A RAPID METHOD FOR DETERMINING THE MAGNESIUM / CALCIUM RATIOS OF WELL SAMPLES AND ITS USE AS AN AID IN PREDICTING STRUCTURE AND SECONDARY POROSITY IN CALCAREOUS FORMATIONS

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A RAPID METHOD FOR DETERMINING THE MAGNESIUM/CALCIUM RATIOS OF WELL SAMPLES AND ITS USE AS AN AID IN PREDICTING STRUCTURE AND SECONDARY POROSITY IN CALCAREOUS FORMATIONS

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ABSTRACT

Fields producing oil from the Rogers City dolomite in the Michigan Basin are becoming increasingly more difficult to discover. To aid in new discoveries, a method of sample analysis based on the Versenate method, which quickly gives the magnesium/calcium ratio of well samples, has been devised. A study of these ratios shows that dolomitization of the Rogers City limestone occurs at two places: (1) on the apices of folded structures, as a result of solution and replacement by ascending waters along tension fractures; and (2) in long narrow bands, the result of high-magnesium waters ascending faults and master fissures. These dolomitized areas have distinct flank-zones of decreasing magnesium/calcium ratios, which aid materially in predicting the location of dolomites, and their distance from control points. Secondary dolomites in the Rogers City limestone are usually porous and serve as good reservoirs for the possible accumulation of oil and gas.

This method of magnesium/calcium ratio analysis should aid materially in predicting the presence of local secondary dolomitization in any calcareous formation and in any area, and thus help to

locate more easily possible oil production in reservoirs created in secondary dolomites.

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INTRODUCTION

In fields producing oil from the Rogers City formation, in the central Michigan Basin, production is generally limited to dolomite zones. This formation is normally a fossiliferous, marine limestone, with no primary dolomite in the central Michigan area.[1] In its normal form, the Rogers City formation apparently has no effective porosity capable of containing oil or water. Yet, fortunately, when the formation is penetrated by wells on structure, it is often found to be an extremely porous and permeable dolomite. This dolomite is common in the western half of the central portion of the "Basin," particularly in Clare, Osceola, Mecosta, Isabella, and Montcalm Counties. The area has been well defined by Cohee and Underwood.[2] Often the oil fields producing from the dolomite zones in the Rogers City formation are very small in area, and are difficult, if not

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[1] G. V. Cohee and L. B. Underwood, U. S. Geol. Survey Oil and Gas Investigations, Preliminary Map 38, "Lithology and Thickness of the Dundee Formation and the Rogers City Limestone in the Michigan Basin" (1945).

[2] *Ibid.*

impossible, to locate other than by closely spacing subsurface contour points.

In some localities the dolomite zones are not directly related to folded structure, but extend in narrow, straight bands often less than one-quarter of a mile in width and sometimes several miles in length.[3] Such zones are impossible to locate by conventional methods, and are found mainly by chance.

Dolomite on top of folded structures, and in bands unrelated to structures, is not limited to the Rogers City formation, nor to the central portion of the Michigan Basin. Landes[4] describes a narrow-banded type of dolomitization, unrelated to structure, in the Adams and Deep River pools in Arenac County, Michigan, and also mentions the dolomitization in Trenton structures of Ohio and Indiana. Similar types of local dolomitization apparently occur in many limestone areas throughout the United States.

Because of the thick glacial drift covering the surface of central Michigan, no geophysical techniques have been developed

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[3] K. K. Landes, "Porosity Through Dolomitization," _Bull. Amer. Assoc. Pet. Geol._, Vol. 30, No. 3 (Mar., 1946), pp. 306-307.

[4] _Ibid._, pp. 305-309.

which will satisfactorily indicate dolomitized structures in this area. To obtain core-test data, wells must be drilled to a depth of approximately 1,200 feet in order to reach reasonably diagnostic marker-beds. Anticipated oil production from the small reservoirs which might be expected to remain undiscovered cannot justify the expense of extensive core-test programs.

It appears, then, that to find further production economically from the Rogers City formation a new simplified technique must be developed which will reveal the presence of potential reservoirs. This paper describes the development of such a technique: the use of magnesium/calcium ratios, to indicate the proximity of porous zones resulting from secondary dolomitization of calcareous formations.

LOCALIZATION OF THE PROBLEM

In order to demonstrate this new technique clearly, a relatively small and closely drilled area seemed desirable, so that an intensive study of geologic data might be made. The area chosen was the east-central portion of Mecosta County, Michigan, including Wheatland (T.14N.,R.7W.), Morton (T.14N.,R.8W.), Sheridan (T.15N.,R.7W.), and Martiny (T.15N.,R.8W.) Townships. This area lies directly southwest of the Coldwater oil field, Michigan's most prolific structural-type Rogers City field.[5] It lies west of the Sheridan field, and four miles south of the Fork field, another prolific producer from the Rogers City formation. Favorable structure and reservoir development are indicated by the forty-four wells penetrating into the Rogers City formation and by forty-five shallower wells. However, only two single well pools have been discovered in the area. The apparent abundance of control is not ample to contour the area satisfactorily. Five separate structural interpretations, each with convincing logic, have been seen by the writer.

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[5] C. R. Criss and R. L. McCormick, "History and Performance of the Coldwater Oil Field, Michigan," Paper 278-G, Amer. Inst. of Mining and Metal. Eng.

STRATIGRAPHY

The study in Mecosta County is centered on the Rogers City formation of Middle Devonian. It is overlain by the Bell shale member of the Traverse Group and lies conformably on the Dundee formation (Figure 1). Because of similar lithology of the Rogers City and Dundee formations in some areas, the term "Rogers City" is seldom used in oil field parlance, but the two formations are spoken of collectively as the "Dundee." In some areas the formations are colloquially designated as "Dundee" for the upper, or Rogers City, formation, and "Dundee Restricted" for the lower, or true Dundee formation. In this report the formations will be referred to by their correct names.

In the area under consideration the Dundee grades from a tan, primary, nonfossiliferous marine dolomite, which in places is porous and permeable, to a limestone with the same general characteristics.[6]

The Rogers City, as described above, is a marine limestone from 25 to 40 feet thick.

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[6] Ibid.

FIGURE 1

GENERALIZED COLUMNAR SECTION OF
THE DEVONIAN SYSTEM IN THE MICHIGAN BASIN

AFTER HELEN M. MARTIN
MICHIGAN GEOLOGICAL SURVEY

SYSTEM	GROUP	FORMATION
DEVONIAN	TRAVERSE	SQUAW BAY
		THUNDER BAY
		POTTER FARM
		NORWAY POINT
		FOUR MILE DAM
		ALPENA
		NEWTON CREEK
		GENSHAW
		FERRON POINT
		ROCKPORT QUARRY
		BELL SHALE
	CAZENOVIA	ROGERS CITY
		DUNDEE
	DETROIT RIVER	LUCAS
		AMHERSTBERG
		FLAT ROCK
		SYLVANIA
		BOIS BLANC
		GARDEN ISLAND

ANALYTICAL TECHNIQUES

In attempting to establish a new technique for locating additional areas of oil accumulation, a careful chemical analysis of well samples from the Rogers City formation was made to determine accurately the relative percentages of magnesium oxide and calcium oxide present. The resultant percentages are expressed as a magnesium/calcium ratio. These ratios were plotted areally on a map,[7] to demonstrate the lateral extent of dolomitization, and thus may be used to predict dolomitized reservoirs within a definable distance of existing wells.

Standard methods of determining magnesium and calcium content of limestone rocks are normally tedious and time-consuming, involving precipitation and separation of the rock constituents.[8,9]

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[7] W. C. Krumbein and L. L. Sloss, Stratigraphy and Sedimentation, Freeman and Co., San Francisco (1951), Chapter 13, "Stratigraphic Maps."

[8] Assoc. Official Agr. Chemists, "Official and Tentative Methods of Analysis," 6th ed. (1945), pp. 42-50.

[9] L. M. Powell, "Calcium Carbonate-Magnesium Carbonate Ratios . . . Of the Pinconning Field," Thesis, University of Michigan.

The method employed in this study was described recently by Cheng, Kurtz, and Bray.[10] It is a rapid, simple, and accurate procedure to directly determine calcium and magnesium, without precipitation. Except for the preliminary work of Cheng, Kurtz, and Bray, this study of magnesium/calcium ratios would have been more difficult. In using this method, a set of well samples may be analyzed chemically for calcium and magnesium in little more time than is needed to examine them microscopically. Because this method has been outlined in chemical publications, not readily available to geologists, it is outlined here in detail. Following the outline of the basic method of analysis is a description of its adaptation specifically for magnesium/calcium ratio determination.

Preparation and Digestion of the Samples

1. Samples should be washed and dried. The "junk" iron may be quickly separated from the sample with a magnet. Separate manually any obvious pieces of "cavings." If a ratio is the result desired, as in this paper, it is not necessary to remove small flakes

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[10] K. L. Cheng, T. Kurtz, and R. H. Bray, "Determination of Calcium, Magnesium, and Iron in Limestone," Anal. Chem., Vol. 24 (Oct., 1952), p. 1640.

of shale (unless extremely limy) and other relatively inert substances. If exact percentages of calcium and magnesium oxide are desired, all foreign substances must be removed.

2. Place a 1.000-gram (approximately, if a ratio is desired) sample into a 250-milliliter beaker and add cautiously 10 milliliters of perchloric acid.

3. Heat the solution gently until it becomes colorless, then evaporate to dryness. After complete evaporation the sample should be cooled.

4. Dissolve the cooled residue by adding 3 milliliters of 1-to-1 hydrochloric acid and 10 milliliters of water. Filter the solution and dilute to 250 milliliters with water. It is essential that distilled water be used for all aqueous solutions, and that all equipment be washed thoroughly with distilled water.[11]

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[11] To determine the effect of common tap water or unclean apparatus on the results, an anlysis was made using 10 ml. of tap water in place of the digested rock sample. The tap water analysis showed that a positive error of 4.6% CaO and 1.0% MgO would result if tap water were used instead of distilled water. This error approaches a maximum of 20%.

Determination of Calcium

Reagents

Versenate solution. Dissolve 4 grams of the disodium salt of (ethylenedinitrilo) tetraacetic acid[12] in 1 liter of water. Standardize this solution against a standard calcium solution by titrating 10 milliliters of the standard calcium solution with Versenate in the manner described below.

Standard calcium solution. Dissolve 2.500 grams of reagent-grade calcium carbonate in approximately 5 milliliters of 1-to-1 hydrochloric acid (warm gently if necessary) and dilute to exactly 1 liter with water. This solution contains 1 milligram of calcium per milliliter.

Potassium hydroxide. Use a 20-percent aqueous solution.

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

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[12] Versenate, Murexide, and F241 indicator may be obtained from the Hach Chemical Co., Ames, Iowa.

Titration

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

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

Determination of Magnesium

Reagents

Versenate solution. Prepare as above.

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

Potassium cyanide. Prepare a 10-percent aqueous solution.

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

Titration

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

2. Stir, and titrate with the Versenate solution. The end point is reached when the color of the solution changes from wine-red to clear blue. Standardization of the Versenate solution for magnesium is calculated below.

Calculations

If 1 gram of sample is "made up" to a 250-milliliter solution, and a 10-milliliter aliquot is taken for titration, calcium and magnesium can be calculated as follows:

$$\frac{A \times 25 \times 1.4 \times B}{1{,}000} \times 100 = \text{percent calcium oxide}$$

$$\frac{C \times 25 \times 1.66 \times (D - B)}{1{,}000} \times 100 = \text{percent magnesium oxide}$$

A = milligrams of calcium per milliliter of Versenate solution (see Example 1 for standardization).

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

C = milligrams of magnesium per milliliter of Versenate solution (see Example 2 for standardization).

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

Example 1. Standardization with standard calcium solution.

The standard calcium solution prepared contains 1 milligram of calcium per milliliter of solution. Twenty-three and seven-tenths milliliters of Versenate solution were necessary to titrate, to the end point, 10 milliliters of the standard calcium solution.

10 mg. calcium (solution) → 23.7 ml. Versenate.

Versenate = 10 mg. Ca/23.7 ml. = 0.422 mg. Ca/ml. ("A" in equation).

Example 2. Computation of milligrams of magnesium per milliliter of Versenate (Standardization).

Versenate = 0.422 mg. Ca/ml. Versenate (above).

$$\frac{\text{Atomic weight of Mg}}{\text{Atomic weight of Ca}} = \frac{24.32}{40.08} = 0.607$$

Versenate = 0.422 x 0.607 = 0.256 mg. Mg/ml. Versenate ("C" in equation).

Example 3. Computation of percent magnesium and percent calcium; and the magnesium/calcium ratio.

If these procedures were followed, and in the analysis 24.2 milliliters of Versenate were used in titration with Murexide and 37.8 milliliters of Versenate were used in titration with F 241, and using standardized solutions, then:

A = 0.422; B = 24.2; C = 0.256; D = 37.8.

Substituting into the formulae above:

$$\frac{0.422 \times 25 \times 1.4 \times 24.2}{1{,}000} \times 100 = 35.7\%\ \text{CaO}$$

$$\frac{0.256 \times 25 \times 1.66 \times (37.8 - 24.2)}{1{,}000} \times 100 = 14.4\%\ \text{MgO}$$

Magnesium/calcium ratio = 14.4/35.7 = 0.403.

If weights and measures are made with reasonable care in the preparation of the standard calcium solution and in each preparation of Versenate solution, the quantities "A" and "C" in the formulae will tend to become constants. The results were identical in each of twenty standardization tests made by the writer, using the same standard calcium solution and successive solutions of Versenate:

A = 10 mg. calcium (solution) → 23.7 ml. Versenate

= 0.422 mg. Ca/ml.

C = 0.422 x 0.607 = 0.256 mg. Mg/ml.

When standardization results in these values they may be substituted in the formulae as constants, greatly simplifying computations. Thus:

$$\frac{0.422 \times 25 \times 1.4 \times B}{1{,}000} \times 100 = \text{percent CaO, or}$$

$$1.477 \times B = \text{percent CaO.}$$

$$\frac{0.256 \times 25 \times 1.66 \times (D - B)}{1{,}000} \times 100 = \text{percent MgO, or}$$

$$1.0624 \times (D - B) = \text{percent MgO.}$$

Reasonable care in this analysis should give values for CaO and MgO within 0.5 percent accuracy. The magnesium/calcium ratio is desirable to express the results of analyses, since the figure may be readily used as a point of contour or graph control. The use of the magnesium/calcium relationship (as opposed to calcium/magnesium) produces a ratio which varies between 0.000 and 1.000 for limestones and dolomites, thus keeping within well-defined limits. The magnesium/calcium ratio accentuates small changes toward the dolomitic rocks, whereas changes in rocks of a predominant calcite nature are minimized. Variance in a calcium/magnesium ratio is from 1.000 to infinity for dolomites and limestones, thus making contouring or graphing impractical. Emphasis is placed on minute changes in rocks containing principally calcium.

MASS ANALYSIS TECHNIQUES

It may be noted that in the computations each individual sample was analyzed for percentage of magnesium oxide and calcium oxide, and these results were expressed as a ratio. If the desired result of analysis is a ratio, much of the foregoing process may be eliminated. The desired magnesium/calcium ratio may be expressed as follows:

$$\frac{\%\ \mathrm{MgO}}{\%\ \mathrm{CaO}} = \frac{\dfrac{A\dfrac{[\mathrm{At.Wt.Mg}]}{[\mathrm{At.Wt.Ca}]} \times 25 \times 1.66 \times (D - B)}{1{,}000} \times 100}{\dfrac{A \times 25 \times 1.4 \times B}{1{,}000} \times 100}$$

$$= \frac{\dfrac{[\mathrm{At.Wt.Mg}]}{[\mathrm{At.Wt.Ca}]} \times 1.66 \times (D - B)}{1.4 \times B}$$

This may be expressed as $(D - B)/(c \times B)$ where

$$c = \frac{1.4}{\dfrac{[\mathrm{At.Wt.Mg}]}{[\mathrm{At.Wt.Ca}]} \times 1.66}$$

In Example 2, $\dfrac{[\mathrm{At.Wt.Mg}]}{[\mathrm{At.Wt.Ca}]}$ is 0.607.

Thus, $c = 1.389$

In its simplest form, the formula for determining the magnesium/calcium ratio for a given sample may be expressed as follows:

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

This basic formula permits the ratio computation without the use of a specific weight of sample (1.000 gram in the original formula) and without standardizing the Versenate solution for either magnesium or calcium. It is desirable to use approximately 1 gram of clean sample and a Versenate solution near the strength described only because these proportions give an optimum reaction without waste of reagents.

Where mass analysis of samples from specific formations or strata covering a large area is desired, there is no apprent reason why all samples through the section cannot be analyzed together. Care must be taken to use a representative sample. This can be done by mechanical means,[13] or by mixing thoroughly all samples after digestion and using a proportionate aliquot of the solution diluted to 250 milliliters for analysis.

To analyze a number of samples it is best to first prepare and weigh all samples. Samples may be digested in groups as large as evaporation facilities will permit. Perchloric acid fumes are

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[13] W. C. Krumbein and F. J. Pettijohn, Manual of Sedimentary Petrography, Appleton-Century, New York (1938), Chapter 3, "Preparation of Samples for Analysis."

EXTREMELY DANGEROUS, and evaporation MUST be done with proper ventilation. After evaporation, samples can be kept in their beakers for an indefinite period in a dry place. Many samples, usually eight to twelve, may be conveniently handled and redissolved at one time. It is desirable to use two or more 250-milliliter calibrated flasks for preparing the sample. The dissolved sample may be filtered directly into the calibrated flasks, and by using two or more, filtering may continue while the preceding sample is "made up" and titrated. A 10-milliliter graduated pipette is used to take the aliquot for analysis (Figure 2).

To determine calcium, a quantity of the potassium hydroxide solution is mixed with 20 times its volume of water. Twenty milliliters of this solution and indicator powder are added to the aliquot before titration. A graduated 50-milliliter burette is best for titration.

To determine magnesium, the buffer solution, water, and potassium cyanide may be combined in the ratio of 26 parts water, 3 parts buffer, and 1 part potassium cyanide. Thirty milliliters of this solution and 8 drops of F 241 indicator are added to the aliquot before titration.

A number of samples may be analyzed in a very short time by using this method.

FIGURE 2

LABORATORY EQUIPMENT

At left is shown the 50-milliliter burette and reagents necessary for titration. The 250-milliliter calibrated flask, with funnel inserted for filtering, and the 10-milliliter pipette for measuring the aliquot of sample for analysis are in the center of the photograph. Evaporated samples, in their beakers, are at the right. The large liter graduate holds distilled water.

ANALYSIS OF THE MECOSTA COUNTY AREA

Well samples, Schlumberger electric logs, and any other pertinent data available were examined to pick formation tops in the area. These data are presented in Table I. Where wells did not penetrate to the top of a formation an "X" is placed in the table. A dash is used where tops could not be determined accurately. Column 11 of Table I indicates the number of feet below the top of the Rogers City formation at which water (or oil) was logged.

Samples of the Rogers City rocks, preserved from thirty-five of the wells drilled in the area, were analyzed as described in the text from the top to the bottom of the formation; or into the Dundee formation in the deeper wells. Samples from wells drilled with both rotary and cable-tool rigs were used. No cores from wells in the area were available. Individual analyses of each sample from each well series were made. The results of the analyses of these samples are shown in Table II. The average magnesium/calcium ratio for the first 25 feet of the Rogers City formation was computed and is presented in Column 12, Table I. This average is limited to the upper 25 feet of formation in order to preclude the possibility of including the primary dolomites of the Dundee.

TABLE I

FORMATION TOPS AND WELL DATA

Well Name	Township	Section	Stray Sand
Darke - Bergelin	Wheatland	3	-415
Merrill and Darke - Guy		4	-406
Fisher-McCall - Ockert	"	6	-390
Michigan Consolidated - Rettinger	"	6	-388
Sohio - Rettinger	"	6	-382
Dye Creek - Lehnert	"	7	-406
Moco - Ortwein	"	7	-402
Rand and Neyer - Mayer	"	7	-389
Rex and Skelly - Mayer	"	7	-405
Smith-Ortwein	"	7	-397
Lueder - Doan	"	8	-384
Lueder - Walker-Skalitzky	"	8	-375
Rex - Skalitzky	"	8	-375
Rex - Skalitzky No. 2	"	8	-384
Rex - Snider	"	8	-402
Carter - Flachs	"	9	-400
Carter - Smith Petroleum Co.	"	9	-380
Carter - Snyder	"	9	-385
Lueder - Flachs	"	9	-401
McGuire - Oliver	"	11	-476
Michigan Consolidated - Keller	"	16	-395
Goll, Graves & Mechling - Ruetz	"	17	-421
Moco - Minkel	"	18	-382
Mehrtens - Beaumann	"	21	-443
Southwest Development - Hewlett	"	26	-584

TABLE I (Continued)

Base of Marshall	Traverse Formation	Traverse Limestone	Bell Shale	Shale Thickness	Rogers City Formation	Feet to Water	Mg/Ca Ratio (avg. 1st 25 feet)
-716	-2136	-2173	-2708	37	-2745	1	0.654
-700	-2125	-2156	-2662	41	-2703	4	0.599
-704	-2120	-2154	-2647	43	-2690	3	0.656
X	X	X	X	X	X	X	X
-709	-2121	-2156	-2643	41	-2684	1	0.662
-713	-2119	-2154	X	X	-2687	14	X
-716	X	-2148	-2636	43	-2679	1	X
-718	-2110	-2155	-2635	47	-2682	2	0.652
-705	-2115	-2151	-2639	49	-2688	2	X
-709	-2113	-2147	-2639	42	-2681	1	X
-698	X	-2154	-2652	46	-2698	6	X
X	X	X	X	X	X	X	X
-690	-2106	-2141	-2629	42	-2671	1	X
-695	-2103	-2134	-2632	42	-2674	3	X
-707	-2122	-2157	-2663	37	-2700	1	0.706
-701	-2117	-2162	-2658	41	-2699	4	0.505
-707	-2108	-2147	-2643	43	-2686	3	X
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
-731	-2121	-2161	-2649	45	-2694	none	0.458
-698	-2100	-2142	-2626	44	-2670	1	X
X	X	X	X	X	-2723	none	X
X	X	X	X	X	X	X	X

TABLE I (Continued)

Well Name	Town-ship	Sec-tion	Stray Sand
Collin - Bowmann	Wheat-	29	-382
Pure - G. T. 41	land	36	-421E
Gulf - Gale	Morton	3	-366
Colmur - Bell	''	6	-297
Colmur - Sapp	''	6	-325E
Chapman - Minkel	''	7	-290
Michigan Consolidated - 131 Austin	''	7	-299
Michigan Consolidated - 133 Austin	''	7	-329
Colmur - Mecosta Lakes	''	8	-342
Michigan Consolidated - Stickler	''	15	-308
Michigan Consolidated - Patrick	''	16	-321
Rex - Mecosta Lakes	''	17	-311
Michigan Consolidated - Austin 9	''	18	-306
West Michigan Consolidated - Minkel . . .	''	18	-312
Collin and Berlin - Ockert	''	19	-331
Ohio - Thurkow	''	19	-328
Mercer - Norman	''	21	-318
McGuire - Smith	''	22	-310
Michigan Consolidated - Berry	''	22	-328
Michigan Consolidated - Smith	''	22	-315
Leonard - Minkel	''	24	-349
Benedum-Trees - Truman	''	26	-354
Smith - Rean	''	29	-349
Taggart - McKeough	Austin	2	-290
Taggart - Barton	''	11	-296

TABLE I (Continued)

Base of Marshall	Traverse Formation	Traverse Limestone	Bell Shale	Shale Thickness	Rogers City Formation	Feet to Water	Mg/Ca Ratio (avg. 1st 25 feet)
-700	-2083	-2122	-2612	45	-2657	none	0.149
X	X	X	X	X	X	X	X
-	-	-2094	-2611	39	-2640	-	0.135
-	-2034	-2070	-2562	40	-2602	none	0.178
X	X	X	X	X	X	X	X
-	-	-2043	-2522	39	-2561	23	0.355
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
-584	-2022	-2060	-2529	49	-2578	none	0.104
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
-595	-2032	-2072	X	X	X	X	X
-600	-2010	-2056	-2529	47	-2576	none	0.064
-589	-2029	-2067	-2553	35	-2588	none	0.073
-577	-2007	-2056	-2554	35	-2589	2	0.559
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
-	-2055	-2092	-2567	56	-2623	5	0.630
-	-	-2085	-2557	48	-2605	6	0.665
X	X	X	X	X	X	X	X
-569	-1979	-2016	-2519	44	-2563	none	0.057
-570	-1994	-2039	-2512	45	-2557	48	0.089

TABLE I (Continued)

Well Name	Township	Section	Stray Sand
Chapman, Union - Proctor	Austin	12	-288
Teater - Wood	Sheridan	2	-450
Daily - Hutchins	"	8	-379
American Gas - Brehm	"	10	-460
Obenauer - Musgrave	"	11	X
King - Gingrich	"	12	-451
Sherrit - Gingrich No. 3	"	12	-452
Gould and Cross - Starks	"	13	-449E
Sherrit - Otterbein	"	13	-448E
Sherrit - Scheibe	"	13	-439E
Sherman - Scheibe	"	13	-457E
Benedum-Trees - Grove	"	14	-457
Gould and Cross - Barrows	"	14	-458E
Gould and Cross - Grove	"	14	-467
Red Man - Floria	"	14	-452E
Michigan Consolidated - Bliss	"	17	-423
Gulf - Warner	"	21	-452
Anderson - Dobben	"	22	-473
Benedum-Trees - Brand	"	24	-449
Collins and Berlin - May	"	26	-460
Merrill and Darke - Fate	"	27	-459
Gulf - Landis	"	30	-441E
Hebard - Weeks	"	32	-432
Michigan Consolidated - Carpentier	"	35	-452
Anderson - Farwell & Loyd	"	36	-488

TABLE I (Continued)

Base of Marshall	Traverse Formation	Traverse Limestone	Bell Shale	Shale Thickness	Rogers City Formation	Feet to Water	Mg/Ca Ratio (avg. 1st 25 feet)
-570	-1992	-2027	-2503	51	-2554	42	0.137
-757	-2162	-2203	-2743	49	-2792	none	0.055
-686	-	-2135	-2671	47	-2718	none	0.040
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
-774	-	-2203	-2729	42	-2771	none	0.051
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
-	-	-2200	-2714	57	-2771	none	0.064
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
-766	-2148	-2190	-2719	43	-2762	none	0.063
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
-773	-2157	-2200	-2717	40	-2757	1	0.698
-742	-2176	-2211	-2718	40	-2758	4	0.557
X	X	X	X	X	X	X	X
-743	-2153	-2195	-2688	46	-2734	6	X
X	X	X	X	X	X	X	X
-736	-2139	-2197	-2694	50	-2744	1	0.702

TABLE I (Continued)

Well Name	Township	Section	Stray Sand
Chapman - Bark	Martiny	1	-373
Gordon - Engleman	"	9	-438
Pure - Smith	"	10	-371
Michigan Consolidated - Alderman	"	11	-409
Rex - Bouck	"	11	-382
Gordon and Chapman - Soule	"	12	-386
Gordon - Soule	"	12	-384
Michigan Consolidated - Evans	"	12	-378
Michigan Consolidated - Evans No. 2	"	12	-389
Michigan Consolidated - State	"	13	-383
Gordon - Bush	"	14	-385
Ross - Oliver	"	14	-350
Gordon - Helmer	"	17	-427
Self - Percy	"	22	-383E
Hall, LaMee - Oliver	"	23	-381E
Lakeside - Dye	"	23	-398
Rand and Neyer - Baker	"	33	-350

TABLE I (Continued)

Base of Marshall	Traverse Formation	Traverse Limestone	Bell Shale	Shale Thickness	Rogers City Formation	Feet to Water	Mg/Ca Ratio (avg. 1st 25 feet)
-	-	-2122	-2661	45	-2706	none	0.088
X	X	X	X	X	X	X	X
-666	-2075	-2119	-2645	44	-2689	none	0.074
X	X	X	X	X	X	X	X
-688	-2083	-2131	-2668	36	-2704	1	0.389
X	X	X	X	X	X	X	X
-667	-2087	-2125	-2657	38	-2695	none	0.054
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
-671	-2101	-2144	-2667	48	-2715	show 1	0.240
X	X	X	X	X	X	X	X
-723	-	-	-2675	42	-2717	none	0.040
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
-640	-2048	-2088	-2583	47	-2630	none	X

TABLE II

INDIVIDUAL WELL SAMPLE ANALYSES RESULTS

Well	Sample No.	Feet Below Top of Rogers City	Pct. CaO	Pct. MgO	Mg/ Ca Ratio
Darke, 1 Bergelin Sec. 3, T.14N.,R.7W.	6A	1 - 8	24.3	15.9	0.654
Merrill & Darke, 1 Guy Sec. 4, T.14N.,R.7W.	3A	0 - 4	21.0	11.2	0.533
	3B	4 - 8	27.5	17.0	0.618
	3C	8 -11	28.6	18.5	0.647
Fisher-McCall, 1 Ockert Sec. 6, T.14N.,R.7W.	7A	0 - 5	25.6	16.0	0.625
	7B	5 -17	28.4	19.7	0.694
Sohio, 1 Rettinger Sec. 6, T.14N.,R.7W.	27A	0 - 3½	24.5	15.1	0.616
	27B	3½-14	25.8	17.7	0.686
	27C	14 -26	26.7	18.3	0.685
Rand & Neyer, 1 Mayer Sec. 7, T.14N.,R.7W.	5A	0 - 1½	25.1	16.8	0.669
	5B	1½- 2	24.3	14.9	0.613
	5C	2 - 4	27.6	18.6	0.674
Rex, 1 Snyder Sec. 8, T.14N.,R.7W.	13A	0 - 1	16.0	11.3	0.706
Carter, 1 Flacks Sec. 9, T.14N.,R.7W.	8A	1 - 6	20.4	10.3	0.505
Goll, Graves, Mechling, 1 Reutz Sec. 17, T.14N.,R.7W.	2A	0 - 8	35.4	13.7	0.387
	2B	8 -11	33.0	18.5	0.561
	2C	11 -16	38.8	12.7	0.327
	2D	16 -21	34.1	16.3	0.478
	2E	21 -25	32.4	17.4	0.537
	2F	25 -30	30.8	19.4	0.630

TABLE II (Continued)

Well	Sample No.	Feet Below Top of Rogers City	Pct. CaO	Pct. MgO	Mg/ Ca Ratio
Collin, 1 Bowmann	28A	0 - 6	35.9	5.0	0.139
Sec. 29, T.14N.,R.7W.	28B	6 -12	34.3	7.0	0.204
	28C	12 -18	39.9	4.1	0.103
	28D	18 -33	37.2	9.5	0.255
Gulf, 1 Gale (Rotary)	31A	1 - 8	24.8	3.6	0.145
Sec. 3, T.14N.,R.8W.	31B	8 -16	25.8	3.8	0.147
	31C	16 -26	30.0	3.4	0.113
Colmur, 1 Bell	30A	1 - 9	34.4	7.3	0.212
Sec. 6, T.14N.,R.8W.	30B	9 -21	38.5	5.5	0.143
	30C	21 -33	34.1	13.5	0.396
Chapman, 1 Minkel	18A	0 - 5	28.7	8.5	0.296
Sec. 7, T.14N.,R.8W.	18B	5 -13	35.7	14.4	0.403
	18C	13 -20	36.9	13.5	0.366
Rex, 1 Mecosta Lakes	35A	0 -14	37.4	3.9	0.104
Sec. 17, T.14N.,R.8W.					
Ohio, 1 Thurkow	22A	0 - 2	38.4	4.0	0.104
Sec. 19, T.14N.,R.8W.	22B	2 - 6	45.0	3.8	0.084
	22C	6 -10	48.2	2.7	0.056
(Coral L.S. in Rogers City)	22D	10 -18	47.0	1.3	0.027
	22E	18 -25	49.2	2.4	0.049
Mercer, 1 Norman	4A	0 - 9	47.8	3.0	0.063
Sec. 21, T.14N.,R.8W.	4B	9 -15	38.5	3.0	0.078
	4C	15 -23	44.4	3.4	0.077

TABLE II (Continued)

Well	Sample No.	Feet Below Top of Rogers City	Pct. CaO	Pct. MgO	Mg/Ca Ratio
McGuire, 1 Smith	12A	0 - 5	10.5	1.8	(0.171)
Sec. 22, T.14N.,R.8W.	12B	5 - 9	9.9	6.2	0.626
(12A mostly cavings)	12C	9 -22	12.8	6.3	0.492
Leonard, 1 Minkel	34A	0 - 3	39.3	18.9	0.481
Sec. 24, T.14N.,R.8W.	34B	3 - 7	26.1	18.6	0.713
	34C	7 -15	21.0	13.8	0.657
	34D	15 -24	27.3	18.3	0.670
	34E	24 -32	26.1	17.6	0.674
	34F	32 -38	25.0	17.5	0.700
	34G	38 -46	31.0	20.1	0.648
	34H	46 -52	25.4	16.3	0.642
Benedum-Trees, 1 Truman	1A	0 -25	26.2	17.7	0.665
Sec. 26, T.14N.,R.8W.	1B	25 -44	29.5	20.1	0.681
	1C	44 -49	27.1	19.3	0.712
	1D	49 -55	29.6	19.6	0.662
Taggart, 20 McKeough	21A	0 - 6	37.7	3.7	0.098
Sec. 2, T.14N.,R.9W.	21B	6 -13	47.4	1.8	0.038
(Coral L.S. in Rogers City)	21C	13 -28	49.5	1.7	0.034
	21D	28 -34	48.0	3.5	0.073
	21E	34 -41	45.0	3.2	0.071
Taggart, 1 Barton	24A	0 - 9	35.9	3.9	0.109
Sec. 11, T.14N.,R.9W.	24B	9 -20	43.0	3.2	0.074
	24C	20 -26	46.8	4.0	0.085
Chapman, 1 Proctor	23A	0 - 3	33.2	4.6	0.139
Sec. 12, T.14N.,R.9W.	23B	3 -10	41.4	6.5	0.157
	23C	10 -15	34.7	4.0	0.115

TABLE II (Continued)

Well	Sample No.	Feet Below Top of Rogers City	Pct. CaO	Pct. MgO	Mg/Ca Ratio
Teater, 1 Wood	11A	0 - 2	39.3	4.1	0.104
Sec. 2, T.15N.,R.7W.	11B	2 - 9	49.9	2.2	0.044
	11C	9 -17	48.3	2.1	0.043
	11D	17 -25	52.0	1.4	0.027
	11E	25 -35	44.9	4.1	0.091
Daily, 1 Hutchins	9A	23 -30	40.1	1.6	0.040
Sec. 8, T.15N.,R.7W.	9B	30 -37	40.2	2.1	0.052
King, 1 Gingrich	17A	0 -10	41.5	2.3	0.055
Sec. 12, T.15N.,R.7W.	17B	20 -25	41.1	1.9	0.046
	17C	25 -31	45.5	2.8	0.062
Benedum-Trees, 1 Grove	15A	0 - 8	28.9	2.8	0.097
Sec. 14, T.15N.,R.7W.	15B	8 -10	31.6	2.9	0.092
	15C	10 -14	48.7	2.0	0.041
	15D	14 -20	47.7	2.7	0.057
	15E	20 -26	48.7	1.6	0.033
Gulf, 1 Warner (Rotary)	10A	3	23.6	2.3	0.097
Sec. 21, T.15N.,R.7W.	10B	14 -19	34.1	1.8	0.053
	10C	19 -24	35.0	1.4	0.040
Collin & Berlin, 1 May Sec. 26, T.15N.,R.7W.	32A	0 - 3	24.5	17.1	0.698
Merril & Darke, 1 Fate Sec. 27, T.15N.,R.7W.	25A	1 - 5	25.3	14.1	0.557

TABLE II (Continued)

Well	Sample No.	Feet Below Top of Rogers City	Pct. CaO	Pct. MgO	Mg/Ca Ratio
Anderson, 1 Farwell & Loyd	33A	1 - 3	26.9	19.2	0.714
Sec. 36, T.15N.,R.7W.	33B	3 -11	27.3	19.8	0.725
	33C	11 -21	23.8	15.9	0.668
	33D	21 -30	25.7	17.2	0.669
	33E	30 -37	25.4	17.3	0.681
	33F	37 -49	26.0	18.2	0.700
	33G	49 -54	25.0	16.5	0.660
	33H	54 -64	26.6	18.9	0.711
	33I	64 -78	22.7	15.4	0.678
	33J	78 -86	25.8	15.9	0.616
	33K	86 -91	24.5	18.2	0.742
Chapman, 1 Bark	26A	1 -14	43.4	4.2	0.097
Sec. 1, T.15N.,R.8W.	26B	14 -21	47.6	4.2	0.088
	26C	21 -33	45.2	3.6	0.080
	26D	33 -44	38.7	7.6	0.196
Pure, 1 Smith	16A	0 - 2	38.4	3.9	0.102
Sec. 10, T.15N.,R.8W.	16B	2 - 8	48.6	3.7	0.076
	16C	8 -16	49.0	2.1	0.043
	16D	27 -37	48.0	3.5	0.073
Rex, 1 Bouck Sec. 11, T.15N.,R.8W. (Sample contaminated with cavings)	29A	0 - 2	18.5	7.2	(0.389)
Gordon, 1 Soule Sec. 12, T.15N.,R.8W.	20A	0 - 5	46.2	2.5	0.054

TABLE II (Continued)

Well	Sample No.	Feet Below Top of Rogers City	Pct. CaO	Pct. MgO	Mg/Ca Ratio
Gordon, 1 Bush	14A	0 - 4	36.2	9.9	0.273
Sec. 14, T.15N.,R.8W.	14B	4 -12	31.3	6.2	0.198
	14C	12 -18	37.1	5.5	0.148
	14D	18 -29	29.2	9.9	0.339
	14E	29 -38	26.3	18.5	0.703
Gordon, 1 Helmer	19A	0 -19	41.7	1.9	0.046
Sec. 17, T.15N.,R.8W.	19B	19 -23	43.6	1.5	0.034

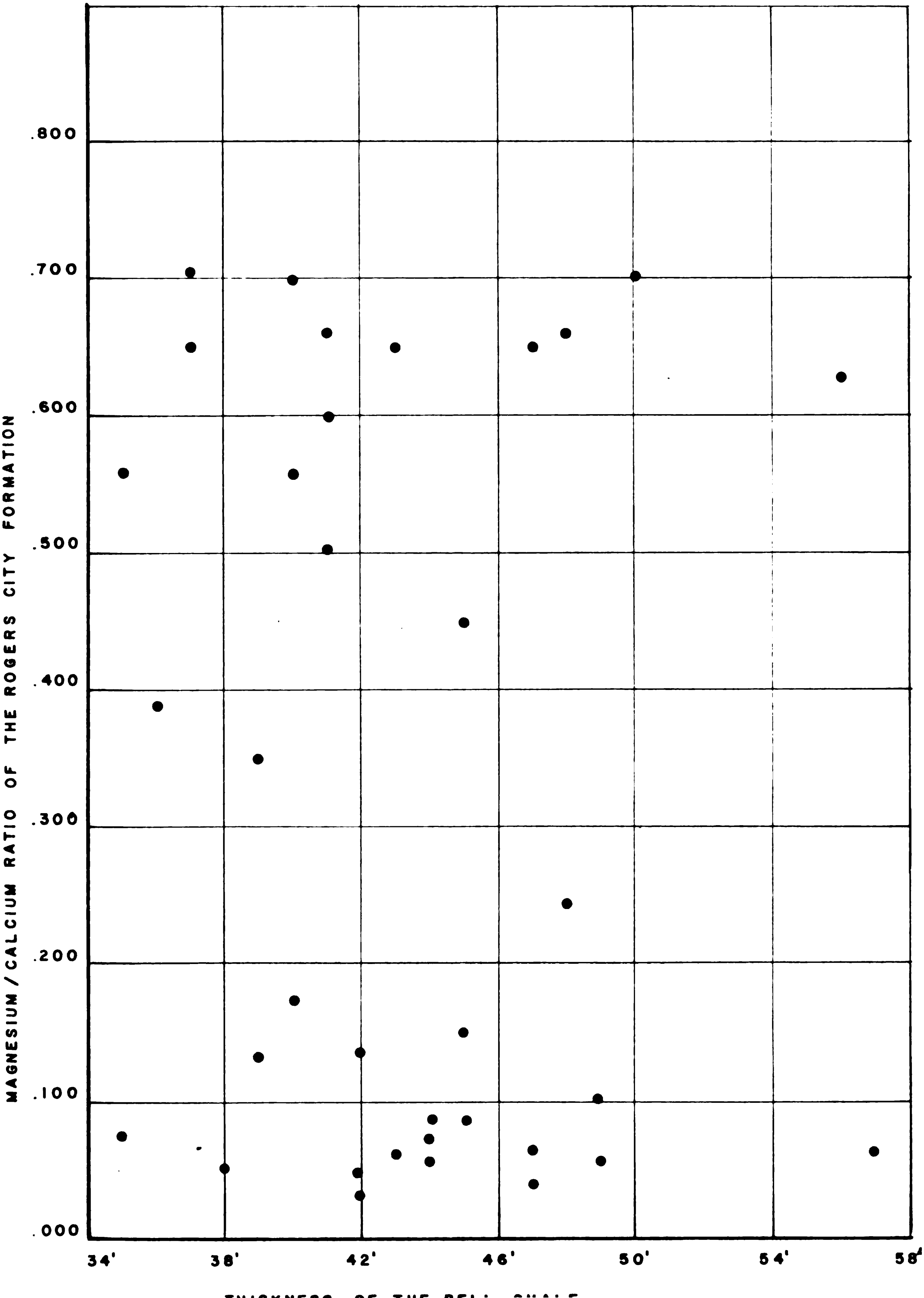
The ratio averages were plotted on a base map, from which data a ratio contour map of the area was constructed (Figure 3--rear pocket). This map shows dolomitization to occur in two long bands extending northeast, joined by a band extending southeast. In this part of the Michigan Basin the dominant structural trend is southeast, with minor trends extending northeast. There is little control in T.15N.,R.8W., but the marked trends of dolomite in the other townships and the magnesium/calcium ratio of 0.240 in Section 14 seems to justify the interpretation given to that township. If these zones of dolomitization are along structural trends, the area may be contoured to show that the shallow horizons (Figure 4--rear pocket), the Rogers City formation (Figure 5--rear pocket), and the dolomitization agree closely (Figure 3). If the assumption that dolomitization coincides with the structural trends is correct, a study of dolomitization in an area which is difficult to contour by other methods should aid materially in eliminating many structural misinterpretations.

ORIGIN OF DOLOMITE IN THE MECOSTA COUNTY AREA

There are two common theories for the origin of porosity in the Rogers City formation in the Mecosta County area. One theory is that the structures are reefs and that dolomitization occurs through replacement. This theory, once strongly considered, is seldom held today. If these were reef structures, one would expect that the overlying Bell shale should show thinning over the dolomite zones, and that a gradual diminishing of structure should be found in overlying formations. Neither is true. There is no correlation between the thickness of the Bell shale and dolomitization within the underlying Rogers City (Figure 6). Even the shallow beds show the same structure as the Rogers City formation (Figures 4 and 5). Samples from three wells listed in Table II (the Colmur, 1 Bell; Ohio, 1 Thurkow; and Taggart, 20 McKeough) indicate coral limestone in the Rogers City, but only the Colmur well samples are dolomitized even slightly. As noted earlier in this report, the Rogers City is an extremely fossiliferous limestone, and probably does contain some reefs, but there is no evidence that such reefs are associated with either structure or dolomitization.

FIGURE 6

RELATIONSHIP OF THICKNESS OF THE BELL SHALE TO DOLOMITIZATION OF THE ROGERS CITY FORMATION



The writer believes that dolomitization occurs along tension fractures[14] formed at the apices of folded structures. These fractures probably formed during a period of gentle folding.[15] The movement of brine from the underlying Dundee along the fractures recrystallized the minerals, dissolved the fossils, and enlarged the fractures. Landes[16] describes in great detail the development of porosity through dolomitization, giving special emphasis to dolomitization along faults, fractures, and joints. He concludes:

> The writer believes that local diastrophism has produced master fissures in the limestone-containing section; that an artesian circulation has been developed which has carried waters through deeper dolomites and up into the limestone; and that these waters have replaced some of the limestone by dolomite that is locally porous where there was an excess of solution over precipitation during the replacement process.

The Rogers City limestone has been altered to a very dark brown, massive dolomite, and the numerous vugs, fractures, and channels formed in the process are lined with white crystals of

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[14] M. P. Billings, _Structural Geology_, Prentice-Hall, New York (1942), Chapters 6 and 7.

[15] C. R. Criss and R. L. McCormick, _op. cit_.

[16] K. K. Landes, _op. cit_.

dolomite. Since these tension fractures apparently do not extend off structure, lateral dolomitization is limited, and is seldom off structure. Dolomitization along master fault or fracture planes is the notable exception. Few faults of consequence have been found in Central Michigan, but those known to penetrate limestone beds frequently provide channels for local dolomitization, developing reservoirs which produce oil prolifically. The development of porosity through dolomitization along faults and tension fractures is apparently the same. Since the throw of these faults in Michigan is apt to be very slight they are generally difficult to locate and follow by normal subsurface methods. The only major fault with appreciable throw now known in the Michigan Basin is along the west flank of the Howell anticline. Current drilling on this anticline (spring, 1954) indicates that the Trenton limestone is locally altered to dolomite and contains oil and gas. This dolomite possibly occurs along fault planes associated with the master Howell fault. It is the conclusion of the writer that dolomitization similar to the type found at Howell is found also in the Adams and Deep River pools. These fault planes have been called "master fissures" by Landes.[17]

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[17] Ibid., p. 318.

In the western half of the central portion of the Michigan Basin where the tops of structures have been dolomitized, the underlying Dundee in places is a primary dolomite, generally not more than 100 feet thick. In the eastern half of the central basin, the Dundee is not normally a dolomite. It is much thicker, and varies from 100 to 400 feet. Here Rogers City dolomitization is rare on structure, but may be found along fault zones. This suggests that expansion fractures on structure may have a limited vertical extent, and that high-magnesium waters percolating from below, working along small fracture systems, have not had sufficient time to dolomitize appreciably more than a 100-foot vertical section of limestone. This hypothesis is supported by the fact that in areas where Dundee limestone is thick the lower 100 feet of the Dundee formation is often dolomitized on structure. The source of high-magnesium waters for this process is apparently from the primary dolomites of the Detroit River formation, which lie below the Dundee limestone. In this area of thick Dundee limestone, the Rogers City is dolomitized where faults or master fissures penetrate both the Dundee and Rogers City formations, thus allowing direct communication with zones of high-magnesium brines below. It would be interesting to compare the horizontal extent of dolomitization away from a fault plane to the vertical extent of the process along a system of expansion fractures to determine if they are equal.

In Mecosta County a distinct pattern of lateral dolomitization exists (Figure 3). At the top of structural trends the magnesium/calcium ratio approaches or slightly exceeds 0.700. This area is dolomitized quite uniformly (Table II).. On the flanks of the structural trends dolomitization was uneven, with the higher-ratio zones probably representing the more infrequent expansion fractures along which the process began. Nowhere in the area does dolomitization extend laterally more than 1½ miles from the top of a structure, at which distance the ratio drops below a value of 0.100. It is interesting to note that the magnesium/calcium ratios coincide closely with percentage figures quoted by Landes[18] as necessary for effective porosity in other areas and formations.

Using the conventional dilute hydrochloric acid test for dolomite, rocks with a ratio distinctly above 0.400 give evidence of dolomitization, while those below produce a typical limestone reaction. Thus, in the conventional examination of well cuttings, the Rogers City formation appears to change abruptly from dolomite to limestone, with no indication of decreasing ratios along the flank-zone. It is this flank-zone which may be important in predicting

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[18] Ibid., p. 310.

the proximity to dolomitized structures, and the proximity to and strike of dolomitized fault planes.

The primary limestones in the area studied show a ratio varying from 0.027 to 0.100. Where ratios exceed 0.100 they continue upward to above 0.500 nearby. No isolated zones of low dolomitization appear to exist which cannot be connected reasonably with structural trends where the formation is dolomitized. It would seem logical to assume that if a well were drilled into the Rogers City formation in any place one might expect similar dolomitization. Thus, in an area where little or no structural control exists a wildcat well which shows a ratio of 0.100 or more would seem to indicate a dolomitized structure within 1½ miles. Similarly, as the ratio increases, one might logically expect that a structure exists at proportionately closer distances.

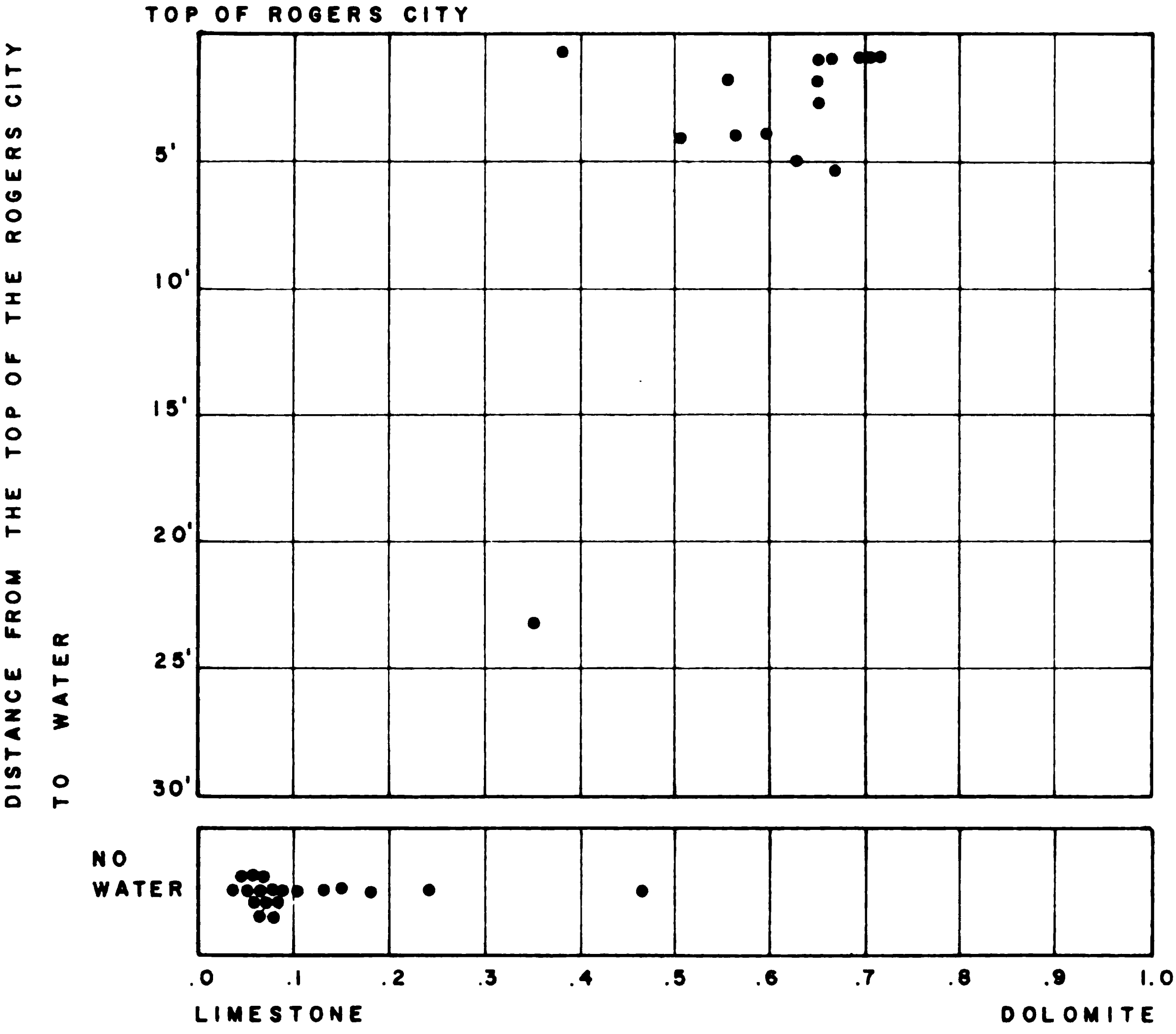
Preliminary investigation indicates that similar magnesium/calcium relationships exist in other areas of secondary dolomitization, and that ratio-distance correlations may be established in them.

RELATIONSHIP BETWEEN DOLOMITIZATION AND POROSITY

A comparison of water zones to the magnesium/calcium ratio (Figure 7) shows that 0.458 is the highest average ratio at which no effective porosity occurs, and that generally the ratio must be above 0.500 before effective porosity results. In some wells slight effective porosity was found where the magnesium/calcium ratio average was below 0.500, but it appears that such porosity was developed along a single fracture from a nearby structure. The Rex, 1 Bouck well, Section 11, T.15N.,R.8W., has extremely effective porosity and shows a ratio of only 0.389. This low ratio, however, is due to the great number of fragments of crinoidal limestone derived from the base of the Bell shale which seriously contaminate the sample. In zones where dolomitization is negligible, the analyses show that the first flank-indication of dolomitization is an increase of magnesium in the top few feet (Table II). Small increases, however, may not be significant, and apparently never develop porosity.

FIGURE 7

RELATIONSHIP BETWEEN DOLOMITIZATION AND POROSITY



AVERAGE MAGNESIUM/CALCIUM RATIO OF THE ROGERS CITY FORMATION

POSSIBILITIES FOR OIL PRODUCTION IN THE MECOSTA COUNTY AREA

Several places in the Mecosta area may have possibilities for oil production; this possibility based on the magnesium/calcium ratio interpretation. Perhaps the most interesting prospect is in Section 8, T.14N.,R.7W. The Rex, 1 Skalitsky, well has every indication of being on the southwest flank of a small, closed structure, which extends into the north half of Section 9. Both structural and dolomitic conditions seem favorable for oil accumulation, despite the seven dry holes which surround the present producing well. A similar area, but somewhat less pronounced, is in the southeast corner of T.15N.,R.7W., at the common corner of Sections 25, 26, and 35.

A strong structure trends across T.14N.,R.8W., with three possible areas of oil accumulation. The most likely is centered at the corner of Sections 25, 26, 35, and 36. Here dolomitization is widespread.

The trend diagonally across T.15N.,R.8W., especially around Sections 15 and 32, has possibilities for oil accumulation. The well in Section 17, exhibiting strong limestone characteristics, casts doubt over the conditions at the center of the township. However, the ratio

0.240 in Section 14, and the ratio 0.178 in Section 6, T.14N.,R.8W., strongly suggest dolomitization in the immediate vicinity. Apparently there is a small, closed dolomitized structure centered in the southwest part of Section 1, but this area is inaccessible for drilling because of the lakes, swamps, and extreme ruggedness of terrain.

The dolomitization in the southwest of T.15N.,R.7W., suggests structure, but there is no evidence of closure between this area and the small producing area in Section 7, T.14N.,R.7W.

CONCLUSIONS

Many geologists who have considered problems of dolomitization have concluded that a need exists for: (1) a method of quick analysis of limestone-dolomite rocks; (2) a ready method of classification for the degree of dolomitization; and (3) a simple method to present this information. The Versenate method of analysis of limestones and dolomites, and the expression of the results of analysis as a magnesium/calcium ratio may fulfill these needs.

The uses of such a method are many. As in the Mecosta area considered here, magnesium/calcium ratios should greatly facilitate the prediction of dolomitization on structure, and should aid in locating dolomitized structures.

Ratio determination should be particularly useful in locating and following dolomitization, either along faults or in areas not related to structure. The Pinconning Field, Fraser and Pinconning Townships, Bay County, Michigan, exhibits the real need for such a tool. In 1944, the Shell Oil Company drilled a well which intersected and produced oil prolifically from a dolomitized fault zone in the Dundee formation. In succeeding years over twenty offset wells were drilled, all dry, before the strike of the fault was found and a second producing well obtained. The field now extends more than three miles along the strike of the fault and is still being extended. It is the writer's belief that a study of the magnesium/calcium ratios in this area could have indicated the dolomitized fault zone with only a fraction of the number of offset wells which were drilled. Such a study should be valuable in determining extent and direction of dolomitization in other areas of Michigan having similar problems.

Preliminary work by the writer indicates that this geologic technique is useful in determining formation boundaries and correlations, and may be very helpful in distinguishing between lagoonal and deep sea facies in reef areas.

It is hoped that this technique will provide the basis for a better understanding of limestone-dolomite deposition and of secondary dolomitization, wherever it occurs.

BIBLIOGRAPHY

Association of Official Agricultural Chemists, "Official and Tentative Methods of Analysis," 6th Edition (1945), pp. 42-50.

Billings, M. P., Structural Geology, Prentice-Hall, New York (1942).

Cheng, K. L., T. Kurtz, and R. H. Bray, "Determination of Calcium, Magnesium, and Iron in Limestone," Analytical Chemistry, Vol. 24, No. 10 (Oct., 1952), p. 1640.

Cohee, G. V., and L. B. Underwood, U. S. Geological Survey Oil and Gas Investigations, Preliminary Map 38, "Lithology and Thickness of the Dundee Formation and the Rogers City Limestone in the Michigan Basin" (1945).

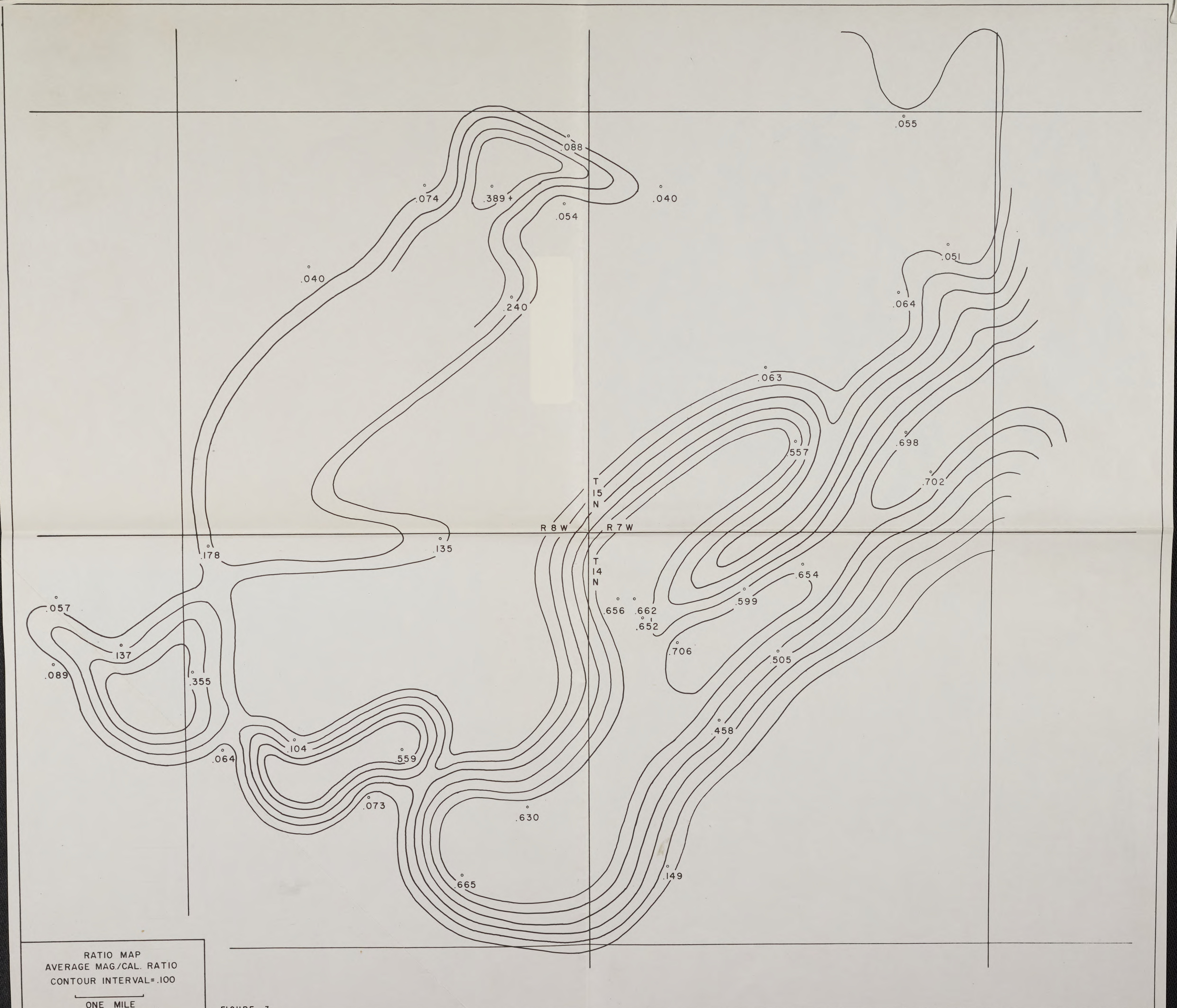
Criss, C. R., and R. L. McCormick, "History and Performance of the Coldwater Oil Field, Michigan," Paper 278-G, American Institute of Mining and Metallurgical Engineers (Oct., 1953).

Krumbein, W. C., and F. J. Pettijohn, Manual of Sedimentary Petrography, Appleton-Century, New York (1938).

Krumbein, W. C., and L. L. Sloss, Stratigraphy and Sedimentation, Freeman and Co., San Francisco (1951).

Landes, K. K., "Porosity Through Dolomitization," Bulletin of the American Association of Petroleum Geologists, Vol. 30, No. 3 (March, 1946), pp. 305-318.

Powell, L. M., "Calcium Carbonate - Magnesium Carbonate Ratios . . . of the Pinconning Field," Thesis, University of Michigan.



RATIO MAP
AVERAGE MAG./CAL. RATIO
CONTOUR INTERVAL=.100

ONE MILE

FIGURE 3

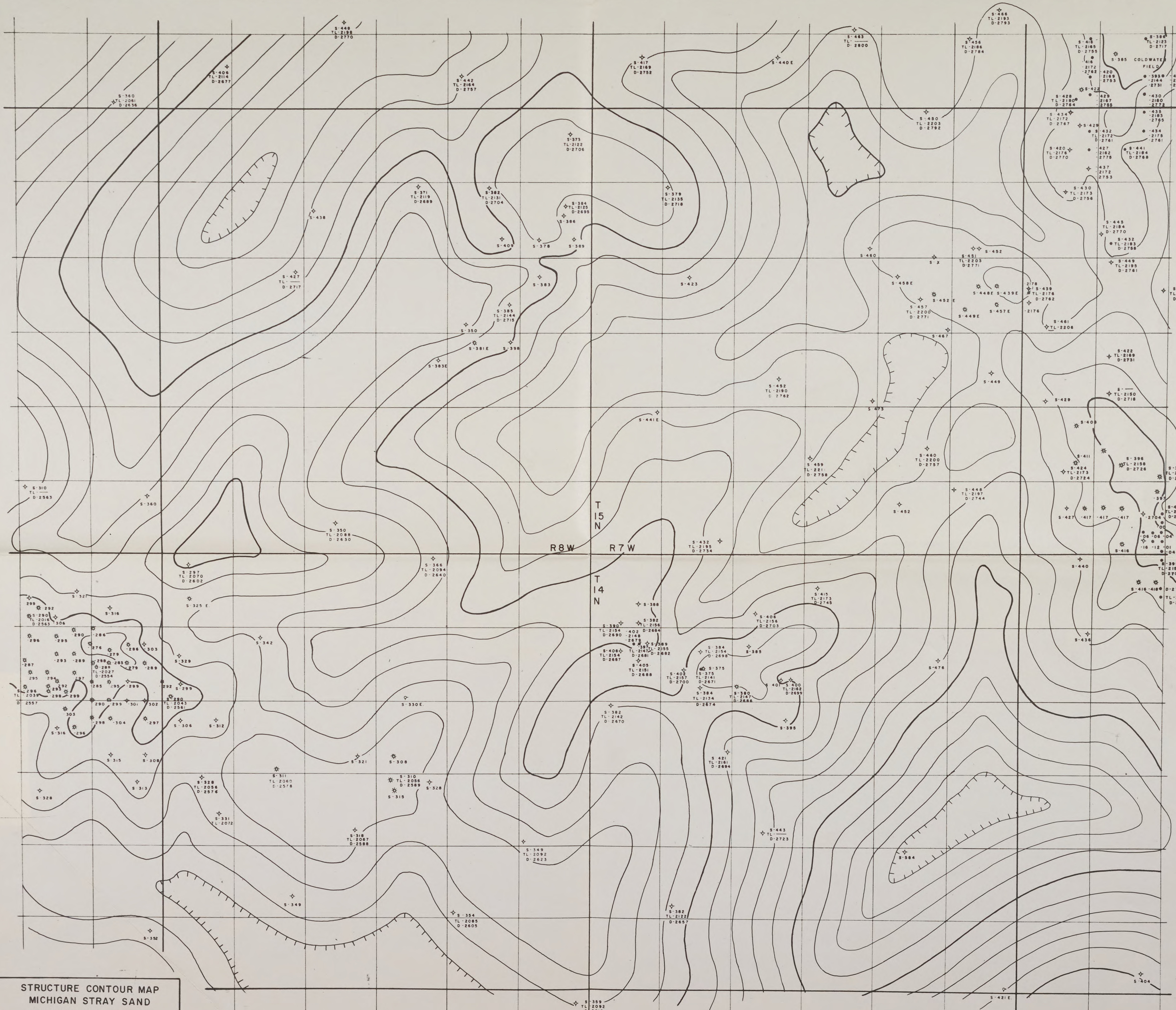
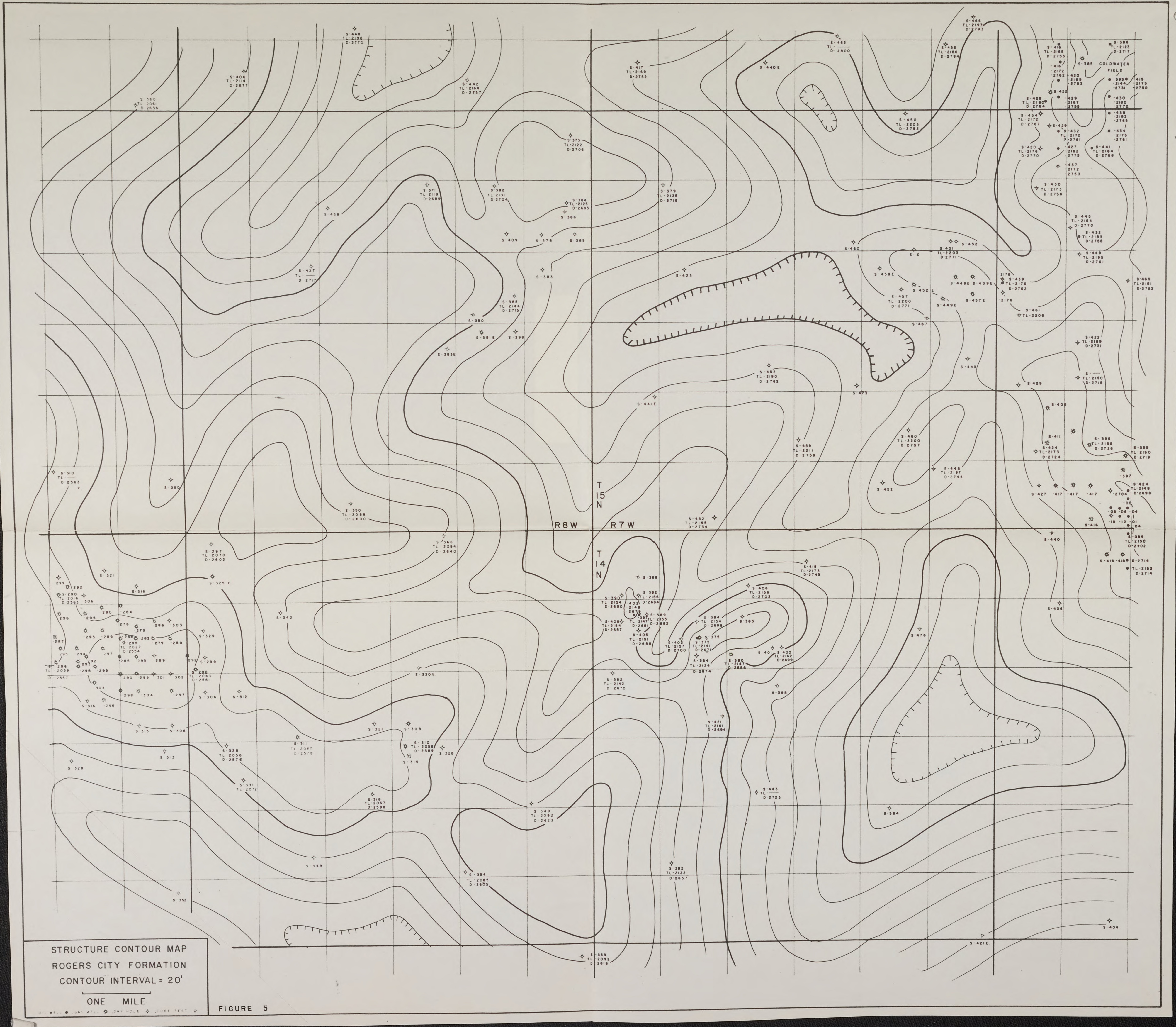


FIGURE 4

STRUCTURE CONTOUR MAP
MICHIGAN STRAY SAND
CONTOUR INTERVAL=20'

ONE MILE

OIL WELL ●, GAS WELL ✲, DRY HOLE ✧, CORE TEST ◇



STRUCTURE CONTOUR MAP
ROGERS CITY FORMATION
CONTOUR INTERVAL = 20'

ONE MILE

FIGURE 5

Pocket has: 3 Tables

112
861
THS
Fig. 3