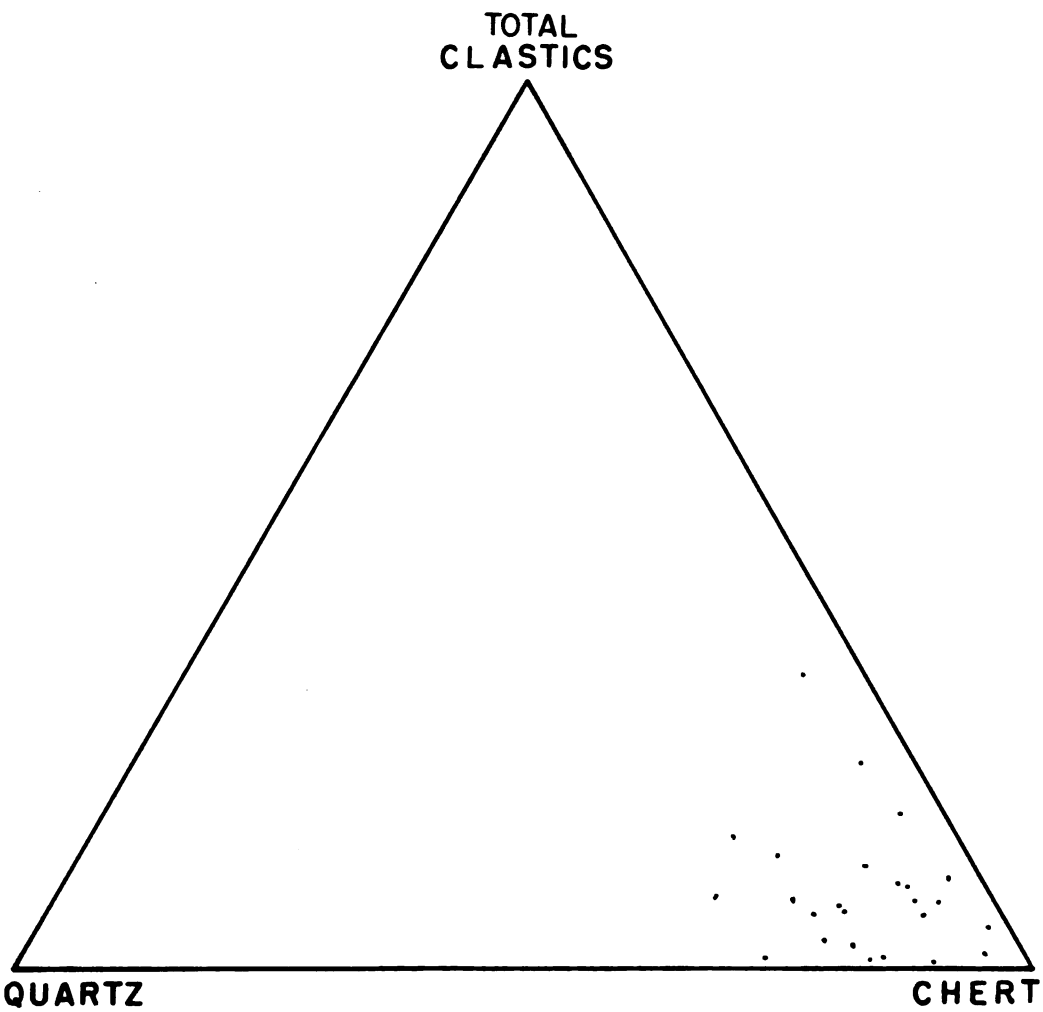
FIGURE 2



SCATTER DIAGRAM

FIGURE 3

(APEXES REPRESENT 100%)



SCATTER DIAGRAM

An isopach map was first constructed on semi-transparent paper; the ratio maps were made on opaque paper. Superimposing the isopach map on the ratio map facilitated interpretation. This was better than constructing isopach lines on each of the ratio maps.

Maps IV, V, VI and VII are the isopach, clastic ratio, evaporite ratio and quartz ratio maps, respectively. The data used in constructing the maps was obtained from the analysis of the "Dundee" samples used in this study.

To get a more accur te isopach map, seven addition control wells were used. (See map II). These seven wells did not contain enough sample for analysis, but the footage of the "Dundee" was recorded and used in the construction of the isopach map.

GEOLOGIC INTERPRETATIONS

Methods of Interpretation

Krumbein (1952) noted that the relations between isopach and facies contours show at least 6 patterns which may be useful in interpreting specific sedimentary conditions. These patterns are shown in Figure 4.

Examples were cited for the conditions shown in Figure 4 by Krumbein (1952) when he stated.

> "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 becomse patchy or spotty."

Krumbein goes on to show that there are three patterns suitable to an intracratonic basin, such as the Michigan Basin.

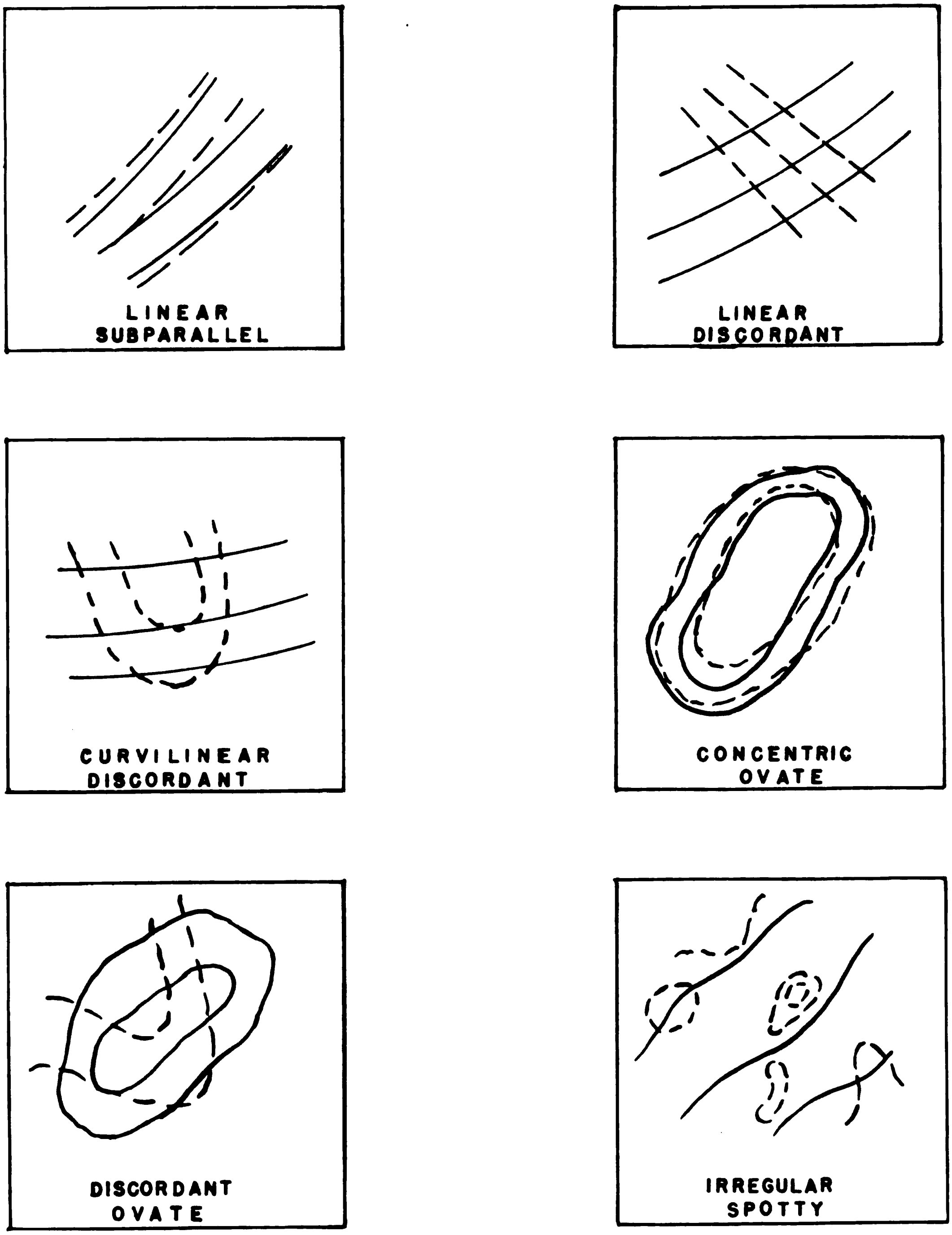
(1) A curviliniear discordant pattern could indicate a nearby orogenic source,

(2) A concentric ovate pattern could indicate either a nearby orogenic source, a nearby epeirogenic source or a distant source,

FIGURE 4

RELATIONS OF ISOPACHS (SOLID) AND FACIES LINES

KRUMBEIN (1952)



(3) a discordant ovate pattern could indicate either a nearby orogenic source or a nearby epeirogenic source.

The patterns formed by the isopach and the lithofacies ratio lines should give a good basis for the interpretation of the direction and distance from a source area.

Errors in the Analysis

In analyzing and interpreting this section it is possible that some errors were unavoidable. One such error is due to the interpolation necessary in constructing the maps. Some minor features are probably omitted. The large irregularities are believed to be brought out and perhaps even accentuated by this analysis.

Some of the minor irregularities may be brought to light due to the fact that this is a study of a relatively short time-rock unit. For example, some feature that may have been noted during the deposition of the "Dundee" formation would not be noticeable in a composite study of the entire Devonian system.

Post-depositional erosion could have an erroneous effect on the isopach and lithofacies maps. However, the author found no evidence following deposition of significantly large scale erosion to cause any serious error; therefore it is believed that the isopach and lithofacies maps are quite accurate.

Analysis of Variance of Acid-Soluables in the "Dundee"

A statistical method of analyzing the amount of scattering of the acid-solubles from the general mean of the solubles can be determined by using the following formulae:

(1) $$S = \sqrt{\frac{E(x-\bar{x})^2}{n-1}}$$

where S is the standard deviation (amount of scattering)

E-represents sigma or summation;

x-is the per cent of acid-solubles;

$\bar{x}$-is the general mean of the acid-solubles, which in this example is 87.30%

n-is the number of wells used.

By substituting the figures obtained from Table II the value of S is 11.35 units.

(2) $$S\bar{x} = \sqrt{\frac{S}{n}}$$

where $S\bar{x}$ is the standard deviation from the mean of the acid-soluble per cent of the samples.

The computed value for $S\bar{x}$ is 2.27 units.

Baten (1957) states that when running an analysis of variance of samples from a similar environment, the mean of the individual samples varies from the general mean of all the samples according to the following figures: 1) 67% of the individual sample averages will fall within one standard deviation (plus or minus) from the general mean; 2) 95% will fall within two standard deviations of the general mean; and 3) 99% will be within 3 standard deviations.

Figure 5 shows the amount of deviation from the general mean that is allowed by the three standard deviations.

Figure 6 shows the analysis of variance of the acid-solubles of all the samples analyzed. The figures in the theoretical column are 67, 95, and 99 per cents of the total wells used in this study. The actual values are the number of wells that are 1, 2, and 3 standard deviations from the general mean.

The data needed to compute the analysis of variance were taken from Table II.

Results of the Analysis

The results tend to show that the acid solubles of the "Dundee" were probably deposited in different environments. This would seem quite logical because of the variance of the per cent of acid-solubles noted between the individual samples.

A study of this nature would, however, be useful in an area where the variations are not so large.

$S\bar{x} = 2.27$; GENERAL MEAN = 87.30 %

RANGE WITHIN: 1 $S\bar{x}$ = 85.03 — 89.57 %

2 $S\bar{x}$ = 82.76 — 91.74 %

3 $S\bar{x}$ = 80.49 — 94.01 %

FIGURE 5

FIGURE 6

RANGE	THEORETICAL	ACTUAL
1 $S\bar{x}$	16.75	7
2 $S\bar{x}$	23.75	12
3 $S\bar{x}$	24.75	14

Statistical Correlation of the "Dundee" and Upper Detroit River Group

Seventeen wells used in this study penetrated the upper members of the Detroit River group. The per cent acid-solubles of the latter group was obtained from Dewey (1957) and correlated with those from the "Dundee". The same wells were used in each analysis. These "simul-wells" are numbered 2,3,4,5,6,7,9,10,12,13,14,17,18,19,20,21, and 23 in Table 1. They may be located on Map II.

To compare the acid-solubles in the "Dundee" and the upper members of the Detroit River group (the Lucas-Anderdon), a statistical method of correlation, as outlined by Baten (1957) and Goulden (1952), was used.

By plotting the per cent acid-solubles and by applying a statistical method of correlation a graphic representation of environmental relationship may be observed. (Figure 7).

The "Dundee" acid-solubles are plotted along the horizontal axis while those of the Detroit River are plotted along the vertical axis.

The predicting lines that parallel the line of linear regression (LR) are spaced according to the standard error of estimate, which is explained in the following paragraph.

To compute the standard error of estimate the following formulae were used:

$$(1) \qquad b = \frac{Exy - \frac{ExEy}{n}}{Ex^2 - \frac{(Ex)^2}{n}}$$

where b is the slope of the line LR:

E-is the summation;

x-represents the "Dundee" acid solubles (%);

y-represents the Detroit River acid sols.(%);

n-is the number of wells used.

The computed value for "b" equals 0.93

$$(2) \qquad a = \bar{y} - b\bar{x}$$

where $\bar{x}$ and $\bar{y}$ are the averages of x and y

The calculated value for "a" is —11.96.

$$(3) \qquad Se = \sqrt{\frac{Ey^2 - aEy - bExy}{n - 2}}$$

where "Se" is the standard error of estimate, which in this case is 6.8 units.

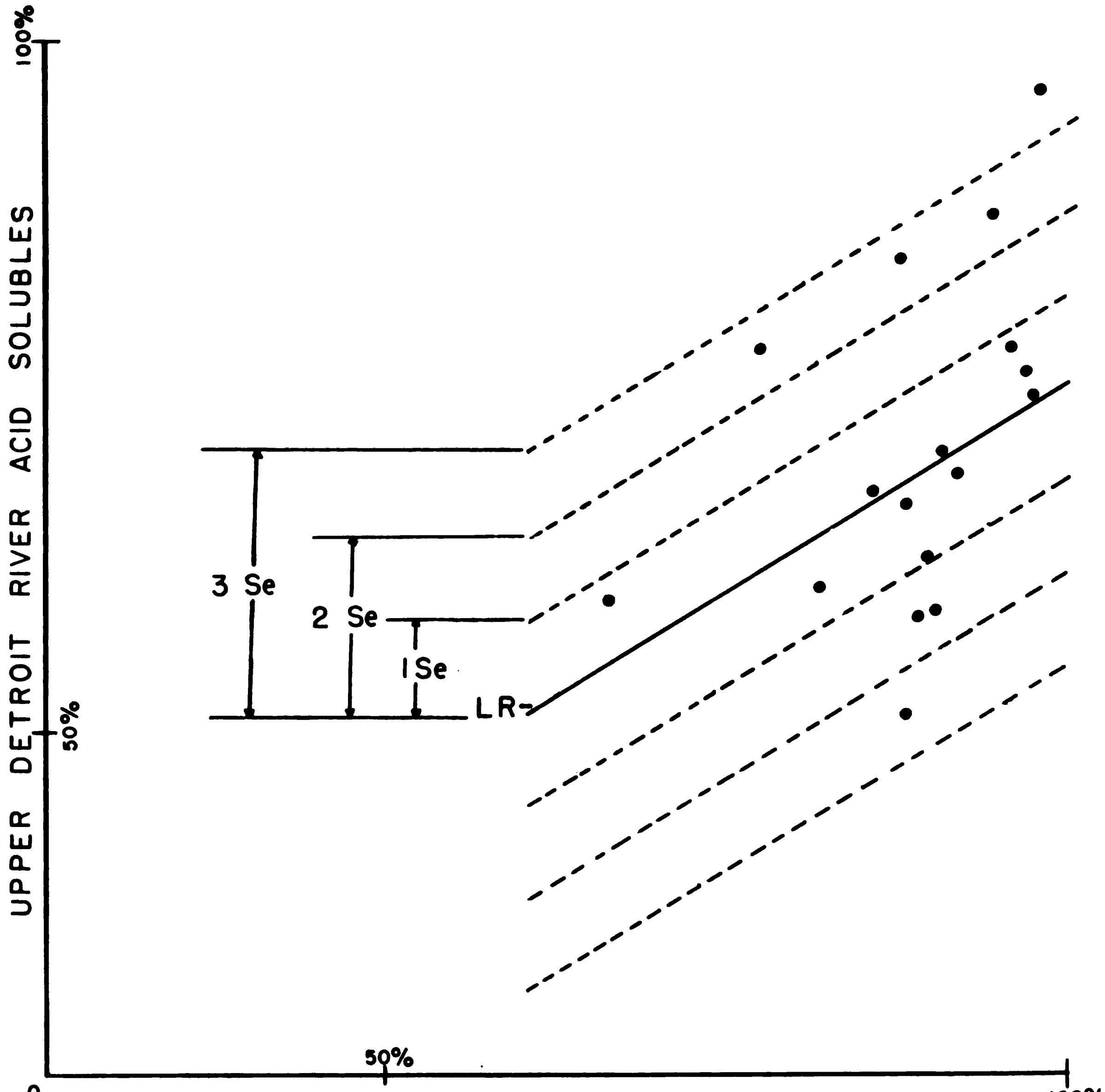
The distance that the predicting (dashed) lines are placed above and below the line LR are equal to 1, 2, and 3 times the computed value of "Se", respectively, and measured parallel to the vertical axis. (See Figure 7).

The dashed lines are called predicting lines because within 1 "Se" (above and below LR) there should fall approximately 65% of the wells tested. Within 2 "Se" 95% of the wells tested should fall and within 3 "Se" there should be 99%, when the materials tested are from a similar environment.

Approximately 60% of the wells lie within 1 "Se" of LR and only 1 well falls outside 3 "Se". (Figure 7). These positions conform roughly with the values mentioned in the preceding paragraph.

However, instead of the 95% of all wells that should fall within 2 "Se", only 70% are within this range. On the basis of this discrepancy, it is probable that the "Dundee" and upper Detroit River sediments were deposited under different environmental conditions.

FIGURE 7



CORRELATION OF "DUNDEE" & UPPER DETROIT RIVER GROUP ACID SOLUBLES

BASED ON THE STANDARD ERROR OF ESTIMATE (Se)

INTERPRETATIONS

The three lithofacies maps were interpreted separately by superimposing the isopach map on each. Features are located in reference to counties; therefore a small map showing the Michigan counties is included in the pocket. (Map III).

The Clastic Ratio Map

The greatest concentration of clastic sediments is where Lake, Newaygo, Osceola and Mecosta counties meet. In the highly calcareous "Dundee", it is significant to mention that in this area about 43% of the material is clastic. During "Dundee" time, the west-central part of the state reveals the highest amount of clastic materials.

The clastic map indicates that these clastics were derived from the west, quite probably from the Wisconsin Dome. Landes (1951) states that there is good reason to believe that many clastic sediments were supplied to the Michigan Basin from the erosion of the Wisconsin Dome and that a large amount of this material was wind-blown.

A clastic high is also noted in Huron county. It would seem quite logical that the source of these sediments is the Canadian Shield-Findlay Arch area in Canada.

In noting the relation of the isopach and facies lines, a curvilinear-discordant pattern is located in Lake, Newaygo, Osceola and Mecosta counties. By applying Krumbein's theory of the tectonic factors controlling deposition in an intracratonic basin this type pattern indicates a nearby orogenic source. This indicates a local concentration of clastics being poured into a moderately subsiding area.

The discordant-ovate patterin in Huron also indicates a nearby orogenic source.

These interpretations strengthen the theory that the Michigan Basin received clastic sediments from the erosion of the Wisconsin Dome. These sediments accumulated in the west-central counties of the lower peninsula of Michigan. Also that the eastern part of the Michigan Basin received sediments from the Canadian Shield-Findlay Arch area in Canada.

Dice (1955) noted that the west-central part of the state received the greatest amount of clastic materials during Devonian time. Dewey (1957) noticed a clastic high in the same area during the deposition of the Detroit River group. In view of these it is assumed that the Wisconsin area was supplying sediments to the Michigan Basin throughout the early and middle Devonian period, rather than the sediments being deposited in a relatively short time.

The Evaporite-Ratio Map

Evaporites are deficient in the "Dundee" formation. It should be remembered that the samples have been subjected to water in drilling, and washed before being bottled and sent to Michigan Geologic Survey. None of the well samples showed as much as a 1% concentration of evaporites. The ratios expressed on the map have been increased a thousand-fold in order to avoid confusion caused by so many zero digits.

Krumbein (1952) predicted that evaporites in an intracratonic basin form a concentric-ovate pattern with the isopach lines. This is quite obvious in Bay and Midland counties and denotes the center of deposition during the formation of the "Dundee".

Alcona County, in northeast Michigan, has the highest concentration of evaporites. This indicates a small area of basinal deposition.

A broad basinal feature is evident in Ingham, Eaton, Barry and Ionia counties which could denote moderately deep sedimentation.

An interesting feature is the linear trough that runs nearly north-south through Huron, Sanilac, St. Clair, Oakland, Macomb and Wayne counties. This "dropping-off" effect tends to show local subsidence along the basin's eastern edge.

In the northwestern counties, there is another high which is probably the result of basinal deposition. The isopach-facies lines form a curvilinear-discordant pattern that indicate a nearby orogenic source, probably the Wisconsin Dome.

Quartz-Chert Ratio Map

The slides revealed that the "Dundee" formation contained very little quartz. As little as 0.4% quartz was noted in some of the slides.

Chert was more dominant than the quartz although the chert content of the slides never exceeded 10% of the total grains mounted.

The map shows that the quartz-high region is in northern Iosco and Arenae counties, where the quartz is presumed to be detrital and to have been derived from the Canadian Shield-Findlay Arch area.

The quartz-chert ratio is essentially a "primary versus secondary" affair. Care was taken while examining the slides to note if there was any secondary growth on primary crystals. Secondary enlargements of detrital quartz crystals were not detected.

The map indicated a deep water deposition in Bay and Midland counties which conforms to the isopach interpretation of this area.

The southern and western parts of the state show the greatest amount of chert. The same condition is also present in the northwestern counties. These areas conform to Krumbein's curvilinear-discordant pattern and indicate a nearby orogenic source.

PALEOTECTONICS AND CONCLUSIONS

The Lower Peninsula of Michigan, according to Eardley (1951), is part of the central stable region which is composed of a foundation of Precambrian crystalline rocks, similar to those of the Canadian Shield, and overlain by a mantle of sedimentary rock.

The sediments in the Lower Peninsula were deposited in an elongate basin somewhat parallel to the Appalachian Geosyncline. The deposits extend into the northern parts of Illinois and Indiana, and western Ontario. Nine thousand feet of sediments, mostly evaporites and carbonates, were deposited in the Michigan Basin prior to the Devonian period.

The studies of many investigators indicate that in early Devonian time the Michigan Basin was affected by the uplift of two northern extensions of the Cincinnati Arch. These two structures were the Findlay Arch, a northeast arm extending through Ohio into Ontario, and the Kankakee Arch which developed through Indiana, northern Illinois and into southern Wisconsin.

The Findlay Arch, according to Cohee (1945), may have been a low ridge at the beginning of Cambrian deposition and subsequent uplift along this arch was localized and of somewhat greater magnitude than uplifts along the Kankakee axis.

Cohee further states that the Kankakee Arch divided the original major basin into two units; thus the Michigan and the Illinois Basins came into being as separate structures.

Since the deposition of the St. Peter sandstone (early Ordovician), and according to measurements made down to the top of the Trenton limestone (Middle Ordovician), the Michigan Basin has subsided about 10,000 feet.

Kay (1947) defines an autogeosyncline as an isolated depositional area within a cratonic unit which accumulates sediments at a greater rate then the surrounding area, receiving those sediments from cratonic sources. The Michigan Basin fits this classification. To substantiate this point, reference is made to Eardley (1951) and Krumbein and Sloss (1951), who state that parts of the Canadian Shield were emergent at intervals during Paleozoic time and served as source areas for cratonic deposition.

By the end of the Devonian, the Findlay and Kankakee Arches and the Wisconsin Dome were well established. Gentle erosion of these uplands served as one source of sediments that were deposited in the Michigan Basin during the period.

In view of these historical events and the lithofacies maps prepared from data obtained by analyzing the "Dundee" formation, certain conditions of sedimentation may be inferred. These conditions, in relation to the Michigan Basin, are:

1) The thickest sediments in "Dundee time accumulated

in the Midland and Bay Counties area, where the formation attained a thickness of 460 feet. (Well #2, Midland County).

2) The thickness of the "Dundee" limestone deposit portrays conditions that were most favorable for direct precipitation in waters which were salty and warm during the period.

3) Aside from fossil evidence, the thickness and areal extent of the "Dundee" indicate marine rather than fresh-water limestone. The term fresh-water limestone refers to the beds of lime carbonates that are deposited as more or less continuous beds in fresh water. Pettijohn (1957), concerning freshwater limestone, states: "They are dense to friable (marl) deposits of small thickness and areal extent."

4) The evaporite facies and isopach lines show a concentric-ovate pattern in Midland and Bay Counties. This agrees with Krumbein's theory of deposition in an intracratonic basin and denotes the center of deposition during the formation of the "Dundee". Figure 4 shows a concentric-ovate pattern.

5) The greatest amount of quartz is in Iosco and Alcona Counties. A microscopic study of the detritals in this area showed a marked degree of

sphericity. In view of the fact that these grains could be water-borne, the author believes that a trough may have been present in this area and that this trough may have permitted the passage of sea-water into the Basin during "Dundee" time. Water entering the Basin through this trough may have transported the detritals by traction and probably caused the sphericity. The Findlay Arch was south of this trough and it probably served as a source area for the sediments that were transported by the water entering the Michigan Basin through this trough and subsequently deposited.

6) The greatest amount of chert in the "Dundee" is in the south and west parts of the Lower Peninsula. Tarr (1926) stated that chert is deposited from sea-water as gelatinous silica. He concluded that the coagulation of the colloidal silica was produced through neutralization of the negative charges on the silica by the positively charged ions of sodium, potassium, calcium, and magnesium. However, there are differences of opinion amoung geologists as to the origin of chert. The author believes that the small amount of chert present in the "Dundee" is of secondary origin and occurs in the formation as nodules and cavity fillings.

7) The conditions indicated in the clastic-ration map are:

a- the greatest amount of clastic sediments was deposited in the west-central part of the Michigan Basin during "Dundee" time. These sediments were derived from the erosion of the Wisconsin upland as indicated by a decrease of clastic material eastward from Lake, Newaygo, Osceola and Mecosta counties. This seems to substantiate the theory that the Wisconsin Dome is the source for the clastic materials deposited in the west-central part of the Michigan Basin during "Dundee" time.

b- the roundness noted in some of the detritals derived from Wisconsin upholds Landes's theory that part of the clastic materials brought into the Michigan Basin from the Wisconsin highland were possibly wind-blown.

c- clastic sediments compose a significant part of the "Dundee" in Huron County. The source for this is probably the Findlay Arch-Canadian Shield area.

d- the relationship of the isopach and facies lines shows a curvilinear-discordant pattern (Figure 4) in Lake, Newago, Osceola and Mecosta Counties. By applying Krumbein's theory of tectonic factors controlling deposition in an intracratonic basin, this pattern is typical of an area where a local concentration of clastics has been poured into a moderately subsiding area.

8) Dice (1955) noted that the west-central part of the Lower Peninsula received the greatest amount of clastic material during the Devonian period. His study does not indicate, however, whether these clastics were being deposited throughout the entire period or whether they accumulated in a relatively short period of time. Dewey (1957) noted a "clastic high" trend in the west-central part of the state in his study of the upper Detroit River group sediments.

In this analysis, the author also found a "clastic high" in the west-central part of the Lower Peninsula. In view of these findings it seems quite probable that the Wisconsin Dome was supplying clastic material to the west-central part of the Michigan Basin throughout early and middle Devonian time.

During the final stages of deposition of the underlying Detroit River group sediments, the Michigan Basin may have been cut off from any major source of incoming water. Evaporation within the Basin caused the precipitation of anhydrite which marks the upper limit of the Detroit River group.

A combination of subsidence of the Michigan Basin and/or a rise in the level of waters surrounding the Basin could have initiated the formation of the "Dundee" sediments.

Warm waters entered the Basin through a trough that extended from Ontario into Iosco and Alcona Counties. Clastic sediments, supplied by the Findlay Arch, were water-transported into the Basin and subsequently deposited in this area.

The salinity of the water in the Basin and the warm incoming waters were ideal for the formation and deposition of marine limestone.

The "Dundee" formation in the Michigan Basin is primarily a carbonate deposit. The greatest amount of clastic material deposited during "Dundee" time is found in two areas. These areas are in Lake, Newaygo, Osceola and Mecosta counties in the west-central part of the Basin and in Huron County in the "Thumb" area of the Lower Peninsula of Michigan.

The center of deposition during "Dundee" time is in the Bay-Midland Counties area. The thickness (460 feet) and the relatively small amount of clastic material in this area lead the author to believe that the thickest deposit of "Dundee" limestone was precipitated in an area where the deposition was contemporaneous with subsidence.

There are several theories as to the environmental conditions that existed during the final stages of the "Dundee" formation. One theory, which seems quite logical to the author, is that in late "Dundee" time the Michigan Basin may have been emergent. Sea-water probably re-entered the Basin and transgressed westward.

Erosion in the western part of the Lower Peninsula before the transgressing sea-water covered the "Dundee" could possibly account for the thinning of the sediments of the formation in this area.

The transgressing sea probably carried the muds that eventually formed the overlying Bell shale and culminated the "Dundee" formation in the Michigan Basin.

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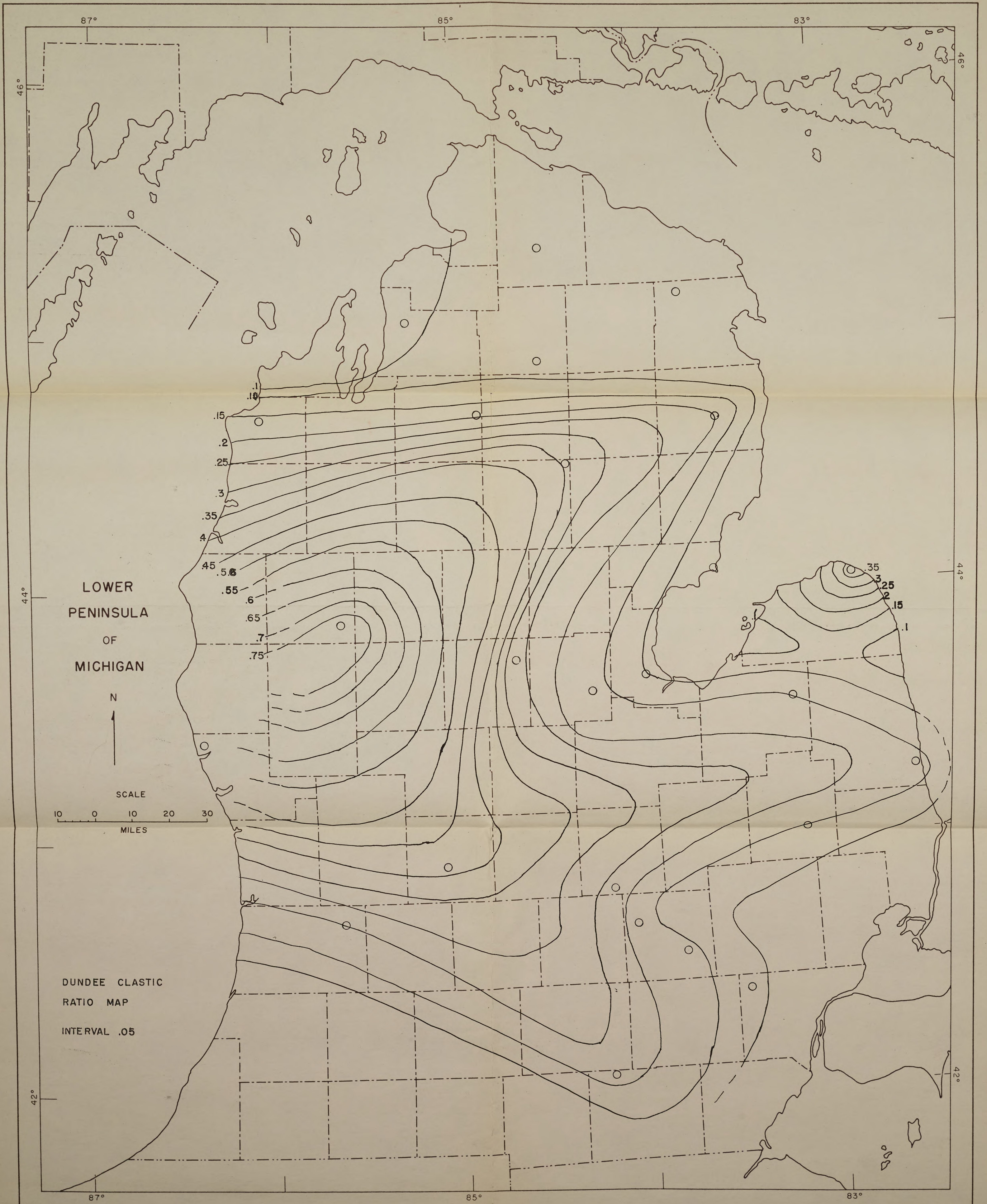
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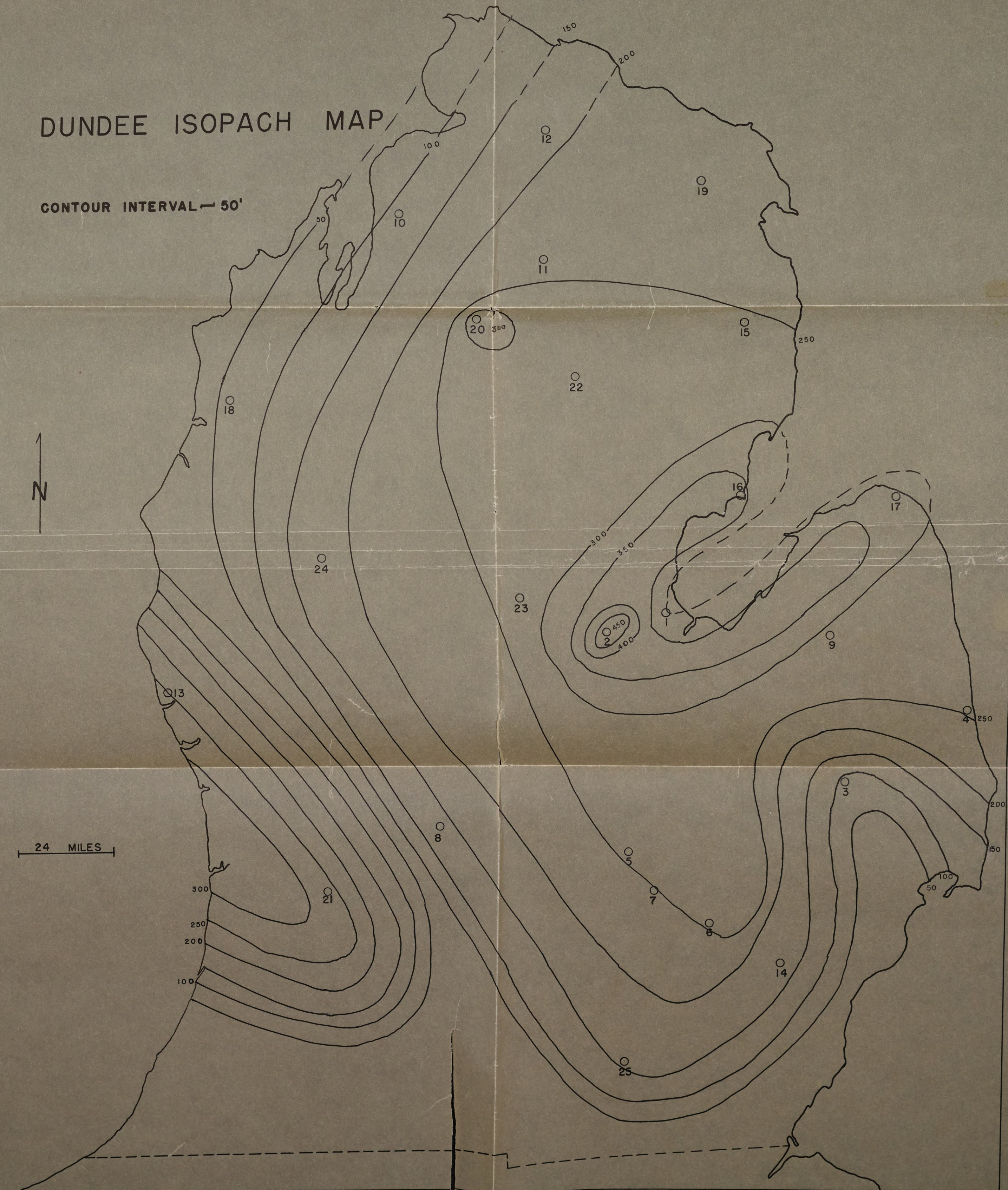
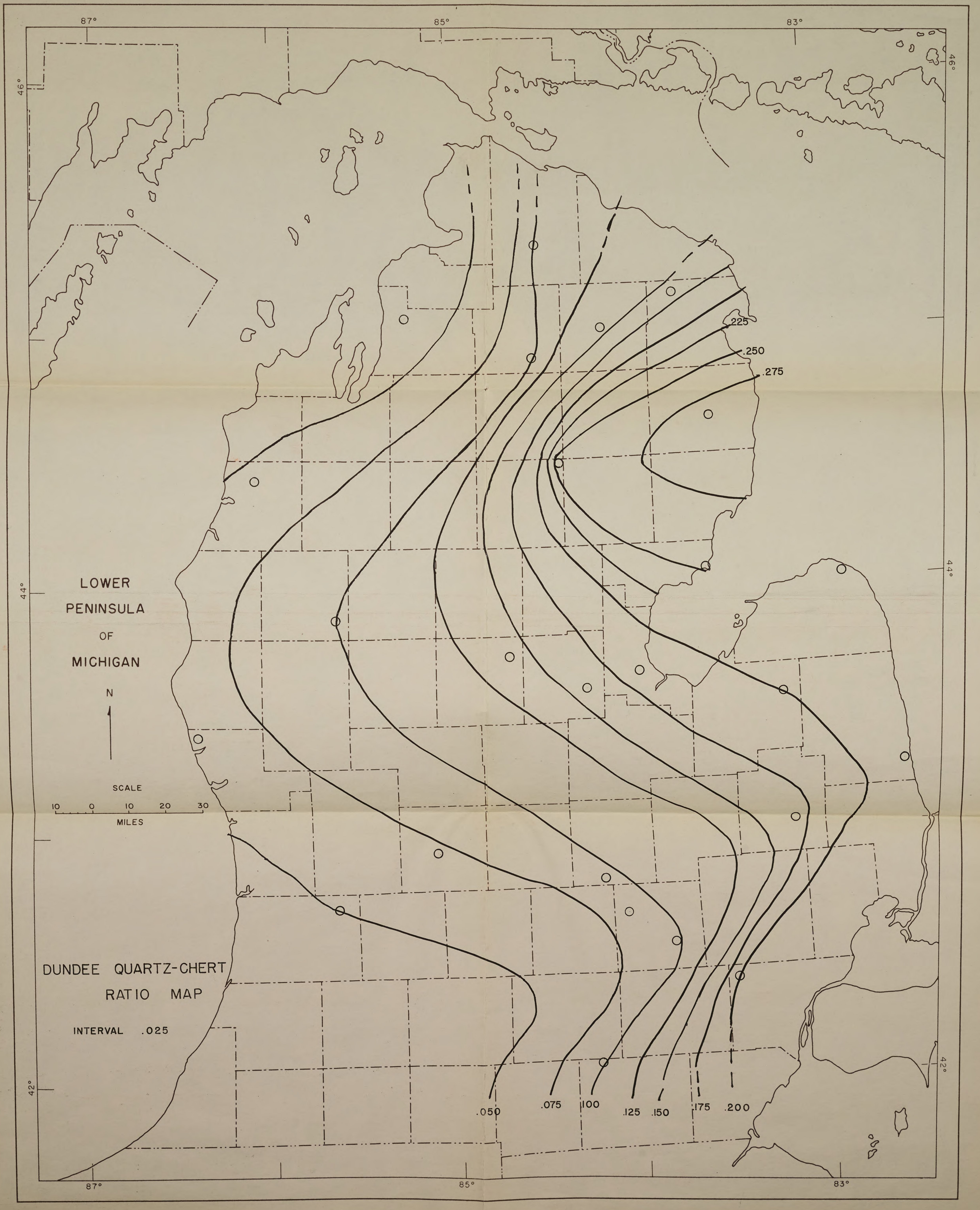
DUNDEE ISOPACH MAP

CONTOUR INTERVAL — 50'

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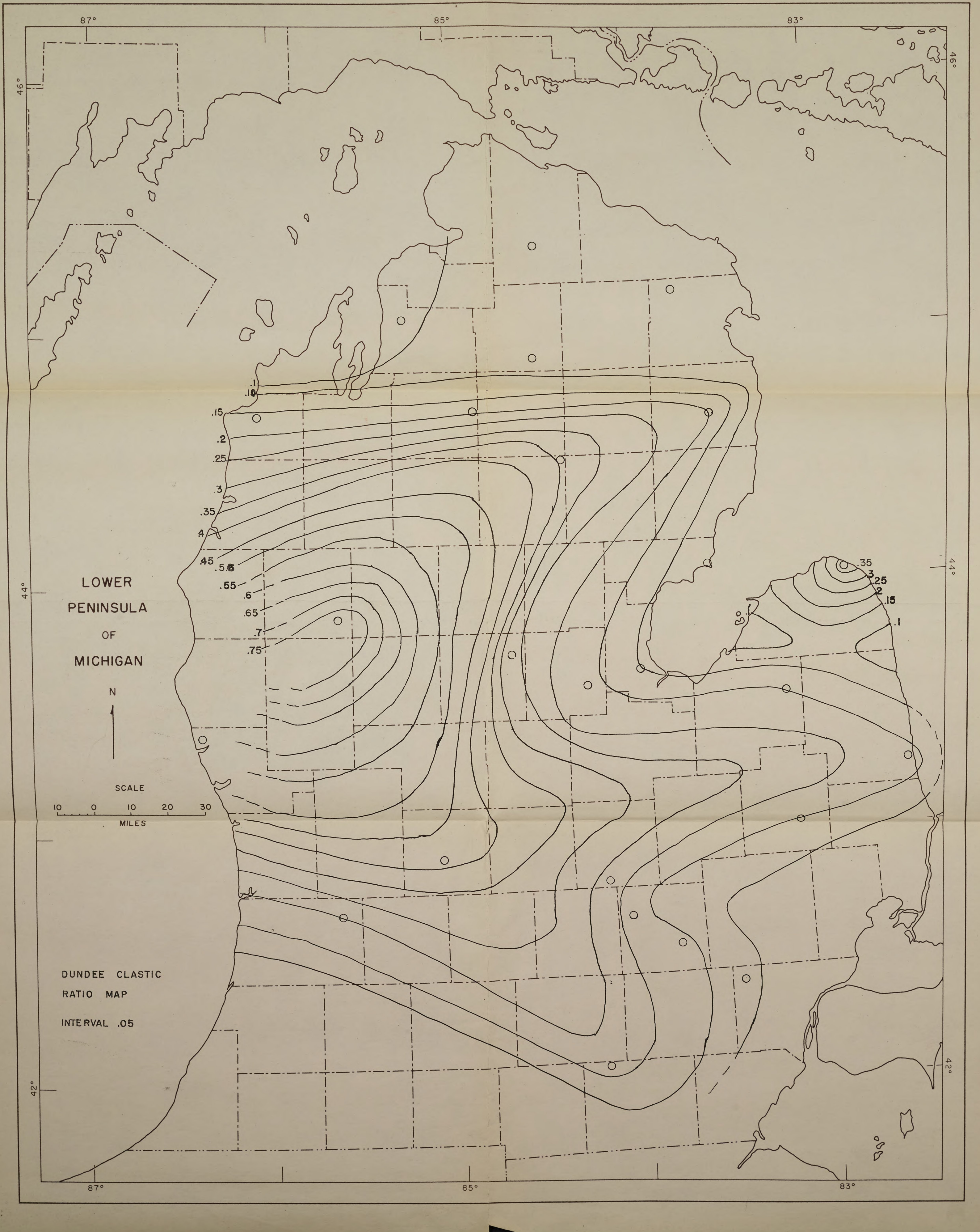

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