AN INVESTIGATION OF THE CARBONATE ROCKS IN THE REYNOLDS OIL FIELD, MONTCALM COUNTY, MICHIGAN

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ABSTRACT

AN INVESTIGATION OF THE CARBONATE ROCKS
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MONTCALM COUNTY, MICHIGAN

By

Mohammad Dastanpour

Devonian dolostones have long been the major reservoir rocks in Michigan. Different theories have been proposed concerning the origin of dolomite. To get a better understanding about the origin of dolomite and its relationship to the structural configuration, it was decided to analyze carbonate samples from producing and nonproducing wells with adequate subsurface structural control.

Reynolds Oil Field in Montcalm County, Michigan was selected for this study. The x-ray diffraction method was used to determine the dolomite percentage in the prepared samples. It was found that the highest degree of dolomitization from the Traverse Limestone interval occurred near the top of the formation. Dolomite in this interval is believed the result of a post-diagenetic process. The degree of dolomitization shows a close correlation with the structural map drawn on top of the Traverse Limestone.

Mohammad Dastanpour

The lower Rogers City-Dundee dolomite occurs over a wide-spread area with no significant variation in lithology. This dolomite is associated with anhydrite which infers an early diagenetic origin. Upper Rogers City-Dundee dolomitization is probably related to early and post-diagenetic processes.

Hydrocarbon production in this field is believed to have been controlled by folding and fracturing rather than dolomitization.

The Rogers City-Dundee structure map shows evidence of cross-structures not reflected in the Traverse structure map. In the former, both the geometry of the folds and distribution of dolomite percentages strongly suggest relationships to faulting. Two episodes of faulting are suggested by the contrasts in the geometry of the structures at the Traverse and Rogers City-Dundee horizons.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

A considerable amount of petroleum in the Michigan Basin is produced from three Devonian reservoirs, the Traverse, Rogers City-Dundee, and Detroit River. Traverse production comes from limestones in the upper part of the unit. A great portion of production from the Rogers City-Dundee is from dolomitic limestones where porosity has developed due to either secondary leaching or to fracturing.

It is the belief of many geologists that dolomitic limestone has a tendency to form along bedding planes, seams, joints, fractures, and faults within limestone formations (Landes, 1946; Powell, 1950; Jodry, 1954; Egleston, 1958; Jackson, 1958; and others).

Others have shown that widespread dolomitic facies formed along shallow epicontinental shelves, or structural highs where the sea and fresh water mixed (Prouty, 1948; Cohee, 1948; Badiozamani, 1973; Folk and Lynton, 1975).

It is the purpose of this study to establish possible relationships between the degree of dolomitization to: (1) structural interpretations within the dolomitized limestone formations and, (2) oil producing and nonproducing areas. It is also the writer's interest to determine the mechanism(s) of dolomitization within the Traverse Limestone and Rogers City-Dundee formations.

It is the hope and purpose of the writer that the information gained from this study will be helpful to further discoveries of oil and natural gas. The Reynolds oil field of Montcalm and Mecosta Counties in Michigan has been chosen as the area of study. The region has a well defined structure with accessible well samples useful to my study.

Analyses of the well samples from the study area were made and percentages of dolomite were determined. Structural interpretations of the area were constructed and interpreted. The percent dolomite of the various samples were plotted and contoured and then compared with the structural maps.

AREA OF STUDY

The Reynolds Field is located in the northwestern part of Montcalm County and in the southwestern portion of Mecosta County, Michigan (Figure 1). It lies approximately three miles north of Howard City and one mile south of Morelytown. Samples used in the study were from the wells that lie in Sections 5, 6, 7, 8, and 18 of T12N-R9W; Sections 1, 11, 12, 13, and 14 of T12N-R10W; and Section 35 T13N-R10W.

The producing area of the Reynolds Field is essentially in Sections 6, 7, 8, 17, and 18 of T12N-R9W, and Sections 1, 2, 18, 13, and 14 of T12N-R10W. Figure 1 shows the location of the Reynolds Oil Field.

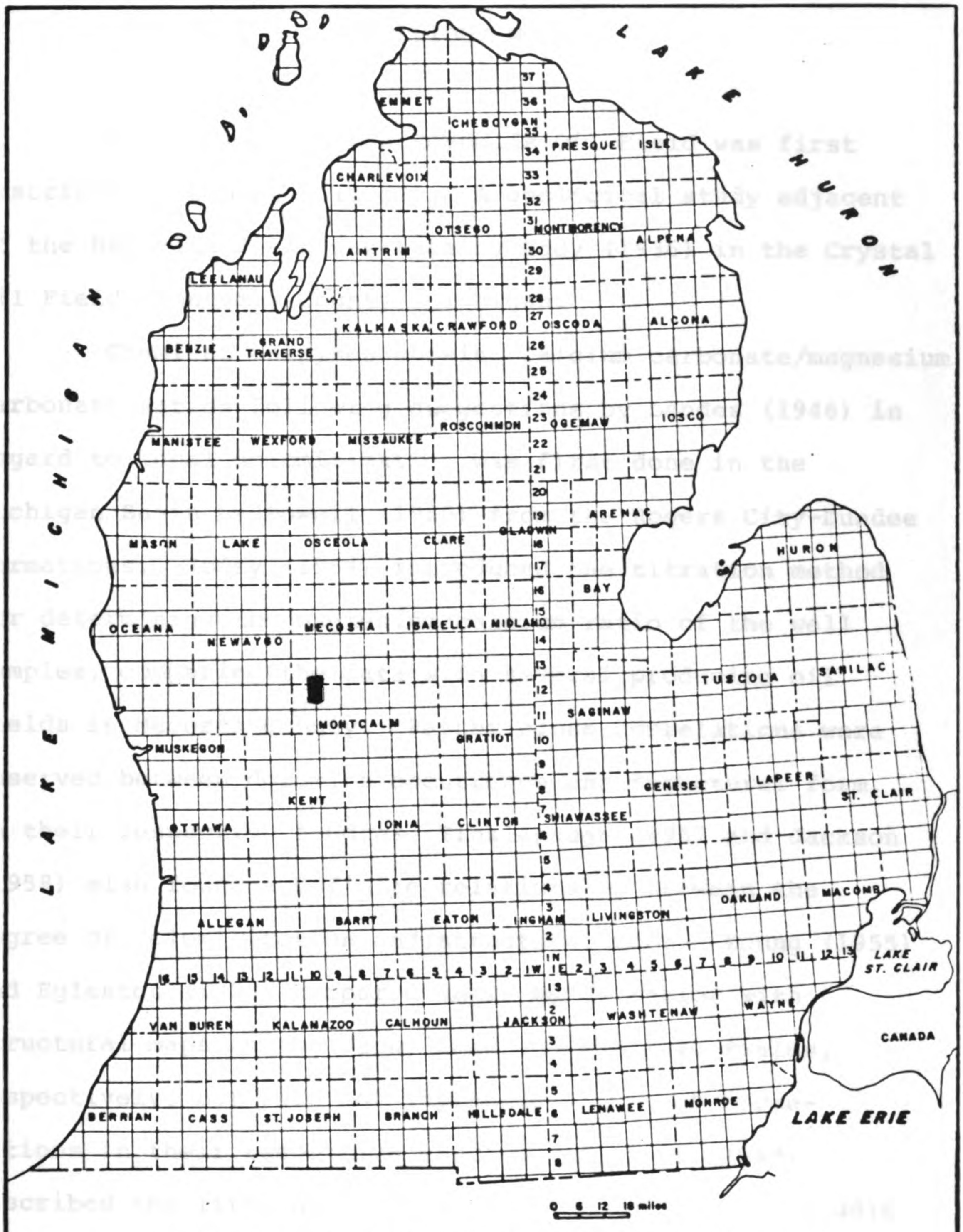


Fig. 1.--Location of Reynolds Oil Field in Michigan.

PREVIOUS WORK

The geology of the Reynolds Oil Field was first described by Goodrich (1957). A geological study adjacent to the Reynolds Field was made by Eddy (1936) in the Crystal Oil Field, Montcalm County, Michigan.

Chemical analyses showing calcium carbonate/magnesium carbonate ratios following suggestions by Landes (1946) in regard to local dolomitization was first done in the Michigan Basin by Powell (1950) from the Rogers City-Dundee formations. Jodry (1954) introduced the titration method for determining the magnesium/calcium ratio of the well samples, comparing the data with several producing oil fields in Mecosta County. Rather close correlations were observed between dolomite occurrence and structural form. In their respective studies, Tinklepaugh (1957 and Jackson (1958) also found a definite relationship between the degree of dolomitization and structural form. Young (1955) and Egleston (1958) compared their Mg/Ca ratios with structural maps in the Stony Lake and Winfield fields, respectively, but were not impressed with such correlations in their respective studies. Bloomer (1969) described the lithology and nature of porosity in a middle Devonian (Dundee) core.

Recent regional dolomitization studies from semi-quantitative analyses in Michigan were made by Newhart (1976) on the Middle Ordovician, Runyon (1976) on the Traverse Group, and Syrjamaki (1977) on the Lower Ordovician.

STRATIGRAPHY

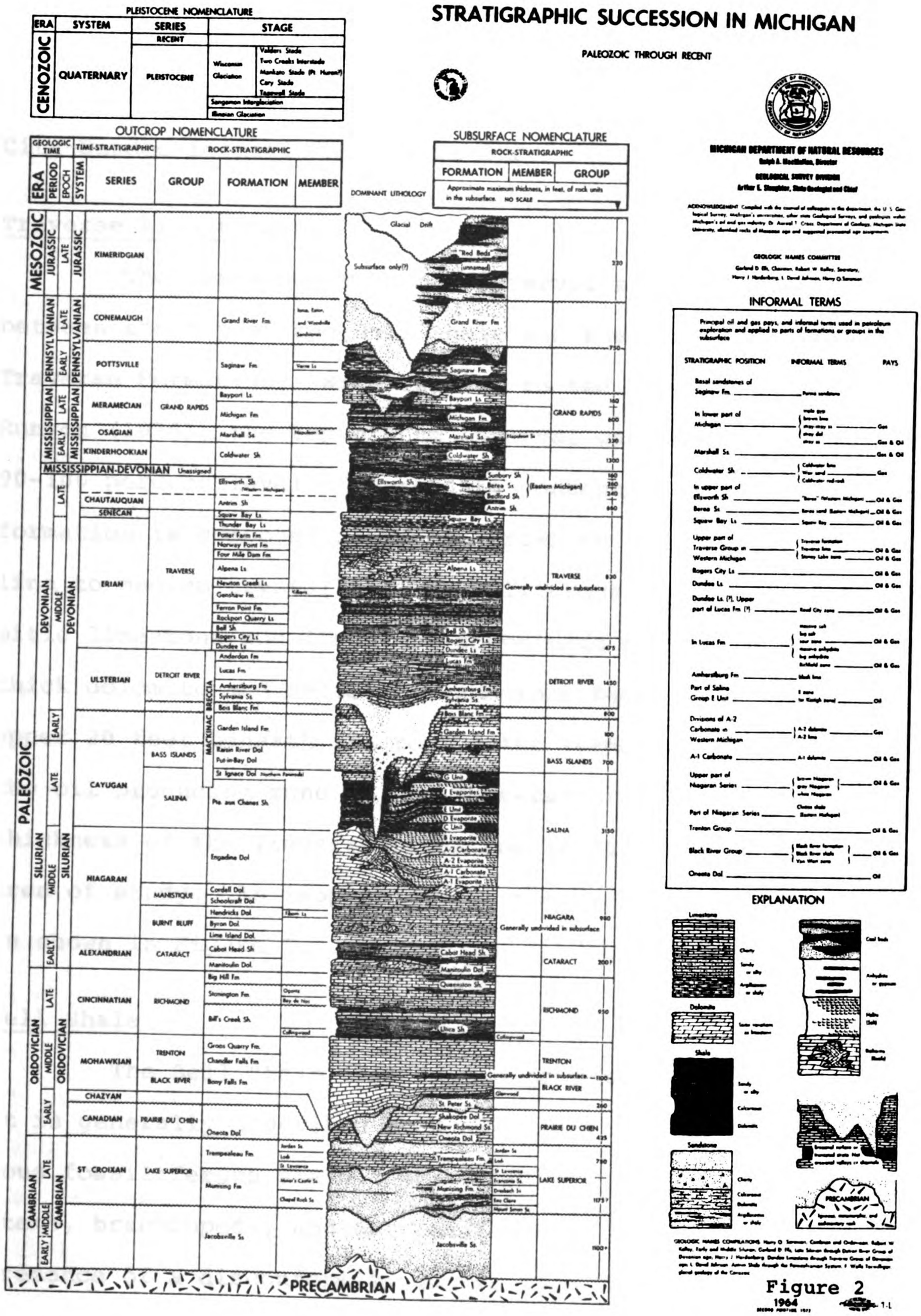
General Stratigraphic Framework

Middle Devonian rocks in the Michigan Basin are represented by the Traverse Group, the Rogers City-Dundee formations, and the Detroit River Group (Figure 2).

The Traverse Group with the Bell Shale at the base lies unconformably on the top of the Rogers City formation (Cohee and Underwood, 1945). The Traverse Group is divided into three major units by Baltrusaitis (1948), the upper part "Traverse Formation," the middle "Traverse limestone" and the lower the "Bell Shale." Cohee (1947) described the lithology of the Traverse Group in westcentral Michigan Basin as relatively pure limestone with some dolomite and argillaceous dolomite.

The Rogers City formation beneath the Bell Shale (Figure 2) rests on top of the Dundee formation. It is typically dark-colored brownish-buff dolomitic limestone or dolomite (Cohee, 1948).

The Dundee formation is underlain by the Detroit River Group and consists of buff to light brown, cherty limestone, dolomitic limestone and dolomite (Cohee, 1948).


STRATIGRAPHIC SUCCESSION IN MICHIGAN
PALEOZOIC THROUGH RECENT
MICHIGAN DEPARTMENT OF NATURAL RESOURCES
PLEISTOCENE NOMENCLATURE
ERA
SYSTEM
SERIES
STAGE
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QUATERNARY
PLEISTOCENE
OUTCROP NOMENCLATURE
SUBSURFACE NOMENCLATURE
GEOLOGIC TIME
TIME-STRATIGRAPHIC
ROCK-STRATIGRAPHIC
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EPOCH
GROUP
FORMATION
MEMBER
DOMINANT LITHOLOGY
MESOZOIC
JURASSIC
KIMERIDGIAN
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POTTSVILLE
MISSISSIPPIAN
MERAMECIAN
OSAGIAN
KINDERHOOKIAN
MISSISSIPPIAN-DEVONIAN
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SENECAN
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PALEOZOIC
SILURIAN
CAYUGAN
NIAGARAN
ALEXANDRIAN
ORDOVICIAN
CINCINNATIAN
MOHAWKIAN
CHAZYAN
CANADIAN
CAMBRIAN
ST CROIXAN
PRECAMBRIAN
INFORMAL TERMS
EXPLANATION

Figure 2

Stratigraphy of the Reynolds Field

The present study involves the section from the top of the Traverse Limestone to the base of the Rogers City-Dundee formations (Figure 2).

Traverse Limestone

The Traverse Limestone interval as noted lies between the top of the Bell Shale and the base of the Traverse Formation. With respect to the suggestion by Runyon (1976), the top of the interval was placed at the 90-100 percent level of carbonate concentration. The formation is composed of white, brown to tan, finely crystalline to medium crystalline, fossiliferous limestone, dolomitic limestone and limestone containing chert. A 5-10 foot thick dolomite and dolomitic limestone bed occurs in the upper 20 feet beneath the top of the formation. This is the oil producing zone of the Traverse Group. The average thickness of the Traverse Limestone is 400 feet in the area of study. An isopach map of the carbonate interval is shown in Figure 5.

Bell Shale

The Bell Shale lies on top of Rogers City formation. It is generally described as a dark gray to black, calcareous fossiliferous shale. The fossils include crinoid stems, brachiopods, and ostracods (Goodrich, 1957). Presence of a disconformity at the base of the Bell Shale is suggested by Newcombe (1933), Eddy (1936) and Landes (1951). However, Bloomer (1969) proposed that the depositional surface in the middle of the Michigan Basin at the close of Rogers City time was irregular with large isolated pools of water. Further he recognized transitional deposition from the Dundee into the Bell Shale. The writer recognizes a sharp break at the base of the Bell Shale in the Reynolds area which could infer a disconformity. An isopach map of the Bell Shale interval is exemplified in Figure 6. The interval averages 60 feet in thickness.

Rogers City-Dundee

The Rogers City and Dundee formations are difficult to distinguish in much of the Michigan Basin subsurface. In this study they are referred to one unit, the Rogers City-Dundee formation. Cohee and Underwood (1945) stated that the Rogers City-Dundee interval in the central portion of the Basin was composed of dolomite and limestone, whereas in the far westcentral and southwestern area it is predominantly dolomite. In the Reynolds Field the upper part of the formation is represented by a light and buff to light gray limestone, dolomitic limestone, or fossiliferous limestone. The Rogers City-Dundee formation becomes more dolomitic toward the base. A 7-10 foot thick bed of anhydrite occurs at a depth approximately 70 feet below the top of the Rogers City-Dundee formation. Underlying the anhydrite is a predominantly fine to medium crystalline dolomite.

A few wells in this field penetrated the entire thickness of the Rogers City-Dundee interval to the Detroit River Group which lies conformably below. Upper Detroit River consists of alternating beds of dolomite, anhydrite, sandstone, and limestone.

A typical well sample description for the Reynolds Field is shown in Appendix I.

STRUCTURE

General

Several theories have been stated about the origin of the Michigan Basin by Newcombe (1930), Kirkham (1937), Lockett (1947), Cohee (1948), and Hinze (1963). A good summarization of these studies can be found in Ells (1969). It is the belief of Newcombe (1933) and Pirtle (1932) that the principal source of the movement and warping in the Basin is related to the Keweenawan disturbance acting against the Wisconsin Arch. Kirkham (1937) thinks that the downwarp of the Basin chiefly resulted from movement of magma from one part of the earth's crust to another.

Hinze believes that the Basin first began to form as a result of rifting in Keweenawan (Precambrian) time followed by isostatic loading of basic lavas.

Intrabasinal structures are generally attributed to reactivation of Precambrian lines of weakness with the principle stresses occurring after middle Mississippian time. Prouty (1976) attributes Basin faults (and fault-related folds) to shearing stresses from a general eastward direction with the principle effects occurring in post-Osagean Mississippian time.

Structural Interpretation of the Reynolds Field

Structural interpretation was based essentially upon sample analyses for the twenty-two wells studied. Location of the well samples, depth, and thickness of intervals are recorded in Appendix II. Further elucidation was made through the use of well logs where samples were not available. The structural configuration of the Reynolds Field, as contoured on the top of the Traverse Limestone (Figure 3) resembles an anticline with the major axis of the structural trend along a northwest-southeast direction. This structural alignment is in agreement with the general structural trends in the central Basin area as described by Runyon (1976).

A general structural contour map of the field on the top of the Rogers City-Dundee formation is shown in Figure 4. This map reveals a regional doubly-plunging anticline, one near the center of Section 18 and another one approximately at the center of the Field. The axis of the major structural trend is northwest-southeast. Two cross structures also are evidenced in the north of Section 18 and southwest of Section 6. The latter occurs at about right angles to the main structure, while the former shows an offset arrangement of two east-west trending folds. The geometry of both structures highly suggest fault-related folding, and as such may well relate to lineaments (faults) as gleaned from LANDSAT imagery (Prouty, 1976) which show,

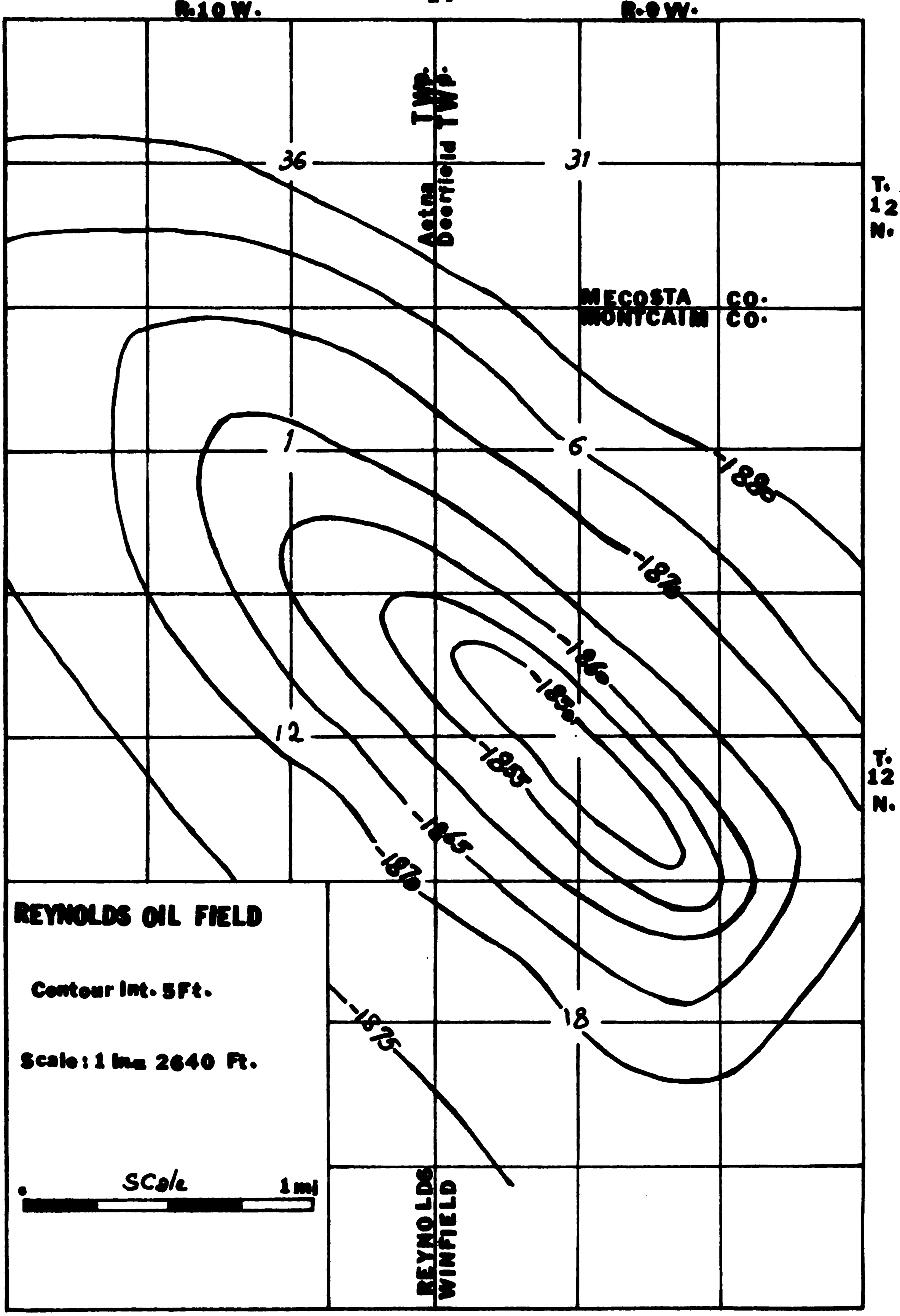

Fig. 3.--Structural Map on Top of the Traverse Limestone.

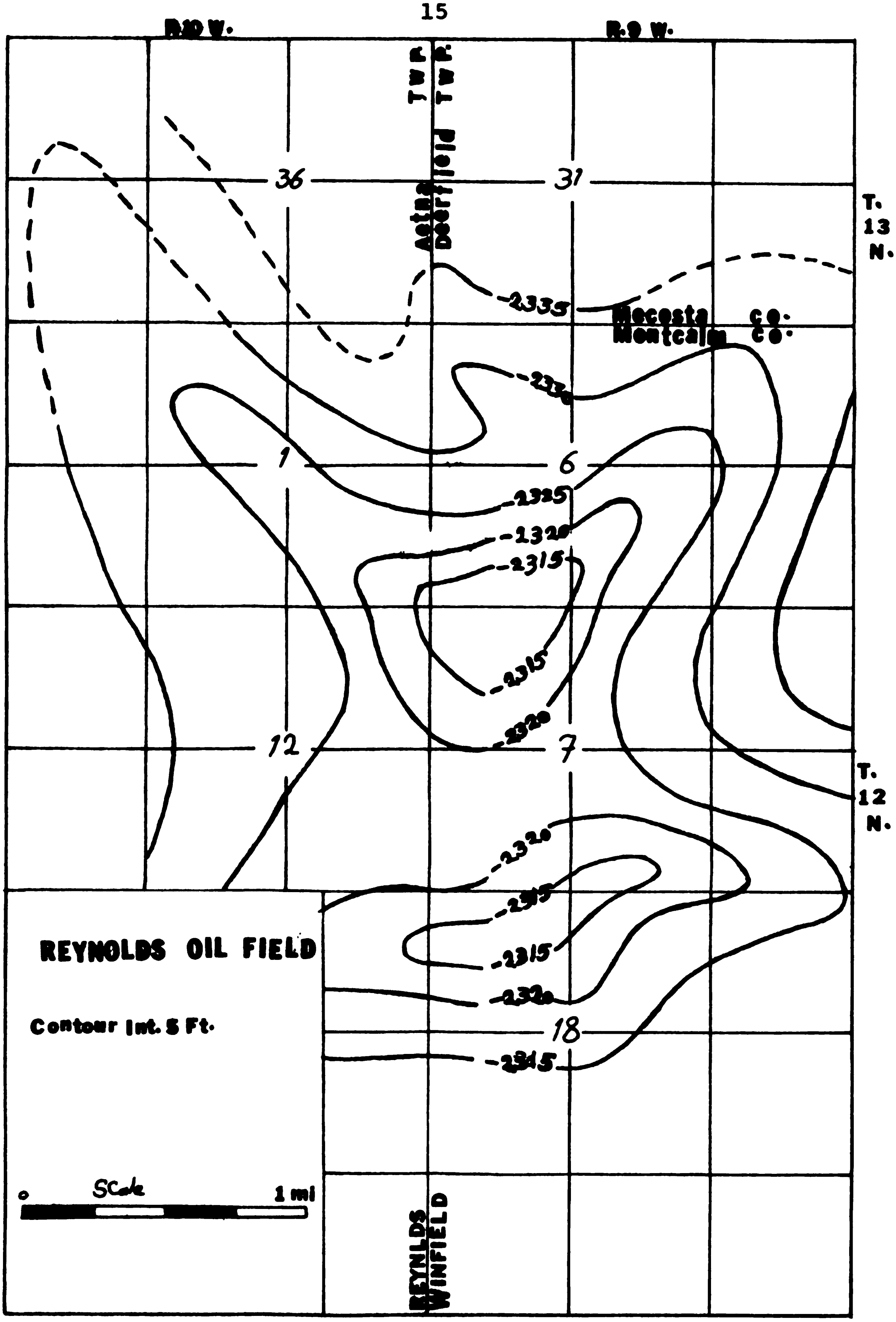

Fig. 4.--Structural Map on Top of the Rogers City-Dundee Formation.

among other orientations, strong northwest, northeast and east-west tendencies. These cross-structures do not show in the Traverse structure inferring that movements are somewhat episodic in nature, whether the folds are related directly to stresses or to shear faulting. A view of Figure 13 supports the latter, as the isolated dolomite ratio highs in sections 7 and 18 show alignments in both a northwestwardly direction (individually) along the main structural trend, and northeastwardly (collectively) subparallel to the cross-fold in sections 6 and 7, of Figure 4. Thus faults (fractures, lineaments, etc.) appear related to dolomitization of the epigenetic type, probably offering permeable zones (channelways) for fluid transport. Conversely, such dolomitized zones can help decipher fault zones that may otherwise go undetected. Dolomitizing processes are discussed later.

ISOPACHS

General

A recent stratigraphic analysis of the Michigan Basin by Runyon (1976) indicates that the Traverse Group isopach map does not portray the Basin as symmetrical nor as circular as the structure contour map though it does possess definite symmetry and roundness. He further suggests that the time of folding in different parts of the Basin was not synchronous.

The isopach map of Cohee (1945) of the Rogers City-Dundee formation shows the lowest thickness in the south and southwest part of the Basin. He indicates that the local thinning of the interval is due to nondeposition rather than erosion. The Saginaw Bay area has been a depocenter intermittently from the Cambrian to Devonian (Fisher, 1969).

Isopachous Interpretation of the Reynolds Field

The isopach map of the Traverse Limestone (Figure 5) shows a general thickening of the carbonate beds toward the southwest and north sides of the field. The general thinning of the beds near the center of this area along an east-west line might reflect subaerial erosion or current scour. If the former, a disconformity is inferred between the Traverse Limestone and Traverse Formation.

The isopach map of the Bell Shale (Figure 6) illustrates a general thickening of the shale beds at the center and along a northwest-southeast direction in the field indicating presence of a depositional trap such as a channel in this area.

Both isopach maps of the Traverse Limestone and the Bell Shale show no thinning along the major structural feature (Figure 3) associated with the Reynolds Oil Field establishing that the movement related to the origin of this structure occurred after Traverse deposition. The most intensive folding is probably post-Coldwater Mississippian in age inasmuch as Young (1955) found that the Traverse Limestone (Middle Devonian) folding is reflected in the overlying Coldwater formation of Mississippian age.

An isopach map was not constructed for the Rogers City-Dundee interval because of insufficient data.

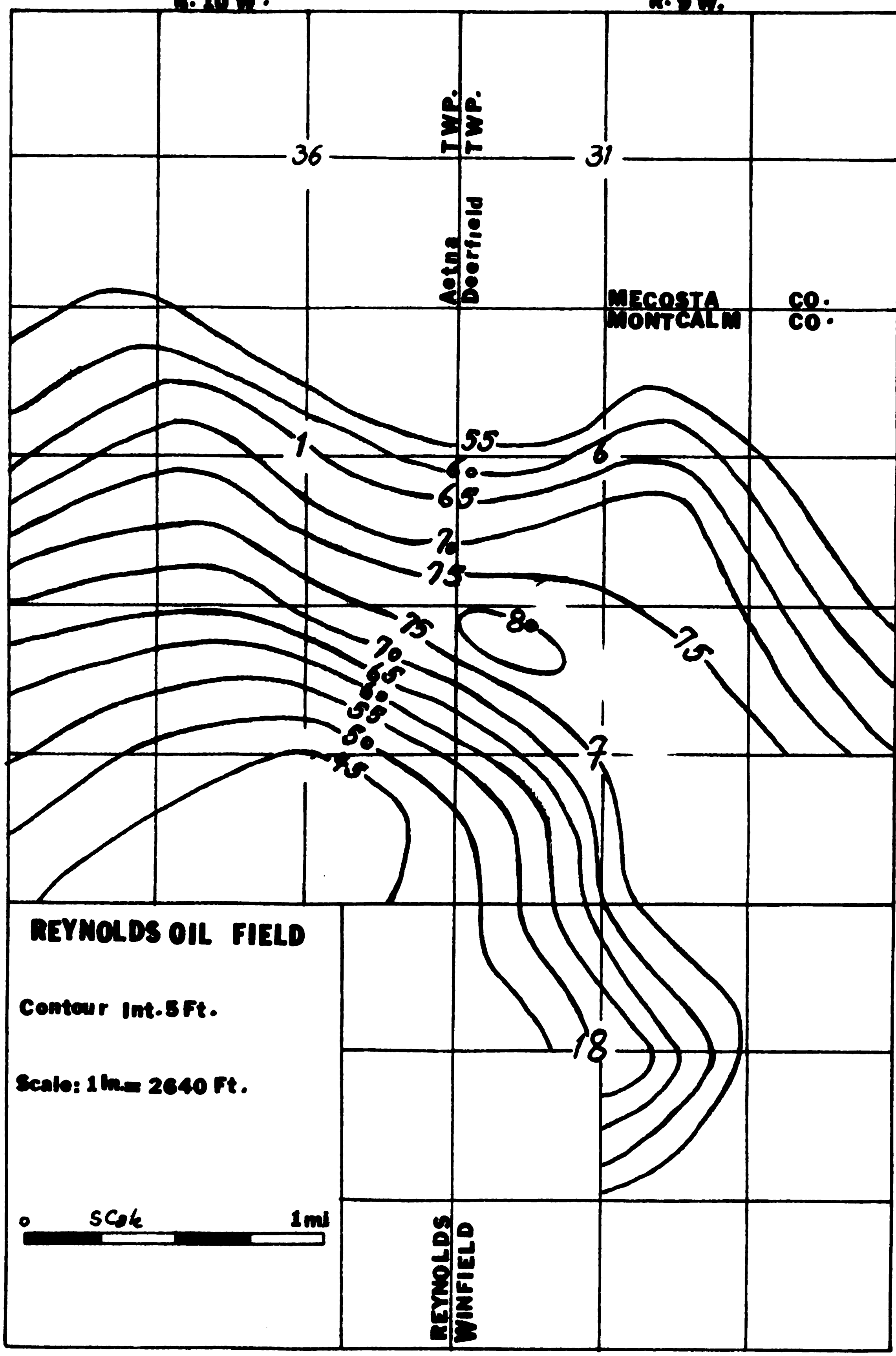

Fig. 6.--Bell Shale Isopach Map.

LIMESTONE AND DOLOMITE ANALYSES

Experimental Procedures

Source of Samples

Carefully selected core chips or outcrop specimens are the best type of samples for analysis owing to known location and lack of contamination. Rotary samples are difficult to work with because of down-hole contamination, often to a degree making it difficult to recognize the first occurrence of a given unit in sample analysis. Cable tool samples are comparatively pure and satisfactory for depth location (Krumbein and Sloss, 1963). Fortunately in the area of study, cable tool samples were available for use.

Sample Selection

Most samples employed in this study had been washed previously. Those samples contaminated by dust or cavings were washed thoroughly with distilled water and dried. Samples representative of each interval were selected microscopically and consisted of 1.50 to 4.0 grams. Variation of sample weight varied with the thickness of the sample interval and the quantity of sample available in each well. A 20-foot interval was sampled at the top of the Traverse Limestone, with a 40-foot intervals sampled below the top 20 feet; then 60-foot intervals were sampled below to the base. Well samples for the Rogers City-Dundee formation were sampled in 20-foot intervals. These intervals were selected from the contact of Rogers City and Bell Shale to the depth of available samples. Most of the wells in this field penetrated the Reed City dolomite. Breaks were found in some well sample suites, but such samples as were available were utilized.

X-Ray Diffraction Procedure

Conventional chemical methods for determining dolomites and limestones are time consuming and tedious. Particular rock specimens contain other carbonate or other calcium or magnesium-bearing minerals in addition to calcite and dolomite. Under such conditions proper calculations of dolomite percent from chemical analysis alone would be difficult. Determination of dolomite percentage with x-ray diffraction method which is based on the crystal phases, calcite and dolomite, are independent of other Mg, Ca, and carbonate-bearing minerals (Tennant and Berger, 1956). Recently, the x-ray system has been applied by various workers (Tennant and Berger, 1956; Weber, 1967; Gunatiala and Till, 1971; Badiozamani, 1973; Folk and Lynton, 1975) for determination of carbonate minerals. This technique offers speed with an accuracy and precision comparable to wet chemical procedures (Kutsykovich, 1971; Gunatilaka and Till, 1971).

The Method

Determination of the relative quantities of a multicomponent mixture by x-ray diffraction is based on the relationship between peak intensities and the absorptive properties of minerals (Jenkins and DeVries, 1968).

The applied method consists of measuring the relative peak heights for calcite and for dolomite from a series of known proportion, and comparing samples of unknown composition with the curve constructed from standards of known relative quantities. The development technique is based on the Tennant (1956) and Otalova (1969) methods. It should be noted that the method is reliable mainly for determining quantitative ratio for the minerals present in a rock specimen. For a precise and accurate quantitative determination of a single mineral, using a spiking (internal standard) system is suggested by Gunatilaka and Till (1971).

Sample Preparation

Both dolomite and calcium carbonate were used for standardization from selected grains from purchased specimens. Dolomite grains were left in 5 percent hydrochloric acid for several hours to dissolve the very fine calcite minerals that might have grown in between the dolomite crystals. The grains then were thoroughly washed with distilled water and dried.

Grain size, sample packing, and mineral orientation have influence on the diffraction peak intensities (Jenkins and Devries, 1968). To minimize these effects all samples were crushed and ground by an electric grinder for about 10 minutes to less than 256 mesh fractions. Samples were packed into the sample holders consistently (loose or tight). Also the sample surfaces were made as smooth as possible.

Procedure

The powdered samples were packed into a sample holder and placed in a General Electric X-Ray Diffraction Goniometer and irradiated using Ni filtration copper Kα radiation, 50 KV, 10MA, scan rate 0.2/minute, rate meter 16, time constant 2, and chart speed of 32"/hour. Further, scans were taken with a 1°, 0.1°slit system. In addition, linear-amplification and pulse discrimination was done.

A calcite intensity of 3.03 A° and a dolomite intensity of 2.88 A° at the 2 position were determined. Each sample was scanned twice (the sample rotated 180°) and the average intensity for each mineral present was found.

Calibration Chart

Different proportions of dolomite and calcite were weighed to an accuracy of a tenth of one mg. Table 1 shows the different mixtures used.

Table 1.--Different Components Used for Standardization.

Weight percent dolomite	Grams Mass dolomite	Mass calcite
15	0.3000	1.7000
25	0.5000	1.5000
30	0.6000	1.4000
50	1.0000	1.0000
60	1.2000	0.8000
75	1.5000	0.5000
90	1.8000	0.2000
100	2.000	0

Each component then was mixed completely. Three samples of each concentration were scanned twice (sample rotated 180°), therefore each point on the curve represents the average results from six points. A calibration curve was established by plotting the dolomite/(dolomite + calcite) x 100 intensity ratio as measured versus the weight percent dolomite in the mixture (Figure 7).

It should be mentioned that the meaning of dolomite percent as used here is the percent of total magnesium

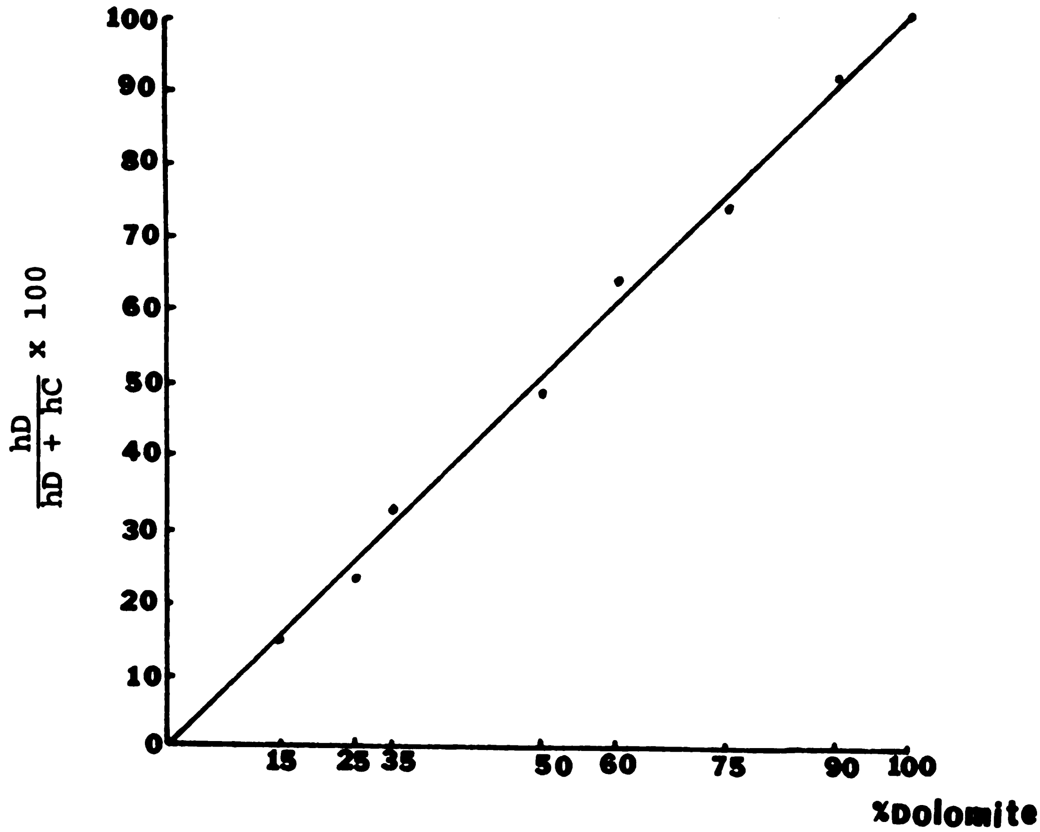

Fig. 7.--Calibration Curve of Dolomite Percent.

hD = Dolomite Hight peak at 2.88
hC = Calcite Hight peak at 3.03

calcium carbonate (Mg Co_3 Ca Co_3) plus calcite (Ca Co_3), which is present as dolomite in a rock specimen.

The dolomite described in this study is an ideal dolomite. Goldsmith and Graf (1958) identified ideal mineral dolomite as a rhombohedral carbonate containing equal molar proportions of calcium carbonate and magnesium carbonate. The characteristic spacing of atomic planes parallel to the [211] crystallographic plane is 2.88 A° in ideal dolomite. This character is seen in x-ray diffraction patterns as symmetrical and sharp peak intensity.

Data Calculation

Correlation coefficient between peak intensities and mass of dolomite percents from the standard samples is 0.998 (r = 0.998) indicating a high correlation between the two variables. As the correlation curve (Figure 7) shows a calculated peak intensity value, $\frac{hD}{hD + hC} \times 100$ represents amount of dolomite percent concentrated in that sample. Expressed in another way:

$$\frac{\text{Dolomite}}{\text{percent}} = \frac{\text{Dolomite mass} \times 100}{(\text{Dolomite} + \text{Calcite})\ \text{mass}} = \frac{\text{Dolomite peak} \times 100}{(\text{Dolomite} + \text{Calcite})\ \text{peak}}$$

All two hundred available samples from twenty-two wells in the area of study were scanned twice and the average intensity peaks for both calcite and dolomite were found. Then the dolomite percent of each sample was calculated by using:

$$\text{Dolomite percent} = \frac{\text{Dolomite average peak} \times 100}{(\text{Dolomite} + \text{Calcite}) \text{ average peak}}$$

Appendix III records the bore well permit numbers and the corresponding dolomite percentages resulting from the x-ray analyses in the Reynolds field. These data were used in plotting and drafting both vertical and lateral variations for interpretations which are presented in the following pages.

Interpreting the Data

Traverse Limestone

The Traverse Limestone in the area of study was divided into a series of 20, 40, and 60-foot intervals in each well. Percent dolomite for these intervals were calculated from the result of the x-ray analyses (see Appendix III). Vertical and horizontal dolomite percents are explained below.

Vertical Dolomite Variation

Dolomite percent values of each well were plotted against their depth below the top of the formation. Typical vertical dolomitization patterns within the Traverse Limestone in the area of study is shown in Figure 8. Three of the four wells show the highest dolomite ratios in the upper 20 feet of the Traverse; the fourth well shows the highest value in the 40-foot sample zone below the top 20-foot zone. All wells show a decrease in dolomite

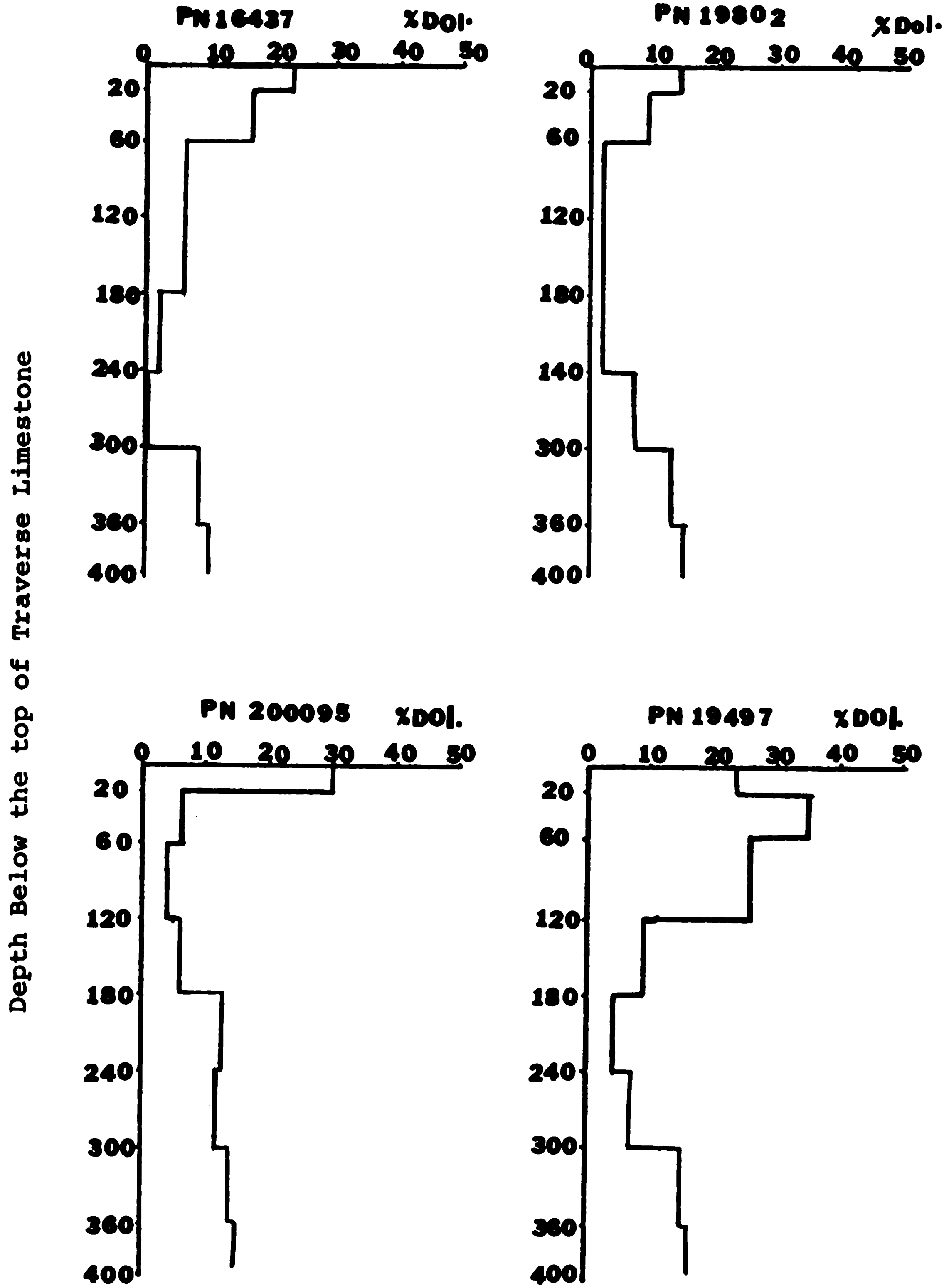

Fig. 8.--Typical Vertical Dolomitization Patterns in the Traverse Limestone.

downward from the high dolomite near the top but increase again as the base of the Traverse and top of the Bell shale is approached.

Lateral Dolomite Variation

The dolomite analyses provided data for a dolomite ratio map which indicates the relative degree of dolomitization along the Reynolds structure. The percent values for the top 20-foot interval below the top of the Traverse Limestone were plotted on the base map of the Reynolds Oil Field. Lines of equal dolomite percent (isodols) were drawn (Figure 9). Values range between 3 and 50 percent.

The dolomitization pattern coincides closely with the structural alignment of the area (Figure 3). The degree of dolomitization increases along the structural trend and along the apex of the major fold. This correlation would infer that the avenues along which dolomitization occurred are related in some way to the axis (and origin) of the fold. This would infer faulting and fracturing. The decrease in dolomite away from the axis of the fold points to the axial position of the channelways controlling circulation of the fluids that brought about, under one or combination of theories discussed later, the dolomitization of limestone.

Similar maps were not constructed beneath the 20-foot interval because of the small lateral variation demonstrated in the lower section. The differences in this

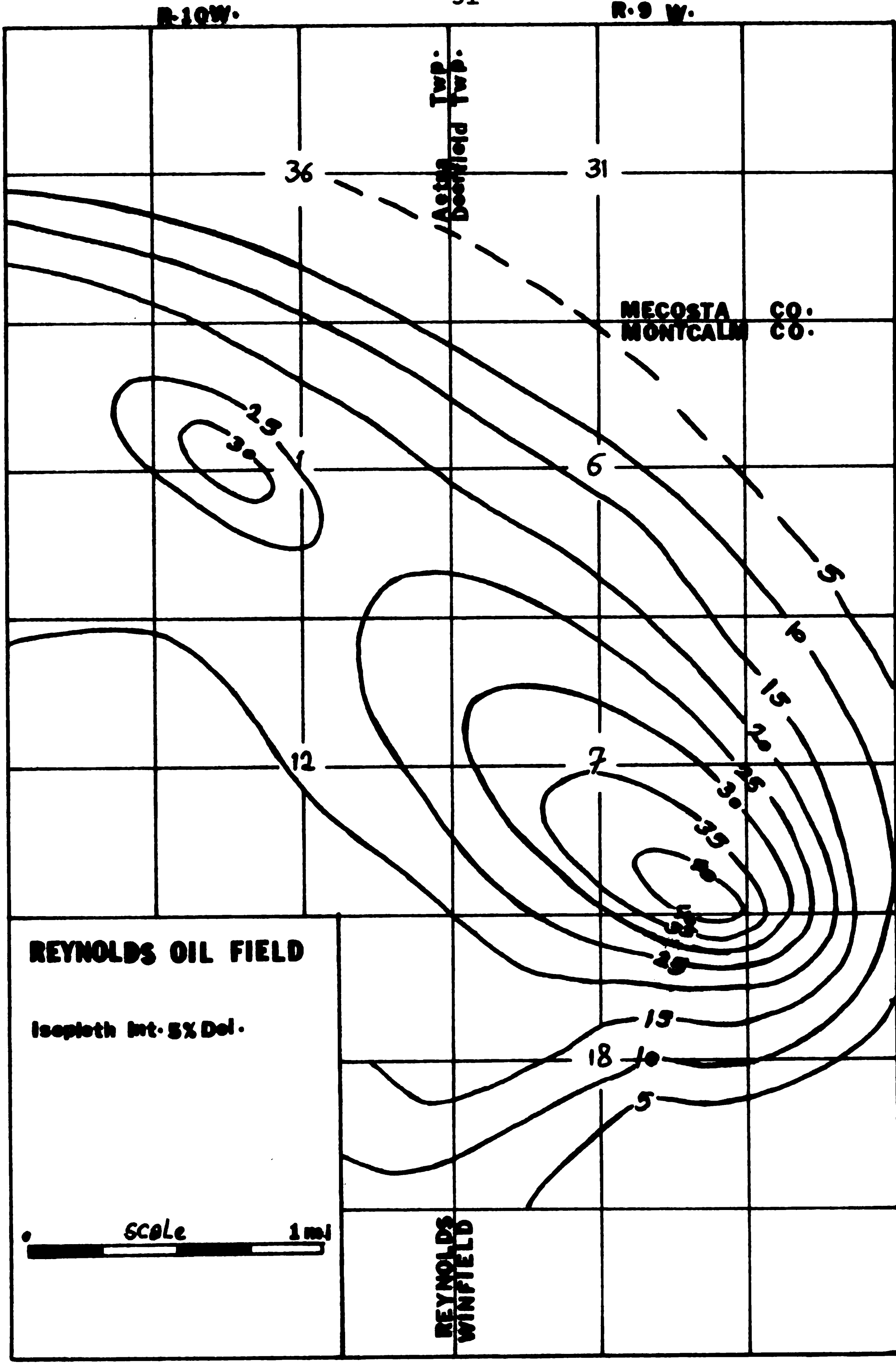

Fig. 9.--Dolomite Ratio Map - Upper 20 Feet Traverse Limestone.

lateral dolomite gradation in the upper and lower Traverse probably have implications as to the ultimate origin of the dolomite, and will be discussed later.

Rogers City-Dundee Formation

The Rogers City-Dundee interval was divided into a series of 20-foot thick intervals in all twenty-two well sample suites from the area of study. Dolomite percent of each individual sample was calculated from the result of the x-ray analyses (Appendix III). Vertical and lateral variation of dolomite percent is explained below.

Vertical Dolomite Variation

Dolomite percent values were plotted against their depths below the top of the Rogers City-Dundee formation. A comparison of vertical variation of the relative degree of dolomitization in several typical well samples are shown in Figure 10. Previous workers supposed that most dolomitization occurred within the top 20 feet of the Rogers City-Dundee formation beneath the Bell Shale. However, the writer found that the relative degree of dolomitization increases downward throughout the formation (Figure 10).

Lateral Dolomite Variation

Though the dolomite increases in percentage downward in the Rogers City-Dundee, only the upper 60 feet (the top three intervals show directional lateral variation.

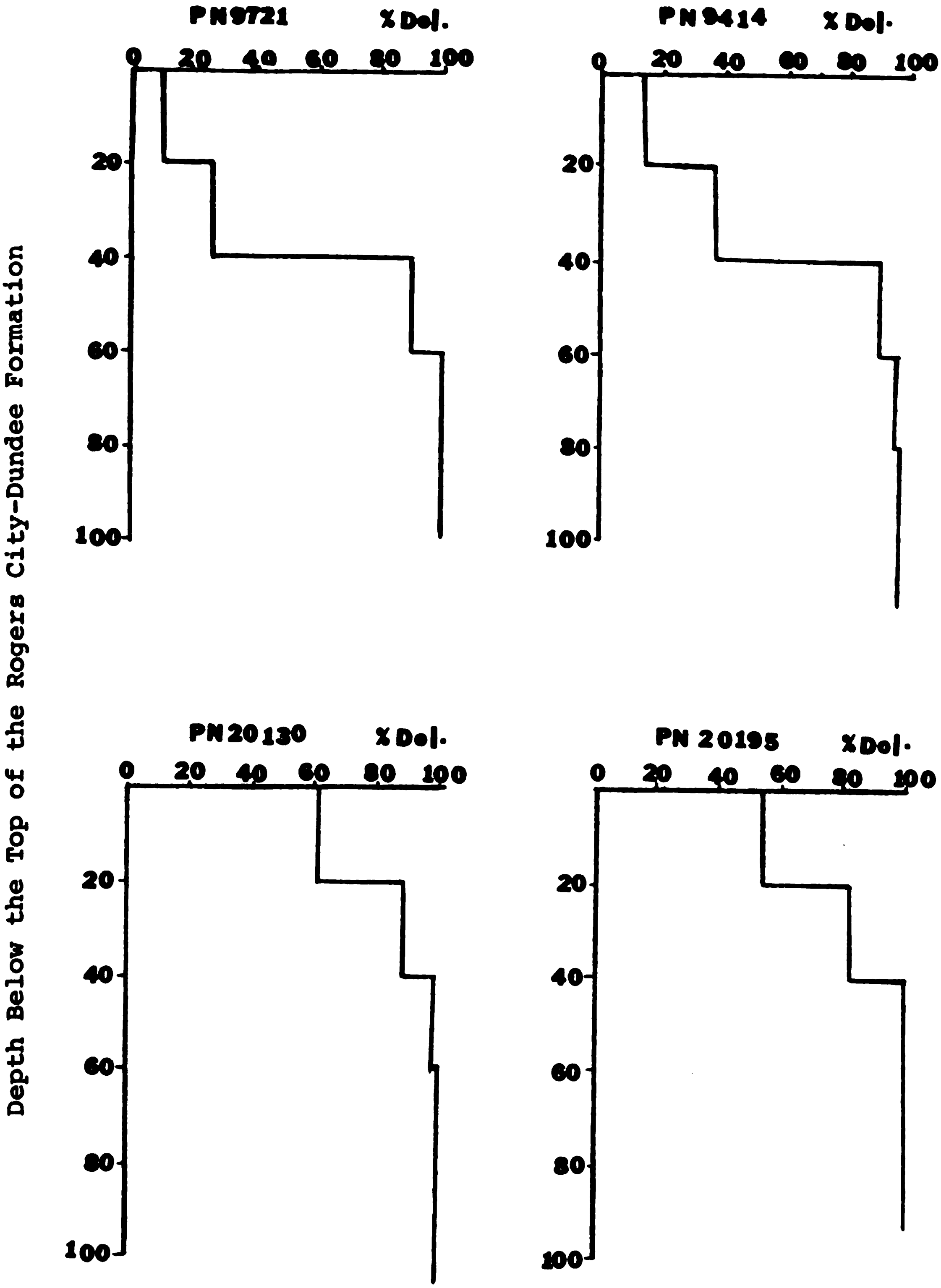

Fig. 10.--Vertical Dolomitization Patterns of Rogers City-Dundee Formation in the Reynolds Field.

Dolomite percent values were plotted on the base map of the area for each of the top three intervals, the isopleths (isodolic lines) representing points of equal dolomite percent. Figures 11-13 show lateral variations of dolomitization for the first, second, and third 20-foot intervals below the top of the Rogers City-Dundee formation respectively.

The structural map on top of the Rogers City-Dundee formation (Figure 4) shows that two obvious cross-structures are present in the northwest portions of Sections 18 and 7. High dolomitization values coincide rather closely with these two structural highs as well northwestwardly along the main structural axis. There would appear to be some relationship between the structural highs, fault and fracture channelways for fluid circulation and a cause and effect relationship between the fault(s) and the folds, in both the main structure and cross-structures. The same relationship was demonstrated along the main northwest-trending structure in the upper Traverse (Figures 3 and 9).

Reynolds Field Dolomitization Models

Traverse Limestone

The dolomitized zone in the upper Traverse Limestone is less than 10 feet thick. Dolomite percent in this area has a wide variation over a short distance, both vertically and laterally. Dolomite grains from this portion

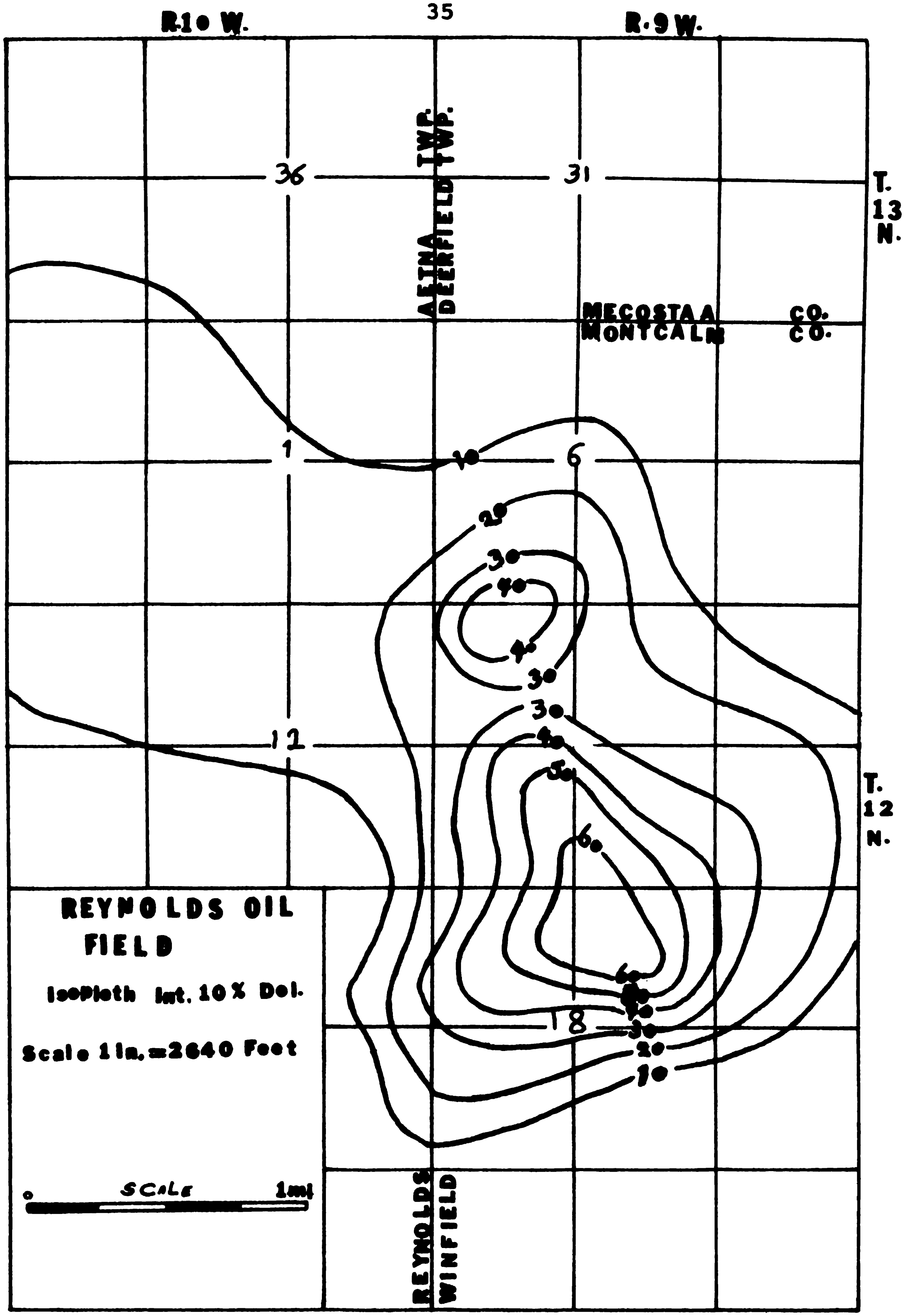

Fig. 11.--Dolomite Ratio Map - Upper 20 Feet Rogers City-Dundee Formation.

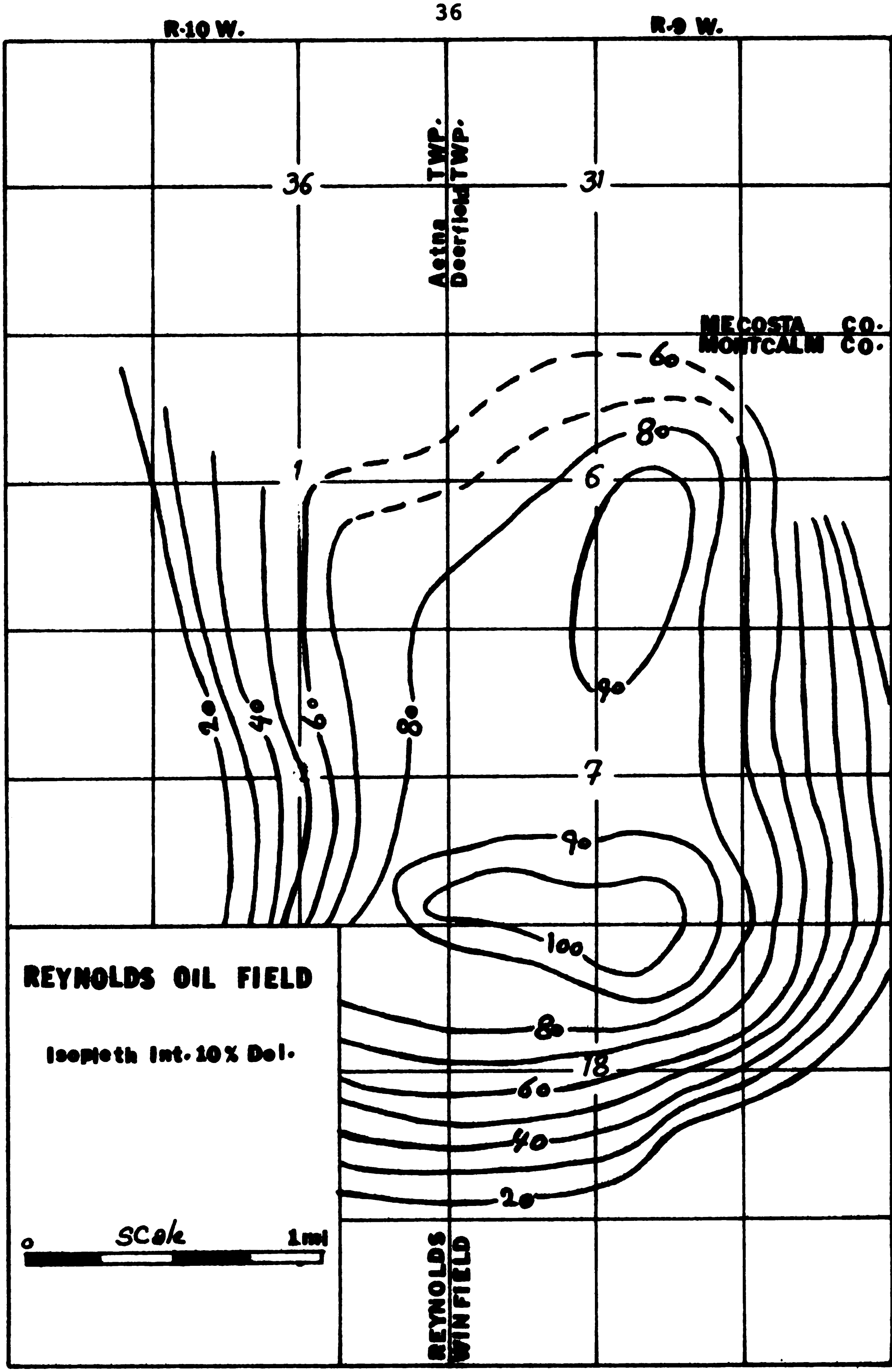

Fig. 12.--Dolomite Ratio Map 20-40 Feet Below the Top of Rogers City-Dundee Interval.

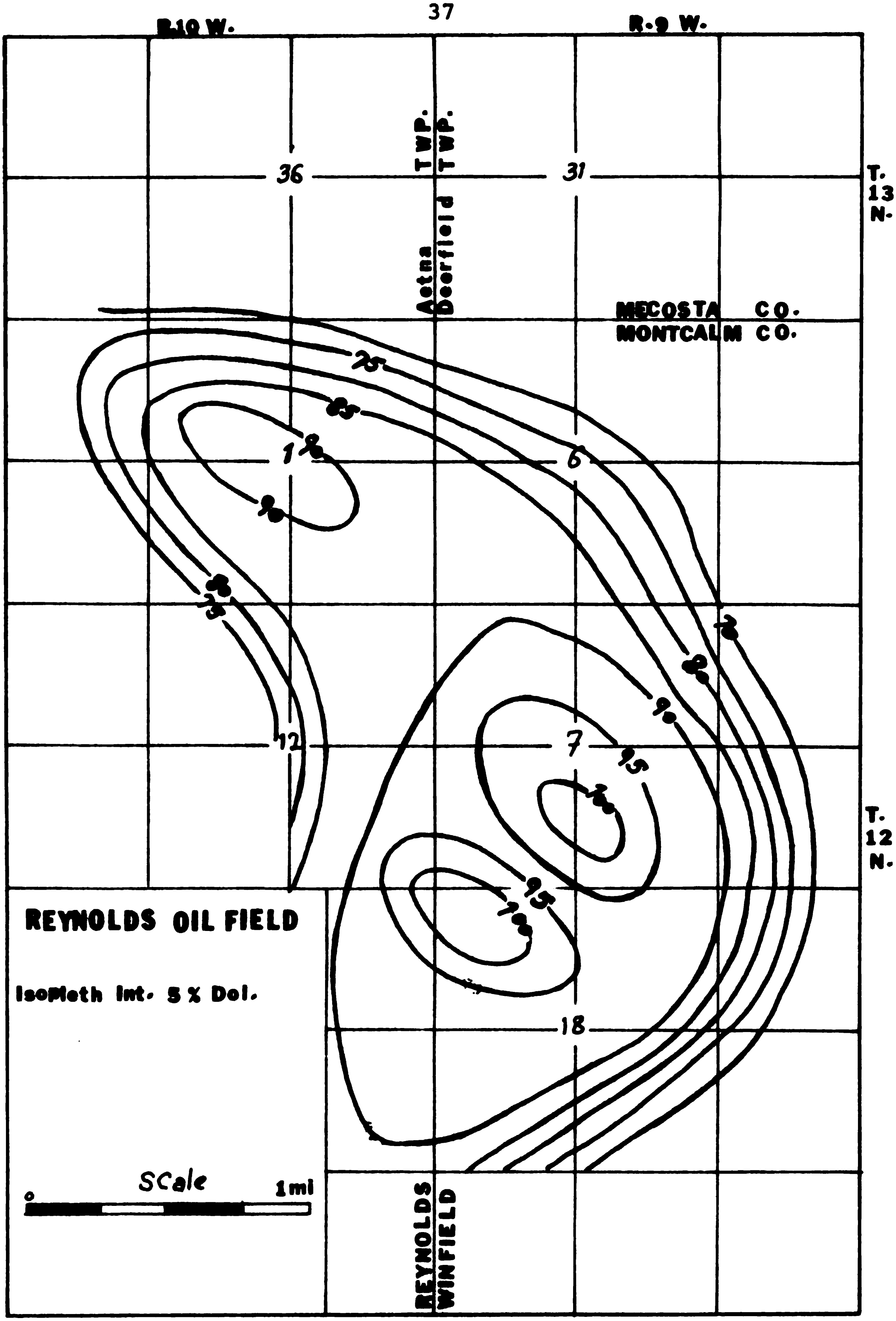

Fig. 13.--Dolomite Ratio Map 40-60 Feet Below the Top of Rogers City-Dundee Interval.

usually do not have uniform grain size and fossils may show relic outlines, the implications being that the rock has been altered later. Thus a post-diagenetic type of dolomitization was assigned to the upper Traverse Limestone in the Reynolds Oil Field. The term "post diagenetic" dolomite is referred to herein as secondary, clearly epigenetic dolomite brought about by ground water percolation through existing fractures present in the brittle carbonate rocks. Ground water in this area percolating along joints, fractures and seams, selectively dissolved the relatively soluble calcite and precipitated dolomite. Hanshaw et al. (1971) in a study of dolomitization by ground water, point out that the "Mg/Ca ratio in aquifer water has low magnitude, where the water is undersaturated with respect to both calcite and dolomite. With time and length of travel path in the system, the water increases systematically in Mg/Ca ratio, then dolomite crystals will form." They also suggest that the small amount of magnesium available from the solution of magnesium calcite and dolomite in the portable zone of active circulation is insufficient to provide extensive dolomitization.

The fact that the percent of dolomite in the Traverse Limestone has a relatively higher value in the upper 20 feet interval beneath the shale of the Traverse formation, and in the lower interval on top of the Bell

Shale indicates that these shale beds were acting as dams for water percolation.

Landes (1946) considered that ascending groundwater was the principal mechanism for local dolomitization in the Middle Devonian carbonates of the Deep River Field of Arenac County. The present study has no evidence for, or against, the possibility of ascending or descending groundwater which may have caused dolomitization of the limestone in the Reynolds Field.

Rogers City-Dundee Formation

The lower Rogers City-Dundee interval is composed of fine-grained dolomites accompanied by significant amounts of anhydrite nodules. The occurrence of the fine grained dolomite could infer early replacement; and the presence of evaporites would further support the thought of an early origin of the associated dolomite. The analyses from this interval indicate that the dolomite is spread over a wide area. This dolomite is probably the result of early diagenetic processes which was probably penecontemporaneous with sedimentation.

A modern type environment for this kind of dolomite was interpreted by Illing et al. (1965) for the "Sabkha" depositional environment of the southwest Persian Gulf, which was described as an extensive flat area, just above normal high-tide level, rising imperceptibly landward. Their explanation concerning the mechanism of penecontemporary dolomite indicates that concentration of the pore waters increases continuously within the near-surface sediments of the Sabkha. As a result of this concentration aragonite and gypsum precipitate and the amount of calcium ions decrease which causes an increase in the Mg/Ca ratio of interstitial waters. The formation of this magnesia-rich brine causes the replacement of aragonite by dolomite.

An early diagenetic type dolomite model for the area of study supports earlier work regarding the Dundee environment in the Michigan Basin by Bloomer (1969) who considered that the major mechanism for Dundee dolomite was seepage refluxion of hypersaline brines. Also a lagoonal and Sabkha-type environment for the Dundee in the west and westcentral part of the Basin was suggested by Gardner (1974).

The upper Rogers City-Dundee dolomite generally differs from the dolomite in the lower part of formation in consisting of larger, nonuniform grain size and lack of evaporites. As mentioned earlier, the pattern of dolomitization within the first three intervals beneath the top of the formation (Figures 11, 12, and 13) show a definite relationship with the structural alignments (Figure 4) of the Reynolds Field. The highest magnitudes of dolomitization occurs along the two cross structures (northwest of Section 18 and northwest of Section 7). Also dolomite percent values show some lateral variations over the area of study. Dolomitization in this instance indicates that a portion of the dolomites were developed by groundwater percolating along existing joints and fractures.

The dolomite percent curves of Figure 10 show a fairly continuous decrease from the diagenetic dolomites of the lower Rogers City-Dundee to the post-diagenetic dolomites nearer the top. It would be difficult to indicate whether the diagenetic processes yielded upwards gradually to the post-diagenetic processes; if post-diagenetic processes entirely replaced diagenetic processes upwards; or if both processes occurred. The first of these three possibilities might be favored on the basis of comparison of Figures 11, 12 and 13, which indicate a decreasing percentage of dolomite away from the structure as one goes up in the section. For example in Figure 13, the outermost isopleth shows 70 percent dolomite well off the Reynolds structure. This suggests a gradation into regional (stratigraphic-diagenetic) dolomite at this level. Figure 12 shows a decrease in dolomite content in the same geographic position; and Figure 11 shows a continued decrease to 10 percent dolomite. Thus the origin of the dolomite appears to be more closely related to the Reynolds structure proper the nearer the top of the formation is approached. The structurally dependent dolomite would then be considered epigenetic (post-diagenetic) in origin as the dolomitizing process would occur through fractures, faults and other post-consolidation channelways.

Additional light no doubt could be shed on this specific problem if quantitative dolomite analyses similar to this study were made regionally.

It is possible that an environment favorable to diagenetic dolomitization may have occurred in late Rogers City time but did not attain the anhydrite stage of the evaporite cycle, such as in a lagoon that was not shallow enough to attain the evaporite depositional stage; or some evaporites may have deposited which later were removed by groundwater percolation. In any event criteria exist that point likely to two dolomitizing processes during Rogers City-Dundee time.

OCCURRENCE AND PRODUCTION OF HYDROCARBONS

Hydrocarbon production in the Reynolds Oil Field is from the uppermost part of the Traverse Limestone and from the Rogers City-Dundee formation. Production occurs on an anticline in a somewhat linear trend. Production is spotty with commercial wells being offset by dry wells which may be only slightly off the main structure. Figure 14 shows the distribution of the productive wells in the Reynolds Oil Field. Traverse productive wells usually show a higher degree of dolomitization. Landes (1959) suggested that the major porosity in the dolomitized limestones is the result of an excess of solution over precipitation during the replacement process.

According to the Michigan Geological Survey reports up to the end of 1972, the greatest amount of oil production in the Reynolds Field had been from the wells located in Section 7 and north of Section 18, the highest part of the field structurally. Most of oil production in these regions comes from a highly dolomitized zone approximately 80 feet below the top of the Rogers City-Dundee formation, directly beneath a 7 to 10-foot thick bed of anhydrite. This producing dolomite is widespread regionally suggesting a stratigraphic (diagenetic) origin.

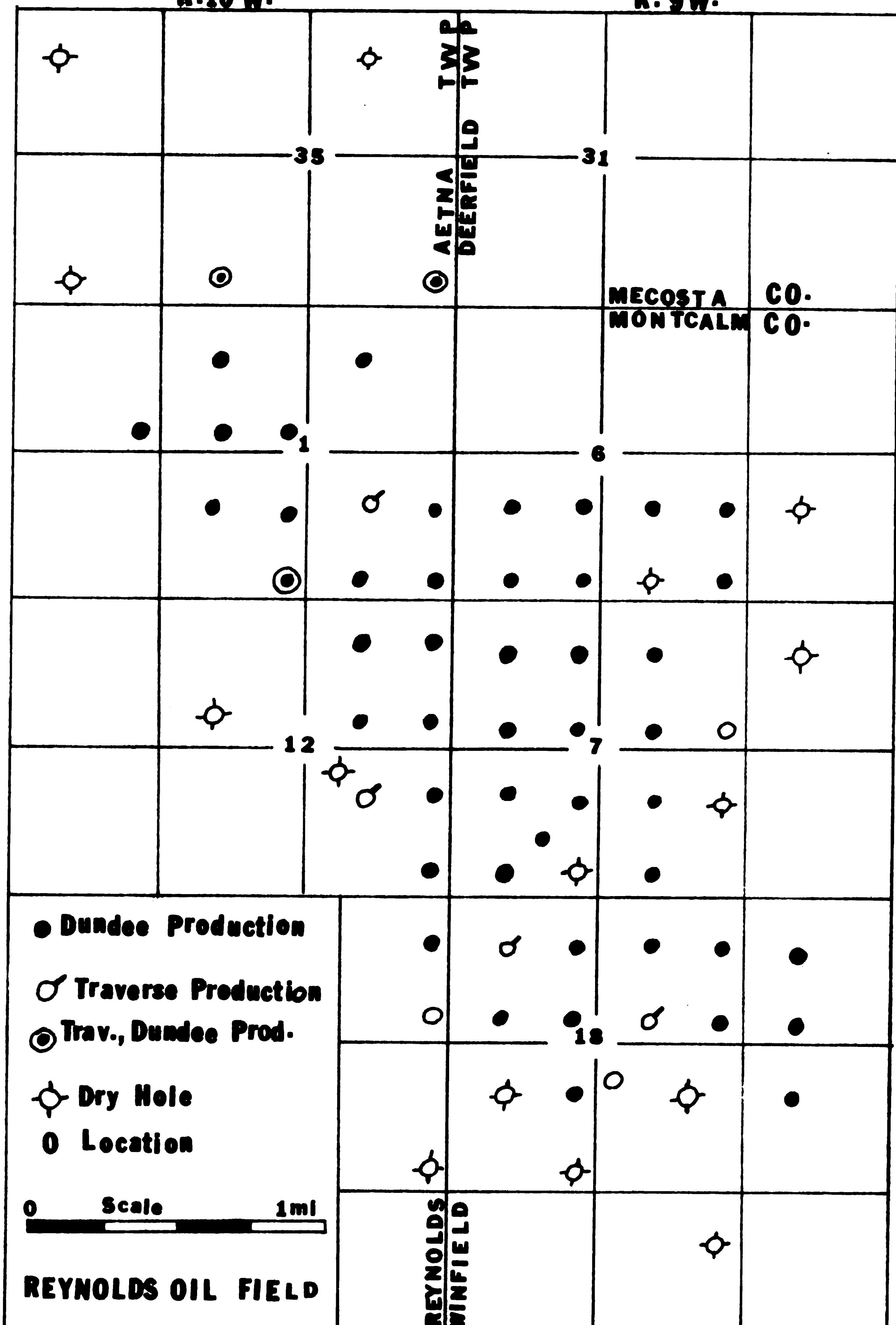

Fig. 14.--Well Distribution.

The degree of dolomitization does not show significant variation between producing and nonproducing wells. The writer believes that porosity in these productive areas of the field probably originated as a result of folding, fracturing and solution activity.

The source of hydrocarbons within the Rogers City-Dundee dolomite is of interest to petroleum geologists. Bloomer (1969), in a regional study of the Middle Devonian dolomite in Michigan, believes that the source of the oil within the dolomitic zone is from the overlying Bell Shale. He observes further that the Rogers City-Dundee formation contains abundant organic material, indicating some intercrystalline oil stain throughout the section.

The Bell Shale disappears in western and southwestern Michigan (Gardner, 1974), where there is very little Dundee production. Therefore it appears logical that the hydrocarbon source for the Rogers City-Dundee dolomite is from the Bell Shale. However, the possibility that the oil was derived in situ from the Rogers City-Dundee interval perhaps should not be overlooked.

CONCLUSIONS

From the analytical data obtained from the Traverse Group and Rogers City-Dundee carbonate rocks certain conclusions may be drawn:

(1) The highest values of dolomite percent were found near the top and close to the base of the Traverse Limestone.

(2) There is a significant relationship between the dolomitization pattern and structural configuration of the upper Traverse Limestone.

(3) Patchy dolomite distribution in the Traverse carbonate interval indicates a post-diagenetic type of dolomitization.

(4) The percentage of dolomite in the Rogers City-Dundee carbonate increases toward the base of the formation.

(5) Widespread dolomite of the lower Rogers City-Dundee interval is associated with significant amounts of anhydrite. This type of dolomite is probably the result of early diagenetic dolomitization, and is penecontemporaneous with sedimentation.

(6) The comparison of dolomite percent and structural trends of the upper Rogers City-Dundee interval reveals, in general, a close relationship.

(7) Both early and post-diagenetic types of dolomitization have occurred in the upper Rogers City-Dundee formation.

(8) Folding, fracturing and solution activity are the major cause for the secondary porosity in the productive zones of this field.

(9) Dolomite percentage determinations can be helpful in detecting fault traces in folded structures as the Reynolds Field that may otherwise go undetected.

(10) There appears to be some relationship between faults and folds in the Reynolds Field.

(11) The intersection of folds (faults) and cross-folds (cross-faults) appear to be the loci of high dolomite percentage where post-diagenetic dolomite is believed to occur.

BIBLIOGRAPHY

BIBLIOGRAPHY

Badiozamani, K. 1973. The Dorag Dolomitization Model Application to the Middle Ordovician of Wisconson. Journal of Sedimentary Petrology 43(4): 965-984.

Bloomer, A. T. 1969. A Regional Study of the Middle Devonian Dundee Dolomites in the Michigan Basin. Unpublished Master's Thesis, Michigan State University.

Cohee, G. V. 1947. Lithology and Thickness of the Traverse Group in the Michigan Basin. U.S. Geological Survey Preliminary Chart 28, Oil and Gas Investigation Services.

________. 1948. A Summary of the Stratigraphy of the Southern Peninsula of Michigan. U.S. Geological Society Report.

Cohee, G. V., and Underwood, L. B. 1945. Lithology and Thickness of the Dundee Formations and Rogers City Limestone in the Michigan Basin. U.S. Geological Survey Preliminary Map 38, Oil and Gas Investigation Services.

Eddy, G. E. 1936. Geology of the Crystal Oil and Gas Field, Montcalm County, Michigan. 8 page report.

Egleston, D. C. 1958. Relationship of the Magnesium/Calcium Ratio to the Structure of the Reynolds and Winfield Oil Fields, Montcalm County, Michigan. Unpublished Master's Thesis, Michigan State University.

Ells, G. D. 1969. Architecture of the Michigan Basin. Mich. Basin Geol. Soc. Annual Field Excursion, pp. 60-88.

Fisher, J. C. 1969. The Distribution and Character of the Traverse Formation of Michigan. Unpublished Master's Thesis, Michigan State University.

Folk, R. L., and Land, L. S. 1975. Mg/Ca Ratio and Salinity: Two Controls over Crystallization of Dolomite. Am. Assoc. Petroleum Geologists Bull. 59(1): 60-68.

Gardner, W. C. 1974. Middle Devonian Stratigraphy and Depositional Environment in the Michigan Basin. Mich. Basin Geol. Soc. Special Papers, No. 1, pp. 41-48.

Goldsmith, J. R., and Graf, D. L. 1958. Structural and Compositional Variations in Some Natural Dolomites. Jour. Geology 66: 678-693.

Goodrich, R. E. 1957. Geology of the Reynolds Oil Field in Montcalm and Mecosta Counties, Michigan. Unpublished Master's Thesis, Michigan State University.

Gunatilaka, H. A., and Till, R. 1971. A Precise and Accurate Method for the Quantitative Determination of Carbonate Minerals by X-Ray Diffraction Using a Spiking Technique. Mineralogical Magazine 38: 481-487.

Hanshaw, B. B.; Back, W.; and Deike, R. G. 1971. Geochemical Hypothesis for Dolomitization by Groundwater. Econ. Geol. 66: 710-724.

Hinze, W. J. 1963. Regional Gravity and Magnetic Anomaly Maps of the Southern Peninsula of Michigan. Mich. Geol. Sur., Rept. Inv. 1.

Illing, L. V.; Wells, A. J.; and Taylor, J. C. M. 1965. Penecontemporary Dolomite in the Persian Gulf. Soc. Econ. Paleontologists and Mineralogists, Spec. Publ. 13, pp. 89-111.

Jackson, R. P. 1958. Dolomitization and Structural Relations of the Deep River, North Adams and Pinconning Oil Fields, Michigan. Unpublished Master's Thesis, Michigan State University.

Jenkins, R., and Devries, J. L. 1968. Practical X-Ray Spectrometry. Springer Verlag, New York, pp. 105-120.

Jodry, R. L. 1954. A Rapid Method for Determining the Magnesium/Calcium Ratio of Well Samples and Its Use As An Aid in Predicting Porosity in Calcareous Formations. Unpublished Master's Thesis, Michigan State University.

Kirkham, V. R. D. 1937. Theory of Origin of the Oil and Gas Bearing Folds in Michigan and Theory of Oil and Gas. Mich. Oil and Gas News, May 15.

Krumbein, W. C., and Sloss, L. L. 1963. Stratigraphy and Sedimentation. Freeman and Co., San Francisco, 2nd Edition, pp. 71-74.

Kutsykovich, M. B. 1971. Roentgen-Diffractometric Method of Determination of Carbonates, Quartz, and Other Minerals in Sedimentations. Lithology and Mineral Resources 6(4): 513-514.

Landes, K. K. 1946. Porosity Through Dolomitization. Am. Assoc. Petroleum Geologists Bull. 3Q: 305-318.

________. 1951. Detroit River Group in the Michigan Basin. U.S.G.S. Circular 133.

________. 1956. Petroleum Geology. John Wiley and Sons, Inc., New York, pp. 191-197 and 398-399.

Lockett, J. R. 1947. Development of Structures in Basin Areas of Northeastern United States. Am. Assoc. Petroleum Geologists Bull. 31: 429-446.

Newcombe, R. B. 1930. Middle Devonian Unconformity in Michigan. Bull. Geol. Soc. of America 41: 725.

________. 1933. Oil and Gas Fields of Michigan. Mich. Geol. Survey Publ. 38, G. Ser. 32.

Newhart, R. B. 1976. Carbonate Facies of the Middle Ordovician of the Michigan Basin. Unpublished Master's Thesis, Michigan State University.

Otalord, G., and Hess, H. H. 1969. Modal Analysis of Igneous Rocks by X-Ray Diffraction Methods with Example from St. Paul's Rock and an Olivin Nodule. Am. Jour. of Science 267: 822-840.

Pirtle, G. W. 1932. Michigan Structural Basin and Its Relationship to Surrounding Areas. Am. Assoc. Petroleum Geologists Bull. 16: 145-152.

Powell, L. W. 1950. Calcium Carbonate/Magnesium Ratios, in the Rogers City and Dundee Formations of the Pinconning Field. Unpublished Master's Thesis, University of Michigan.

Prouty, C. E. 1948. Trenton and Sub-Trenton Stratigraphy of Northwest Belts of Virginia and Tennessee. Am. Assoc. Petroleum Geologists Bull. 32: 1596-1626.

________. 1976. Implications of Imagery Studies to Time and Origin of Michigan Basin Linear Structures. Abstract, Am. Assoc. Petroleum Geologists 61st Annual Meeting, p. 102.

________. 1976. Michigan Basin--A Wrenching Deformation Model? Abstract with program, Geol. Soc. of America 8(4): 505.

Runyon, S. L. 1976. A Stratigraphic Analysis of the Traverse Group of Michigan. Unpublished Master's Thesis, Michigan State University.

Syrjamaki, Robert. 1977. Stratigraphy of the Prairie du Chien Group of the Michigan Basin. Master's Thesis, Michigan State University.

Tennant, C. B., and Berger, R. W. 1956. X-Ray Determination of Dolomite-Calcite Ratio of a Carbonate Rock. Am. Mineralogist 42: 23-29.

Tinklepaugh, B. M. 1957. A Chemical, Statistical, and Structural Analysis of Secondary Dolomitization in the Rogers City-Dundee Formation of Central Michigan Basin. Unpublished Ph.D. Thesis, Michigan State University.

Weber, J. N. 1967. Factors Affecting the Carbon and Oxygen Isotopic Composition of Marine Carbonate Sediments, Part 1--Bermuda. Am. Jour. Sci. 265: 586-608.

Young, R. T. 1955. Relationship of the Magnesium/Calcium Ratio as Related to Structure in the Stoney Lake Oil Field, Michigan. Unpublished Master's Thesis, Michigan State University.

APPENDICES

APPENDIX I

TYPE SAMPLE DESCRIPTION

APPENDIX I

TYPE SAMPLE DESCRIPTION

Well Name: A. Williams No. 1

Location: SE-NW-SE Sec. 1, T12N, R10W

Permit No. 16437

Elevation: 913.0 feet above sea level

<u>Top of Traverse Formation: 2745</u>	Thickness (feet)	Depth from surface
Shale, medium gray, fossiliferous, dark gray, finely crystalline	20	2765
Shale, dark gray, fossiliferous, calcareous; limestone, medium gray, fossiliferous, finely crystalline	17	2782
<u>Traverse Limestone</u>		
Limestone, white, corallian shaly carbonate, dolomitic limestone with some gray shale; limestone, fine to medium crystalline; shale, calcareous	23	2805
Limestone, 60-70%, white corallian (stem of crinoid); shale, medium gray, slightly calcareous; very little chert	68	2873

	Thickness (feet)	Depth from surface
Limestone, 60-70%, fossiliferous, white and brown finely crystalline, dolomitic; shale, calcareous, gray; trace of chert	54	2927
Limestone, 50-60%, buff and brown, very finely crystalline; shale, calcareous, bluish	44	2971
Limestone, brown and dark brown, fine crystalline, fossiliferous; trace of chert	42	3013
Limestone, 60-75%, brown, white, fossiliferous; some gray calcareous shale	59	3072
Limestone, white, coralline; limestone, medium gray fossil fragments; no shale	50	3122
Limestone, buff, brown, dolomitic, white, coralline	66	3188

	Thickness (feet)	Depth from surface
<u>Bell Shale</u>		
Shale, gray, almost pure, fossiliferous; fossils of crinoid stems and brachiopods	26	3214
Shale, dark blue, medium gray, slightly calcareous, fossiliferous	40	3254
<u>Rogers City-Dundee Formation</u>		
Limestone, brownish gray, fine to medium crystalline, dolomitic; some coral fragments; trace of shale	30	3284
Limestone, gray-buff, fine to medium crystalline, dolomitic	34	3318
Limestone, brown, finely crystalline and dolomite	17	3335
Dolomite, brown, finely crystalline	20	3355
Anhydrite (Reed City), 70-80% white brown, medium crystalline; some dolomitic limestone	23	3378
Total depth (bottom elevation) =		3378

APPENDIX II

LIST OF WELLS USED IN STUDY

APPENDIX II

LIST OF WELLS USED IN STUDY

Permit Number	Well Name	Location	Ground Elevation	Traverse Limestone Top	Bell Shale Top	Traverse Limestone Thickness	Rogers City-Dundee Top	Bell Shale Thickness
Montcalm County, Winfield Township, T12N, R9W								
19991	J. Dennis No. 1	SE, NW, SW -5	948	-1887	-2272	385	-2338	76
19892	Mich. Consolidated Gas Co. No. 1	SE, NW, SE -6	941	-1873	-2256	383	-2329	73
5130	A. L. Jacks Estate No. 2	NE, NW, NW -7	927	-1850	-2240	390	-2323	83
17332	Clyde Cole No. 1	SW, SE, SE -7	891	-1853	-2247	394	-2325	78
20095	Frank Schnick No. 1	SE, NW, SW -7	922	-1860	-2262	402	-2314	52
20196	Schnick No. 3	SE, NE, SW -7	915	-1856	-2255	399	-2317	62
20004	Lint Heirs No. 1	SE, SW, NE -8	940	-1892	-2288	396	-2351	63
13616	Elisha A. Jonos No. 1	SW, NE, SE -18	923	-1872	-2255	383	-2314	59
20037	Catherine L. Crimmins No. 1	SE, NW, NW -18	910	-1870	-2258	388	-2313	55
20130	Marshall, Steven and Mered Louayran No. 1	SE, NE, NW -18	914	-1872	-2270	398	-2322	52
20186	M. Steven and M. Louayran No. 2	SE, NW, NE -18	912	-1863	-2253	390	-2323	70
20193	Charles Buck No. 1	SE, SW, NE -18	919.5	-1869	-2252	383	-2315	63
Reynolds Township, T12N, R10W								
16437	A. Williams No. 1	SE, NW, SE -1	913	-1869	-2275	406	-2341	66
19414	Kohn No. 3	SE, SW, NW -1	908	-1864	-2260	396	2330	70
19016	Peter and Ima Nelson No. 1	SE, NE, NW -11	895	-1881	-2277	394	-2330	53
19046	E. Maude Halladay No. 1	NW, NW, SE -12	908.6	-1870	-2284	414	-2327	43
19802	James U. and Stella Long No. A-1	SE, SW, NW -12	908	-1876	-2280	404	-2327	47
20132	E. Maude Halladay No. 2	SE, SE, SE -12	900	-1868	-2274	406	-2321	47
9721	Von-Klein Smid No. 1	C, SE, SE -13	903	-1875	-2279	404	-2322	43
19391	Clayton E. Sorensen	SE, SE, SW -14	900	-1875	-2257	381	-2337	80
Mecosta County, Aetna Township, T13N, R10W								
19095	Line back No. 1	SE, NW, NE -35	878.5	-1881	-2303	422	-2334	31
19497	Zierke No. 1	SE, SW, SE	907	-1868	-2285	413	-2332	47

APPENDIX III

DOLOMITE PERCENT FROM TRAVERSE LIMESTONE

APPENDIX III

DOLOMITE PERCENT FROM TRAVERSE LIMESTONE

Permit Number	Dolomite % First 20 feet of Traverse Limestone	Depth Below the Top of Traverse Limestone						
		20-60	60-120	120-180	180-240	240-300	300-360	360-base
Montcalm County, Winfield Township, T12N, R9W								
19991	2.6	3	2	3	31	17	6.4	8
19892	15	X	X	1.5	0	6	4	5
5130	29	6	4	3	X	6	X	X
17332	50	19	11	6.5	8	4	5.5	6
20095	30	6	4	6	13	12	14	15
20196	X	X	X	2	9.5	39	14	16
20004	3	X	X	X	X	4	1	7
13616	25	7	9.75	X	X	X	X	X
20037	No Sample							
20130	23	9	No Sample					
20186	24	2	No Sample					
20193	2	7	3	2	2	5	5	6
Reynolds Township, T12N, R10W								
16437	23	17	6	6	2.3	0	8.5	10
19414	36	25	16	9	6	9	16	16

Permit Number	Dolomite % First 20 feet of Traverse Limestone	Depth Below the Top of Traverse Limestone						
		20-60	60-120	120-180	180-240	240-300	300-360	360-base
19016	19	19	3.6	1	2.6	4	13	12
19046	23	6	9	2	6	X	X	X
19802	14	9	2	2	2	X	13	15
20132	21	-	No Sample					
9721	10	1	1.4	6	X	8.5	31	30
19391	8	25	6	4	9	7	7.6	8
<u>Mecosta County, Aetna Township, T13N, R10W</u>								
19095	3	3	7	4	2	5	25	21
19497	24	35	26	9	4.5	7	15	16

APPENDIX IV

DOLOMITE PERCENT FROM ROGERS CITY-
DUNDEE FORMATION

APPENDIX IV

DOLOMITE PERCENT FROM ROGERS CITY-

DUNDEE FORMATION

Permit Number	Upper 20 feet	2nd 20 feet	3rd 20 feet	4th 20 feet	5th 20 feet
Montcalm County, Winfield Township, T12N, R9W					
19991	4	20	30	X	X
19892	15	100	75	X	X
5130	46	85.7	90	X	91
17332	48	100	X	X	X
20095	40	89	90	X	X
20196	55	82	100	100	100
20004	5	8	X	X	X
13616	14	9	X	43	93
20037	47	87	97	100	X
20130	61	89	98	100	100
20186	65	100	93	X	X
20193	35	X	X	93	X
Reynolds Township, T12N, R10W					
16437	X	70	92	X	X
19414	14	36	91	95	96

Permit Number	Upper 20 feet	2nd 20 feet	3rd 20 feet	4th 20 feet	5th 20 feet
19016	X	X	X	X	X
19046	15	55	X	X	X
19802	16	19	40	100	100
20132	14	100	100	100	100
9721	10	26	91	100	100
19391	8	X	X	X	X
<u>Mecosta County, Aetna Township, T13N R10W</u>					
19095	8	8	34	65	100
19497	8	10	65	97	98