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A SEDIMENTARY ANALYSIS OF THE LOWER
DEVONIAN BOIS BLANC FORMATION
IN MICHIGAN

Thesis for the Degree of M. S.
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Donald Larry Goodrich
1957



SUPPLEMENTARY
MATERIAL
IN BACK OF BOOK

A SEDIMENTARY ANALYSIS OF THE LOWER DEVONIAN
BOIS BLANC FORMATION IN MICHIGAN

by

DONALD LARRY GOODRICH

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ABSTRACT

A quantitative analysis was performed on the sections from 24 wells representing the Lower Devonian, Bois Blanc formation, in the Michigan Basin.

This quantitative study involved sampling, removal of water solubles, removal of acid solubles, disaggregation, sieving, mounting and analyzing the quartz grains. The results of these analyses were expressed as numerical values of the lithologic ratios, which were used in the construction of the clastic, evaporite and chert-carbonate ratio maps.

The interpretation of the tectonic conditions was made by superimposing the isopach map over the various lithofacies maps and making a study of the patterns formed. These patterns indicate that the major portion of the sediments were derived from the Wisconsin Arch region and were deposited under stable shelf conditions.

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INTRODUCTION

History of the Michigan Basin

Since the beginning of extensive oil and gas development in Michigan, subsurface investigation of the Michigan Basin has been of increasing importance. In the past 30 years over 20,000 oil and gas wells have been drilled in Michigan. These have greatly contributed to our knowledge of stratigraphy and structure of the Basin.

Newcombe (1933) describes the areal extent of the Michigan Basin Province as follows:

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

The Basin is postulated to have been formed during Precambrian times. The sedimentary rocks which conform to this structure were deposited during Paleozoic and late Cenozoic times. During the Paleozoic, shallow bodies of water occupied the Michigan Basin at successive intervals. The various physical and chemical depositional agencies formed concentric saucers of sediments, each on top and smaller than the preceding, with each saucer representing a period of time. The total thickness of Paleozoic rocks within the central part of the basin approximates 15,000 feet. The Cenozoic deposits are

only represented by the various glacial features and strata deposited during the Pleistocene glacial epoch. These deposits occur as a mantle over most of the Paleozoic rocks, and attain a thickness up to 1200 feet in the northwestern section of the basin.

The tectonic elements surrounding the basin are closely related to the structural and depositional history of the Michigan Basin. Pirtle (1932) defines these elements as,

1. The Wisconsin Arch in the west.
2. The two limbs of the Cincinnati Arch, the Findlay Arch in the southeast and the Kankakee in the southwest.
3. The Canadian Shield on the north.

A recent article by Green (1957), expresses some doubt as to the correlation of the Kankakee Arch as part of the Cincinnati Arch complex. He stated, "no arching extends from Indiana into Illinois, where the Kankakee Arch is supposedly located." Green (1957) suggested that the name Kankakee Arch be dropped from the literature, and the name Francesville be given for the arch in Indiana.

The principal lines of folding of the Paleozoic rocks within the Michigan Basin trend in a northwest-southeast direction. Pirtle (1932) believes these folds were controlled by lines of structural weakness, which existed in the basement rocks at the time of deposition.

Newcombe (1933) believes the accumulation of oil and gas in local anticlines and folds within the basin were controlled by erosional unconformities, which show a direct relation to the various porous zones.

The development of oil and gas within the basin has been of great economic importance. With the increased knowledge of the sedimentary and structural characteristics revealed by the drill holes, investigation of individual stratigraphic units will be a contribution to the future studies of the Michigan Basin.

Sedimentary Facies

In the past 20 years, the facies concept of sedimentation has become increasingly important. The recognition and evaluation of facies changes are of prime importance for proper interpretation of the stratigraphic and structural fabric of an area.

Moore (1949) defines sedimentary facies as, "areally segregated parts of differing nature belonging to any genetically related body of sedimentary deposits." Moore also emphasized that facies are "variants or aspects of stratigraphic units having mutually exclusive space distribution." Krumbein (1952) states, "these variants or aspects may be expressed in terms of lithology, faunal content, tectonic implication, inferred environment of deposition, or in other

ways." This would in turn give rise to lithofacies maps, biofacies maps, tectofacies maps and environmental pattern maps. A sedimentary facies may involve a member, a formation or a group.

Facies changes are the direct result of irregularities, such as variations in climate, changes in sea level, tectonic adjustments or erosional cycles.

Lithotopes and Lithofacies

Krumbein and Sloss (1951) refer to lithotopes as, "an area of uniform sedimentation." Single or successive lithotopes can be observed in an area of sedimentation, i.e., marine to lagoonal.

Moore (1949) has also defined lithofacies as, "groups of strata demonstrably different in lithologic aspect from laterally equivalent rocks." The lithologic aspect is controlled by the lithotopes of which the lithofacies are composed. Therefore, a number of lithotopes form a lithofacies, which are derived from the gross aspect of the lithology.

The various groups of lithofacies can be expressed in the form of a lithofacies map. The various lithofacies maps provide a pattern and the means for interpreting the significant tectonics and environment that existed during the deposition of a rock unit.

Purpose

The purpose of this investigation is to determine the structural and environmental conditions which existed during the deposition of the Bois Blanc (Lower Devonian) formation in the Michigan Basin. This will be done largely by the preparation and interpretation of lithofacies maps.

Dice (1955) made a composite study of the Devonian rocks in the Michigan Basin. It is felt that a more accurate picture of the tectonic environment could be produced by analysing and interpretating lithofacies of the individual members of the Devonian period.

The author hopes that the maps and data obtained from this analysis will provide a better understanding of the various features during the deposition of the Bois Blanc formation.

STRATIGRAPHY OF THE BOIS BLANC FORMATION

Discussion

Until 1945 the Bois Blanc formation was not recognized as a separate formation in the Lower Devonian series. The lithologic subdivisions of this formation were considered by some as the upper portion of the Bass Island formation (Upper Silurian); others thought it to be in the Sylvania formation (Lower Devonian).

Landes, Ehlers and Stanley (1945), named and described the type section for the Bois Blanc formation. They described the type locality as, "the rocks of the formation are well-exposed on Bois Blanc Island, situated in Lake Huron, slightly less than $2\frac{1}{2}$ miles southeast of Mackinac Island." Most of the formation in the subsurface consists of light-colored carbonate and chert. The chert is most abundant in the lower part of the section and is usually interbedded with dolomite. The middle and upper parts consist mostly of limestone with some interbedded dolomite and are considered quite fossiliferous by these authors.

Rocks of the Bois Blanc formation crop out in the extreme northern part of the southern peninsula of Michigan. The strata is then only present in the subsurface, except in the southwestern area and along the southern margin of the

state where they have been removed by pre-Sylvanian erosion.

The thickness of the formation is approximately 300 feet at the outcrop on Bois Blanc Island and it attains its maximum thickness of 1,000 feet in southwestern Ogemaw county. The strata then progressively thin out to the south and southwest.

The Bois Blanc rocks lie unconformably on the Bass Island formation, except where the Garden Island formation exists in a patchy distribution in portions of the northern extremities of the southern peninsula. Where the Sylvania formation is absent, the Bois Blanc formation is overlain by the lower formation of the Detroit River Group.

Table I shows the stratigraphic position of the Bois Blanc in relation to Middle and Upper Silurian and Middle and Lower Devonian groups and formations. The Michigan formations were correlated with the New York formations of the same age.

TABLE I

GENERALIZED COLUMN OF LOWER DEVONIAN FORMATIONS
IN MICHIGAN CORRELATED WITH THE NEW YORK,
LOWER DEVONIAN FORMATIONS

Michigan Lower Devonian (Generalized)			Lithology and Thickness of Michigan Section		Correlated New York Lower Devonian (Generalized)		
Devonian	Middle	Dundee Formation		Limestone 0-400 Feet		Marcellus Formation	
		Det. River Grp.	Lucas Formation	Dolomite, Salt, Anhydrite 0-1124 Feet		Onondaga Group	
	Amherstberg Formation		Dolomite, Limestone and Sandstone 0-200 Feet				
	Sylvania Formation		Sandstone, Dolomite, Chert 0-540 Feet				
	Lower	Bois Blanc Formation	Limestone Dolomite, Chert 0-1000 Feet		Scholarie Formation		
		Garden Island Formation	Dolomite, Sandstone 0-30 Feet		Oriskany Formation		
		Mackinaw Breccia			Port Ewen Formation		
					Olsen Formation		
					Bercraft Formation		
	Silurian	Upper	Bass Island Group	Dolomite 50-570 Feet		Keyser Group	
Salina Group			Salt, Anhydrite, Dolomite, Shale 400-2300 Feet		Salina Group		
Middle		Lockport Group	Dolomite 55-130 Feet		Lockport Group		
		Clinton Group	Dolomite, Chert 150-275 Feet		Clinton Group		

LOCATION AND SELECTION OF WELLS

Requirements for Selection of Wells

In this study, special consideration should be given to the selection of the wells for the analysis. Wells should be selected to give the best vertical and lateral coverage of a particular formation.

Consideration should also be given to the type of drilling to obtain the subsurface samples. The common types of drilling, rotary or cable-tool, have a direct bearing on sample collection. The rotary type of drilling causes a certain amount of contamination by cavings, while the cable-tool drilling is almost free of foreign materials.

Selection of Wells

The availability of wells that penetrated into the Silurian rocks, thusly giving a complete section of the Bois Blanc formation, were fairly poor. Twenty-four wells were selected for this study, with the majority of these wells drilled by the rotary method. The location of the wells are shown on Map I. Table II describes the wells by county, township, driller, farm and thickness of formations.

A binocular microscope was necessary to pick the top and bottom of the Bois Blanc formation, for most of the wells.

MICHIGAN
DEPARTMENT OF CONSERVATION
GEOLOGICAL SURVEY DIVISION

MAP I

Location of Wells
Used in Bois Blanc
Facies Investigations

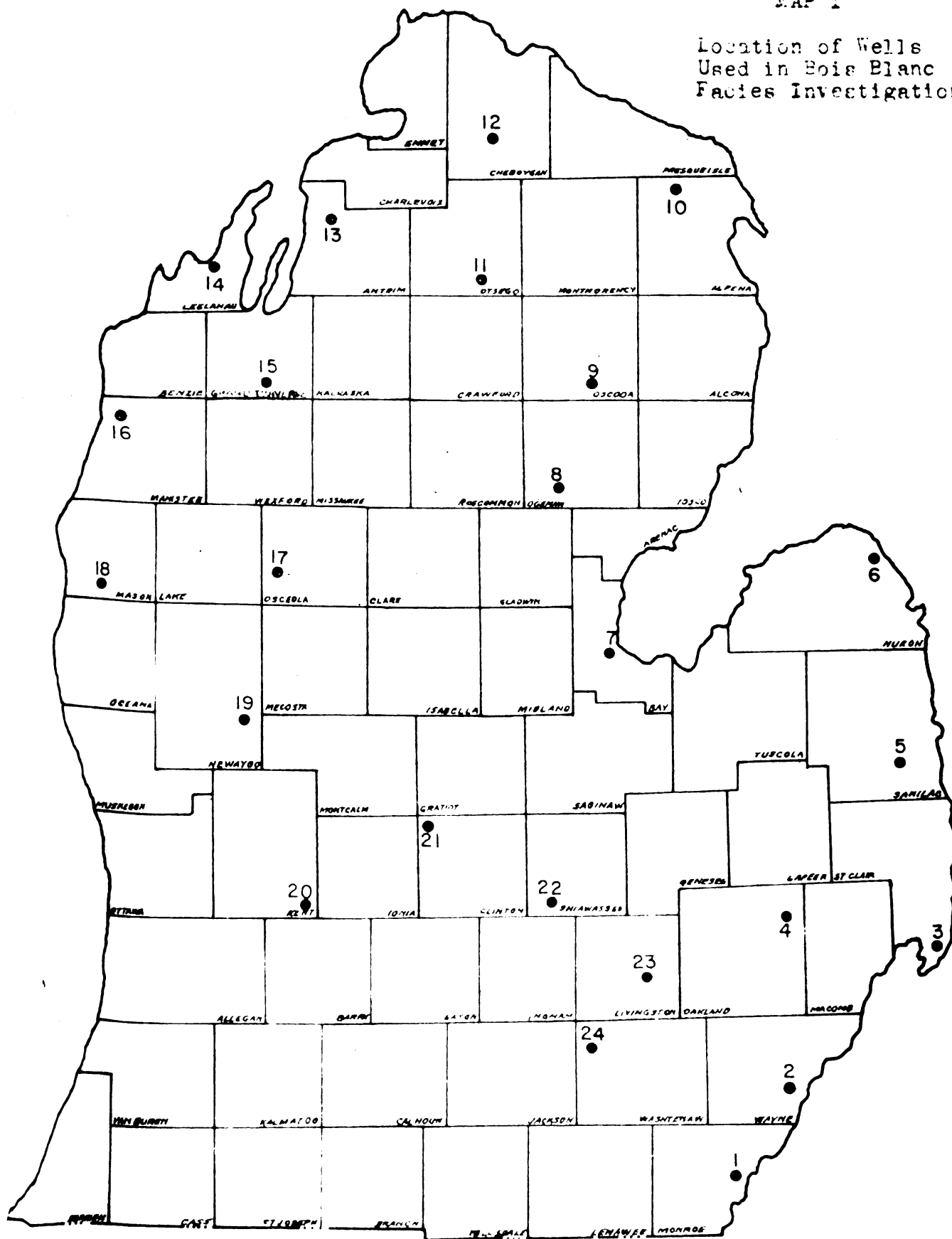


TABLE II
WELLS USED IN ANALYSIS

Well No.	County and Township	Company and Farm and Permit No.	Sec.	Twp.	Rg.	Thick-ness of Section in Feet
1	Monroe Frenchtown	Francis T. Canon E. Compau No. 1 No. 13867	12	6S	9E	38
2	Wayne Taylor	Sun Oil Co. Sun Inkster Jct.No.1 No. 17574	7	3S	10E	45
3	St. Clair Clay	Panhandle Eastern Sass No. 1 No. 19632	31	3N	16E	134
4	Oakland Oakland	Panhandle Eastern Schroeder No. 1 No. 19633	11	4N	11E	70
5	Sanilac Buel	Shell Oil Co. Burch No. 1 No. 11405	15	10N	15E	390
6	Huron Rubicon	Pure Oil Co. J. Stapleton No.1 No. 11834	22	17N	15E	522
7	Bay Kawkawlin	Gulf Refining Co. Salina No. 1 No. 10551	34	15N	4E	335
8	Ogemaw West Branch	Ohio Oil Co. Reinhardt Con.No.1 No. 12898	35	22N	2E	955
9	Oscoda Mentor	Ohio Oil Co. Mio Unit Area No.1 No. 11995	30	25N	3E	600
10	Alpena Long Rapids	C. W. Teater Nevins No. 1 No. 2960	18	32N	6E	300
11	Otsego Chester	Brazos Oil & Gas State-Chester HENo.1 No. 16902	15	29N	2W	458

TABLE II--Continued

Well No.	County and Township	Company and Farm and Permit No.	Sec.	Twp.	Rg.	Thick-ness of Section in Feet
12	Cheboygan Ellis	Roosevelt Oil Co. Ormsbee No. 1 No. 14936	1	34N	2W	310
13	Antrim Central Lake	Ohio Oil Co. H. Chamberlain No.1 No. 10004	14	31N	8W	360
14	Leelanau Centerville	Copeland-Barton L. Overby No. 1 No. 10103	5	29N	12W	385
15	Gr. Traverse Paradise	Carter Oil Co. Lemcool No. 1 No. 18512	9	25N	10W	390
16	Manistee Pleasanton	Carter Oil Co. Fred Crook No. 1 No. 17709	35	24N	15W	240
17	Osceola Lincoln	Ohio Oil Co. P.N. Stedman No. 3 No. 12802	29	18N	10W	120
18	Mason Eden	Superior Oil Co. M. Sippy etal No. 17 No. 18905	25	17N	16W	80
19	Newaygo Croton	Sun Oil Co. Hotchew No. 1 No. 15373	29	12N	11W	73
20	Kent Bowne	Skelly Oil Co. Alto L.P.G. Storage No. 1, No. 17535	3	5N	9W	50
21	Clinton Lebanon	Parsons Brothers Angie Sillman No. 1 No. 19272	27	8N	4W	95
22	Shiawassee Perry	Panhandle Eastern S. Nemcik No. 1 No. 16738	23	5N	2E	220
23	Livingston Genoa	Panhandle Eastern M & G Bauer No. 1 No. 11818	25	2N	5E	187
24	Washtenaw Sylvan	Johnson & Pew Mohrlock Comm No. 1 No. 19751	14	2S	3E	80

The top of the formation contains light carbonates and some brown to gray nodular chert. The chert differs from the sandy, and white tripolitic variety found at the base of the Sylvania formation. Dark carbonates occur at the base of the Detroit River Group, which overlies the Bois Blanc formation where the Sylvania formation is missing. The bottom of the Bois Blanc formation is characterized by chert, which is lacking in the underlying Garden Island or Bass Island formations.

LABORATORY PROCEDURES

Sampling Method

The samples used were obtained from the Michigan Geological Survey or the Gulf Sample Well Library at Michigan State University.

The section representing the Bois Blanc formation was picked from each set of selected sample wells. The vertical section ranged from about 50 feet to approximately 1,000 feet. The maximum allowable by the Michigan Geological Survey was removed from each sample vial to represent the section. The weight of sample per foot depended on the vertical distance represented by each vial. The sample was then stirred with a magnet to remove the small pieces of drill bit and other iron. Obvious contamination, such as fragments of shale, which are foreign to the section, were removed. The composite sample was then weighed and made ready for the following treatments.

Removal of Water Solubles

Weigner (1927) found that by boiling the sample in water, the water soluble salts will go into solution and then may be removed by filtering or pipetting.

Each sample was treated with about 200 milliliters of tap water and boiled for two hours. Ten milliliters of clear

solution were siphoned off, and half a gram of silver nitrate was added to check the salinity of the solution. This process was repeated until the precipitate formed was not more dense than that formed by treatment of normal tap water, indicating that about all chlorides had been removed. The sample was then dried and weighed.

Removal of Acid Solubles

A 25 percent solution of hydrochloric acid was then added to the remaining sample, to remove the carbonates. After the effervescence has ceased; the sediment was allowed to settle. The supernatant liquid was drawn off and filtered. A 50 percent hydrochloric acid solution was added to the sediment, pipetted and filtered, and then a 100 percent hydrochloric solution was added and gently heated to remove the less soluble carbonates, which resisted the earlier treatments. The sediment was then washed several times, and tested with blue litmus paper, until no acid remained. The sediment was dried and weighed and its weight added to the dry weight of the material retained by the filter paper. The difference in weight was recorded as acid solubles.

Disaggregation

The major portion of the argillaceous material and Quartz grains are scattered in the carbonates of the Bois Blanc formation and were therefore, broken free from the

sample by the preceding treatments, but there are minor amounts of argillaceous material and quartz grains, included in the chert. In order to determine these minor amounts some type of disaggregation was necessary.

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

Two techniques of disaggregation were investigated and validated. First, the Super-Sonic disaggregation was investigated. This type of experiment has been suggested by various individuals, but no literature was found on the subject.

For the experiment the author used the Sonic Oscillator in the Microbiology department at Michigan State University. A small sample of the Antrim shale was placed in the oscillator, using water as the immersing medium. The machine was allowed to operate for seven minutes. Upon removal of the sample, it was found that approximately one-fourth of the material had been broken free from the massive fragments. The sample was poured into a vial and placed on a centrifuge for ten minutes, to speed up settling velocities. After removing the sample from the centrifuge the solution was allowed an additional settling period of 24 hours. At the end of this time, some of the material still remained in suspension.

It is felt by the author that more experimental work should be extended to the application of the idea of super-sonic

disaggregation, before it can be successfully used in this type of research.

Potassium hydroxide was used for the second technique. This proved to be the best disaggregation agent. A crystal of quartz, and a fragment of chert, both of known weight were allowed to boil in a supersaturated solution of potassium hydroxide. After three hours, the fragment of chert was completely dissolved, while the quartz remained insoluble. It was also noted that a part of the beaker had also been taken into solution. In order to correct for this error, the residue and potassium hydroxide were boiled in nickel crucibles. All of the sediment was treated in this way.

The sample was washed until it was neutral, and then dried and weighed. The difference in weight yielded the chert fraction.

Sieving

The remaining residue contained quartz and argillaceous material.

The 230 and 325 mesh sieves were chosen for this analysis. The 230 sieve divides sand and silt, while the 325 sieve separates the silt from the clay.

The material caught on the 230 mesh screen was found to be quartz. Microscopic examination of the material caught on the 325 sieve, revealed it to be subangular quartz, with a few stray clay particles. The silt portion was, therefore,

included with the quartz fraction caught on the 230 sieve. The minus 325 material was the clay fraction.

This material was dried and weighed, the quartz and clay fractions were thus obtained for the completion of the quantitative analysis.

Mounting and Analyzing the Quartz Grains

The material represented by the quartz fraction was used for further microscopic examination.

A portion of the materials were mounted in Canada balsam on clean glass slides. Microscopic examination of the slides revealed that the large "egg-like" grains were quartz. These quartz grains were also quite round and nearly spherical.

Twenty-five of the grains were traced under low power of the polarizing microscope. A few of the grains are shown on Plate I. The methods and formulas outlined by Krumbein and Sloss (1951) were used to determine the sphericity and roundness of the quartz grains.

The average sphericity was found to be .856, with perfect sphericity equal to one.

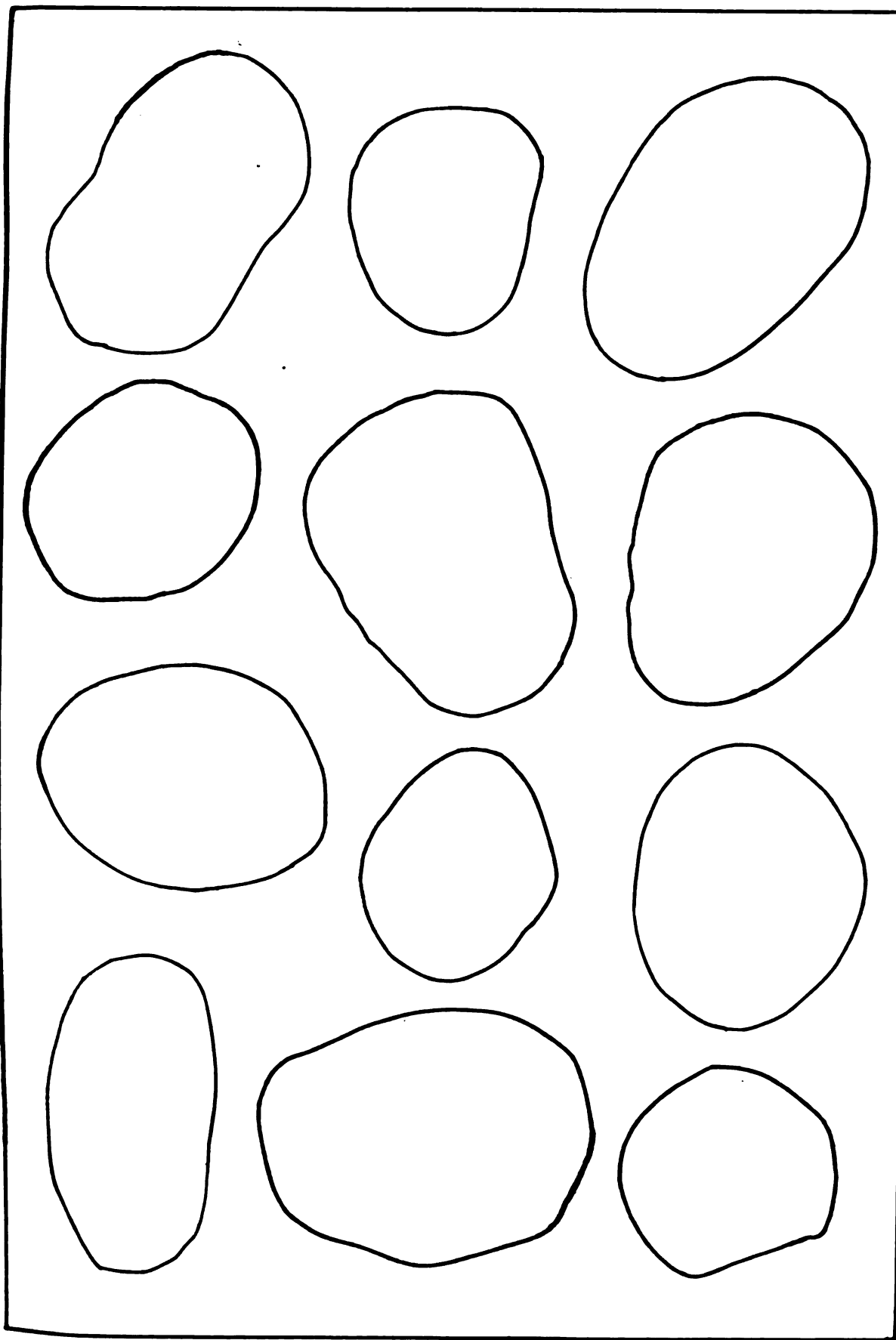
The average roundness was found to be .643, with perfect roundness, also one.

Errors in Sampling and Treatment

Changing the sample from one container to another and wet sieving of the samples introduced minor errors. These

PLATE I

REPRESENTATIVE QUARTZ GRAINS FOUND IN THE BOIS BLANC FORMATION
(NORMAL SIZE X 30)



errors are only a small percentage of the original sample weight, and, therefore, would not alter the computations derived from the sample weights.

Results of the Laboratory Analysis

The results of the laboratory analyses performed on the 24 wells are listed in Table III.

TABLE III
QUANTITATIVE ANALYSIS

Well Number	Sample Weight	Water Solubles	Acid Solubles	Chert Fraction	Clay Fraction	Quartz Fraction
	<u>Grams</u>	<u>Grams</u>	<u>Grams</u>	<u>Grams</u>	<u>Grams</u>	<u>Grams</u>
1	19.32	0.11	10.56	7.21	0.44	1.02
2	62.88	0.20	43.34	14.66	3.40	1.28
3	51.92	0.08	35.38	12.98	1.16	2.32
4	40.98	0.02	28.96	8.30	2.36	1.34
5	107.94	0.12	82.58	12.08	8.84	4.32
6	104.67	3.33	60.79	35.22	3.23	2.10
7	96.87	0.10	63.34	26.32	4.45	2.66
8	94.51	0.15	57.07	28.21	4.34	4.73
9	118.43	0.27	69.85	32.74	6.17	9.39
10	118.71	0.38	63.45	45.19	4.57	5.11
11	118.10	0.30	71.80	31.25	6.20	8.56
12	123.02	0.08	57.51	57.60	3.41	4.43
13	94.69	0.11	65.19	19.42	6.03	3.93
14	143.82	1.21	94.61	26.02	12.55	9.43
15	116.41	0.60	65.99	33.81	4.88	11.63
16	121.69	0.99	97.57	11.61	9.14	2.37
17	59.98	0.28	40.48	14.39	2.31	2.53
18	48.49	0.90	41.72	3.86	1.19	0.82
19	77.01	0.51	64.67	6.78	3.91	1.16
20	24.96	0.08	19.96	0.87	3.39	0.66
21	48.01	0.74	31.66	10.00	2.75	2.86
22	110.26	0.13	78.87	17.96	6.11	7.18
23	101.11	0.08	80.70	12.84	3.02	4.47
24	47.23	0.42	33.66	9.11	2.44	1.60

LITHOLOGIC INTERPRETATIONS

Lithologic Ratios

Krumbein (1948) has devised a system of ratios for mapping purposes. The most important factor of a section is the gross lithologic character. Krumbein, therefore proposed,

Group the rocks into clastics and non-clastics on the usual conventional basis. Add the thicknesses (or percentages) of the clastics, and divide by the sum of the thicknesses (or percentages) of non-clastics.

This constitutes a clastic ratio, which can be more easily visualized by the formula:

$$\text{Clastic Ratio} = \frac{\text{conglomerate} + \text{sandstone} + \text{shale}}{\text{limestone} + \text{dolomite} + \text{evaporites} + \text{chert}}$$

A clastic ratio of two, for example, means that two feet of clastics were deposited for every foot of non-clastics.

Variations within the non-clastics or clastics can be represented by ratios of lithologic subtypes. The common non-clastic subtype is the evaporite ratio and the chert-carbonate ratio. These ratios are formed by the formulas:

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

$$\text{Chert-Carbonate Ratio} = \frac{\% \text{ chert}}{\% \text{ carbonate}}$$

The chert-carbonate ratio was used because of the prominent quantities of non-clastic chert and carbonate within the Bois Blanc formation.

Table IV shows the lithologic ratios for each well. These ratios were computed from the information listed in Table III.

Construction of Lithofacies Maps

In a highly diversified section, with alternating beds of shale, limestone, sandstone, and anhydrite in lenses or discontinuous beds, it is practically impossible to show by conventional maps what and where the facies changes take place. These relationships, in respect to other lithologic groups, can be shown clearly on lithofacies maps.

Lithofacies maps do not depict a complete geologic history, but they do offer the interpreter a simplified form of complex stratigraphic data, so that broad concepts can be expressed.

The ratios obtained from Table IV were plotted in their respective positions on a base map. Lines of equal ratios, expressed as an arithmetic number, were contoured from this data.

An isopach map of the Bois Blanc formation was constructed on semi-transparent paper. By placing the isopach map over the specific ratio map, interpretation of Krumbein's relationships of isopach and facies lines was facilitated.

The maps constructed from the data compiled in Table IV are the clastic ratio, evaporite ratio and chert-carbonate

ratio maps. The isopach map was constructed from the thicknesses given in Table II. These maps are located in the pocket on the back cover of this thesis.

TABLE IV
LITHOLOGIC RATIOS

Well Number	Clastic Ratio	Evaporite Ratio	Chert-Carbonate Ratio
1	0.081	0.0104	0.683
2	0.080	0.0023	0.414
3	0.072	0.0046	0.299
4	0.099	0.0007	0.287
5	0.139	0.0015	0.146
6	0.054	0.0549*	0.579
7	0.079	0.0016	0.416
8	0.106	0.0026	0.494
9	0.151	0.0039	0.469
10	0.089	0.0060	0.712
11	0.143	0.0042	0.435
12	0.068	0.0014	1.002
13	0.118	0.0018	0.298
14	0.180	0.0128	0.275
15	0.165	0.0091	0.512
16	0.105	0.103	0.119
17	0.088	0.0069	0.356
18	0.043	0.0216	0.093
19	0.071	0.0079	0.105
20	0.194	0.0040	0.044
21	0.132	0.0234	0.316
22	0.137	0.0017	0.228
23	0.080	0.0099	0.159
24	0.094	0.0125	0.271

* This value was disregarded, because it is completely out of proportion with the other values.

INTERPRETATION OF FACIES MAPS

Methods of Geologic Interpretation

Krumbein (1952) found that by superimposing isopach and facies contours, six types of patterns were evolved. These are illustrated in Plate II, Figures 1 through 6, with the solid lines representing the isopach lines and the dotted lines as any specific lithologic ratio.

In describing some of the patterns, Krumbein stated:

1. The linear subparallel [Plate II, Figure 1] may occur under conditions where clastic sediments are spread over a subsiding area in decreasing amounts away from the source, so that the clastic ratio lines tend to decrease as the isopachs increase, because of increasing lime deposition.

2. The curvilinear discordant pattern [Plate II, Figure 3], may arise when a local concentration of clastics is poured into a subsiding area, as in a delta. Here the clastic ratio lines may project farther into the basin than normally.

3. The concentric ovate pattern [Plate II, Figure 4] is characteristic of evaporites in an intracratonic basin.

4. The irregular spotty pattern [Plate II, Figure 6] occurs near the deteriorating edges of sheet sands, where the accumulation becomes patchy or spotty.

Within an intracratonic basin, such as the Michigan Basin, Krumbein (1952) recognized three predominate patterns. The interpretation of these patterns would infer the tectonic conditions, which controlled deposition. The three patterns and their related tectonics are:

**RELATIONS BETWEEN
ISOPACHS (SOLID) AND FACIES LINES (AFTER KRUMBEIN, 1952)**

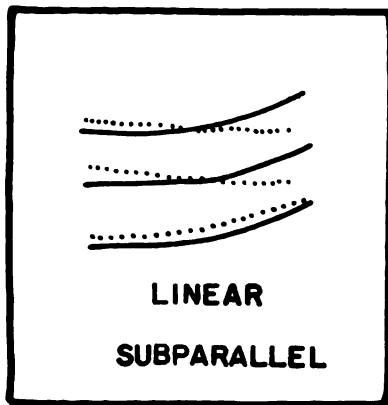


FIG. 1

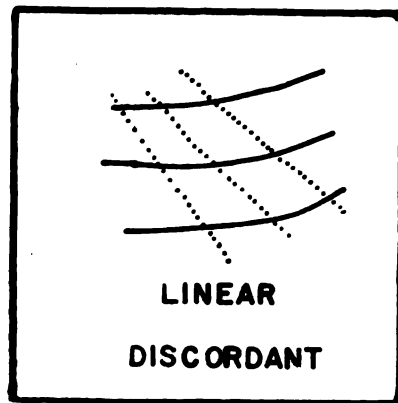


FIG. 2

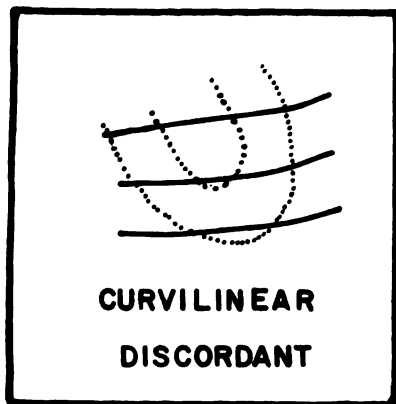


FIG. 3

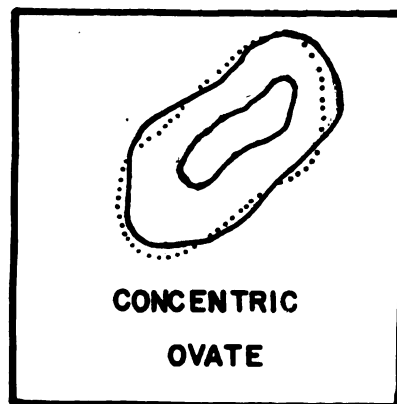


FIG. 4

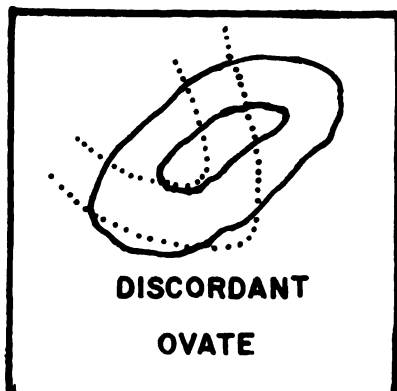


FIG. 5

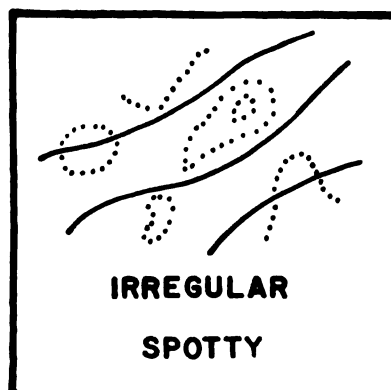


FIG. 6

1. Curvilinear-discordant pattern, suggesting a nearby orogenic or epeirogenic source.

2. Concentric-ovate pattern, infers a nearby epeirogenic or orogenic source, or a possible distant source.

3. Discordant-ovate pattern, indicates a nearby or distant epeirogenic source.

If there has been erosion after deposition, the relationship between facies and isopachs may not be clear. The stratigraphic unit being studied should have a conformable top for proper interpretation. A discordant trend of the isopach and lithofacies lines suggests a possible erosional rather than depositional surface.

Geological Interpretation

By superposing the isopach over the individual facies maps, separate interpretations were possible. The different types of structures resolved from the maps will be made in reference to the counties of Michigan.

The Clastic Ratio Map. Starting in the northeast section of the Southern Peninsula of Michigan, the significant pattern in the Alpena, Montmorency area is represented by the curvilinear discordant type. Proceeding to the south and west, the pattern changes into the linear discordant type in Oscoda, Alcona, Roscommon and Clare counties. The outline reverts to the curvilinear discordant type in Ogemaw county.

The northwest and western parts of the southern peninsula are represented by a linear subparallel pattern. This

is recognized in Benzie, Mason and Lake counties.

To the south, the prominent pattern is the linear discordant variety. This pattern seems to be more dominant in the southwest, in Kent, Calhoun and Gratiot counties. In a restricted area in the region of Livingston county, an inverted curvilinear discordant pattern is noted.

The thickest accumulation of sediments is in Ogemaw County. If more control were available, a discordant ovate pattern would have been present and this would suggest deposition in an intracratonic basin from a nearby epeirogenic or orogenic source. This seems quite feasible, because the linear discordant pattern which is found north, west and south of Ogemaw county, suggest a possible shelf area, with the sediments coming from a western orogenic source.

The curvilinear discordant pattern is seen further north and south away from Ogemaw county, suggesting deep or shallow neritic conditions.

The western side of the lower peninsula, with its linear subparallel pattern, is characteristic of a shelf area receiving its sediments from a nearby orogenic or epeirogenic source, or even possibly a distant source.

The major structural trends determined from the clastic ratio map are summarized as follows:

1. A broad trough is noted from Cheboygan, south to Clare county, with the source of materials possibly coming from the northwest.

2. A possible ridge, extending from Newaygo county east to Tuscola county, averages 20 miles in width.

3. Another trough, but not quite as broad, in the vicinity of Clinton county, is receiving its sediments from the southwest. This trough is separated by a ridge, from the small, but not very deep, set of eastern troughs. Two of these depressions are receiving their sediments from the northeast and the other trough received deposits from the southeast.

The Evaporite Ratio Map. In the Cheboygan, Alpena area, the curvilinear discordant pattern is again present. From Ogemaw county and westward to Grand Traverse, and then south to the southern extent of Clare county, the linear subparallel pattern prevails. South of this line, the dominant pattern is the curvilinear discordant type, except in a portion to the southeast, where a linear discordant pattern is recognized.

Krumbein (1952) states, "the concentric ovate pattern is characteristic of evaporites in an intracratonic basin." It is conceivable that possible pre-Sylvanian erosion would have destroyed a concentric ovate pattern in the southwest.

The curvilinear discordant and linear subparallel patterns indicate a probable shelf deposition from a nearby orogenic source.

The structural features represented on the evaporite ratio map are as follows:

1. A trough-like structure in Antrim county, with a source area of sediments from the north.

2. Another trough in the Crawford, Wexford areas, with the probable source of sediments from the west.

3. A fairly wide trough in the Oakland, Washtenaw area, which received its sediments from the southwest.

4. The prominent feature on the map is the concentration of evaporites produced by basinal or restricted deposition, in the vicinity of Kent, Clint, Newaygo, Montcalm and Gratiot counties. This deposit has a northwest trend.

The Chert-Carbonate Ratio Map. A curvilinear discordant pattern is again seen in the vicinity of northern Otsego and Cheboygan counties.

Proceeding south or west, a linear discordant pattern seems to cover the major portions of the remaining area. Some spotty, linear subparallel patterns appear, such as in the south central area, around Livingston and Ingham counties, but they are not as clearly defined as the particular linear discordant type.

The pattern in the Cheboygan area, shows a possible deeper section, which received the sediments. This deeper intracratonic area is bordered on the south and west by a possible shelf feature.

There is also the possibility that a discordant ovate pattern would have appeared again in the Ogemaw area, if more control indicated closure of the isopach lines.

The structures of the chert-carbonate ratio map are:

1. A trough in the Cheboygan, Otsego area, which was fairly broad, and trending to the southwest.
2. A second trough was found in Monroe and Washtenaw Counties.

GEOLOGIC HISTORY

With the knowledge of the features that have been brought out by the facies maps, the various structural forms associated with the area, and the paleontologic forms that have been recognized and identified within the formation, an attempt will be made to reconstruct the geologic history immediately before and during Bois Blanc time.

The Silurian period closed very quietly in the Michigan Basin. The epeirogenic sea that occupied the area was partially isolated and fairly warm. These features are attributed to the deposition of the Bass Island formation.

An unconformity exists between the Bass Island and the Garden Island formations. The correlative of the Garden Island, the Oriskany sandstone in eastern New York, was deposited on eroded Lower Devonian strata. This correlation can be observed in Table I. As you trace the formations westward to southwestern Ontario, the Oriskany strata lie directly on Upper Silurian sediments. This suggests the possible conclusion that one of the first inundations of the Devonian sea deposited these sediments in New York and also in the Michigan Basin area.

Withdrawal of the sea, accompanied by some subsidence in the eastern New York area, and subsequent erosion of some of the sediments, opened the way for the deposition of the

Oriskany (New York) and the Garden Island (Michigan) formations.

An erosional unconformity also exists, but not quite as sharp between the Garden Island and the Bois Blanc formations. Small, low areas of the Garden Island formation remained in the northern portion of the southern peninsula, and were not subject to complete erosion. This would account for its patchy and restricted distribution.

The major structural features that surrounded the Michigan Basin, and were present during Bois Blanc time are: The Cincinnati Arch to the south with its two limbs, the Kankakee (?) to the southwest and the Findlay to the southeast; the Wisconsin Dome to the west, and the Canadian Shield Complex to the north.

The Kankakee and Findlay arches started to rise in early Devonian time, and were well established at the conclusion of the Devonian period.

The post-Garden Island emergence and erosion interval was followed by widespread inundation of the Onondaga sea. The Bois Blanc formation was deposited in this sea, covering the remnants of the Garden Island and the twice eroded Bass Island (pre-Garden Island and pre-Bois Blanc) sediments.

Chert and dolomite are abundant in the lower portion of the Bois Blanc formation. The chert in this section occurs in irregular masses, beds, and nodules. Some speculation has been made as to the origin of chert. Twenhofel (1950) stated

that nodular and irregular masses of chert can be attributed to primary deposition. He also attempted to correlate these cherty deposits with river mouths. Pettijohn (1957) regards most of the chert nodules and discordant masses as secondary and of organic or metasomatic origin.

Landes, Ehlers and Stanley (1945) discovered the reef forming coral, Favosites, present in the chert section. This might be indicative of a biohermal structure.

The middle section of the Bois Blanc formation is composed of limestones, dolomitic limestones, and irregular masses or nodules of chert. Landes, et al. (1945) described this portion of the formation as being highly fossiliferous, and correlated these fossils with the fauna of Lower Onondaga age of southwestern Ontario and New York.

The upper portion is predominately limestone. Landes, et al. (1945) recognized a southwest trending biohermal structure in the vicinity of Mackinaw City.

Erosion of the area, following the withdrawal of the Onondaga sea to the east, removed most of the Bois Blanc formation from the flanks of the Kankakee and Findlay arches. The surface that remained, was subsequently covered by Sylvania or higher Detroit River strata.

CONCLUSIONS

The geologic interpretation of the various facies maps, and other information substantiated the idea of a stable shelf condition in the western side of the Michigan Basin. A few of the important reasons are listed below:

1. Minor amounts of detrital material.
2. Abundant silt-size quartz.
3. Marine limestone, containing highly spherical quartz grains.
4. Biohermal structures.
5. Linear subparallel pattern.

Minor downwarping of the Michigan Basin also took place during Bois Blanc times.

The concentration of evaporites in the southwest portion of the Southern Peninsula of Michigan, indicates a lagoonal type of environment might have been present.

The basin deepened to the east, and the invasion of the Bois Blanc Sea was from the east.

The basin was receiving sediments from all of the structures surrounding the basin. The greatest thickness of sediments seem to have been derived from the Wisconsin Dome region. Minor amounts of sediments were also being received from the Canadian Shield complex.

SUGGESTIONS FOR FURTHER STUDY

In the process of doing this research, many problems confronted the author. It is felt that some of these problems are in themselves, individual theses.

More research should be done with chert. Quite a few articles have been written on the subject, but its possible origin is still in doubt.

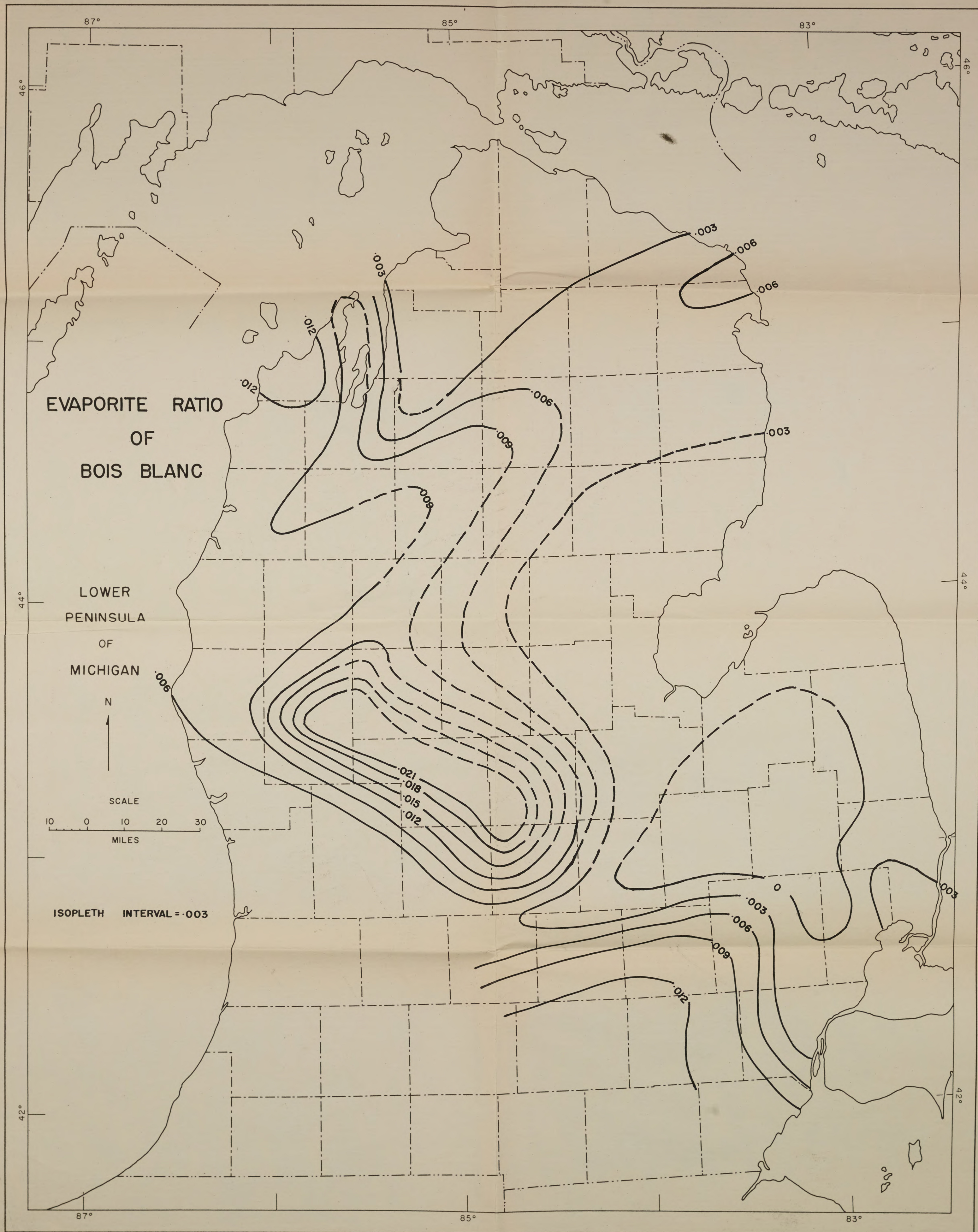
If the proper equipment is available, the new study of super-sonics, as applied to problems in sedimentation or other geologic fields, may prove of immense value.

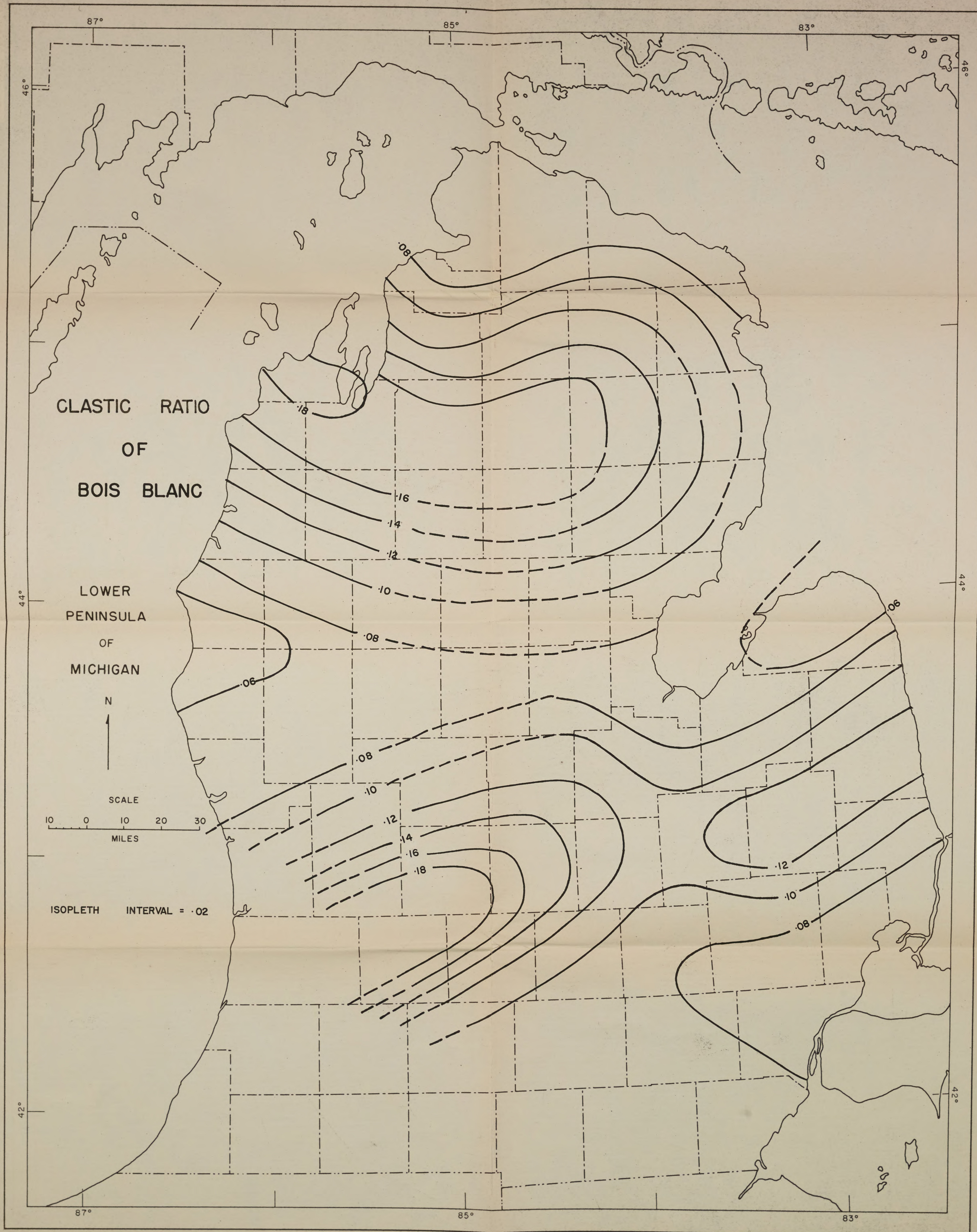
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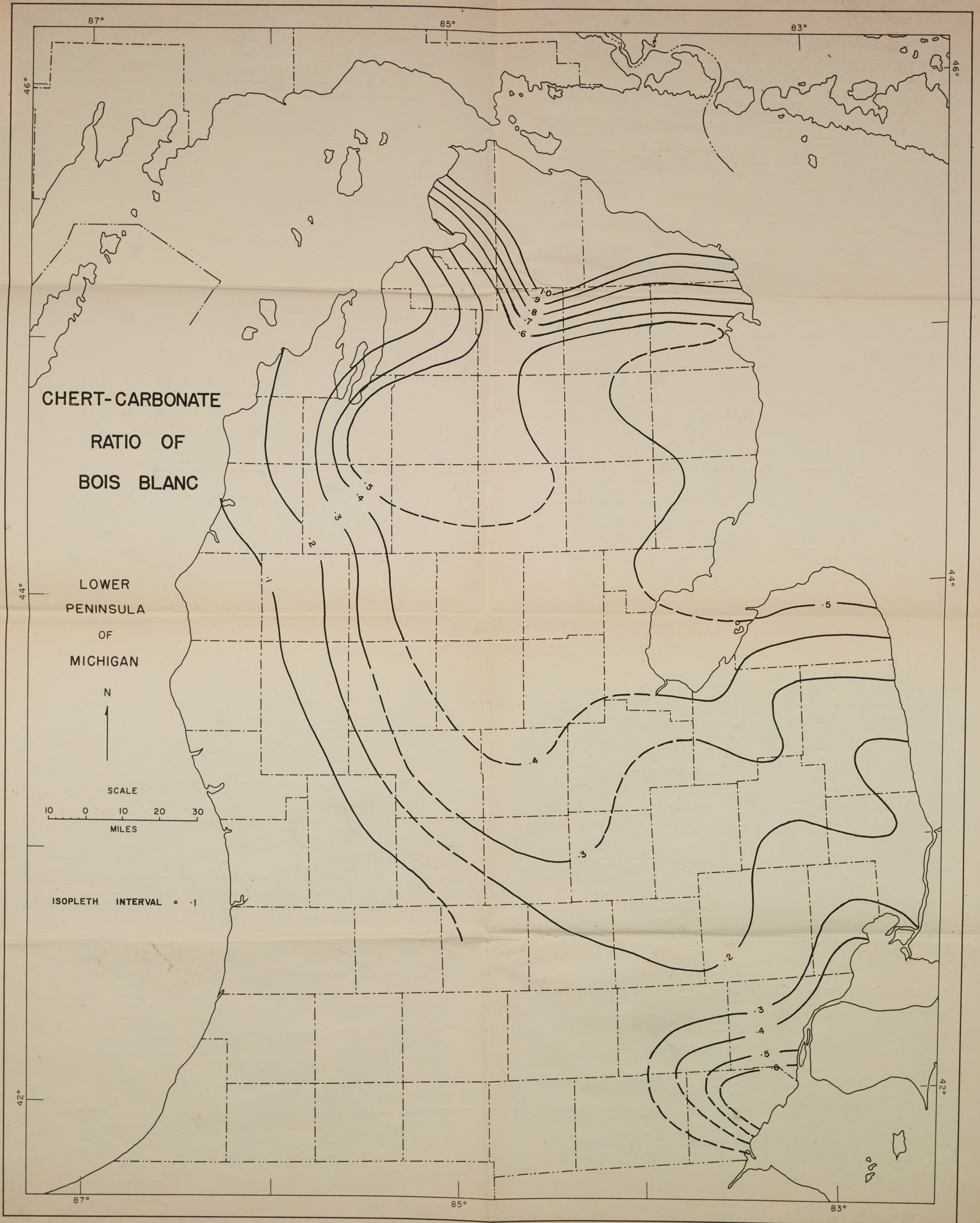
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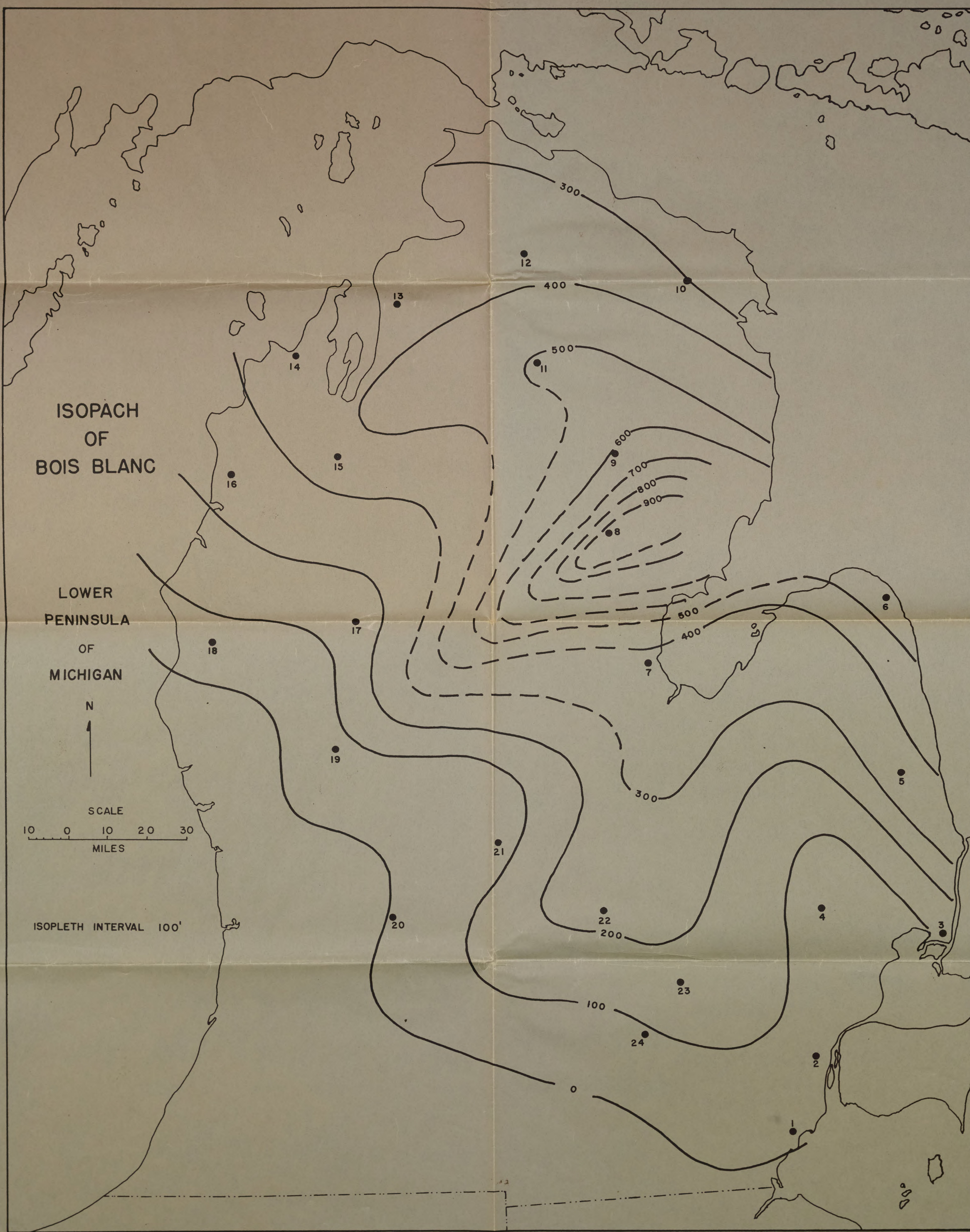
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