This is to certify that the

thesis entitled

Dolomitization in the

North Adams Oil Field,

Arenac County

presented by

Ronald Glenn Richey

has been accepted towards fulfillment
of the requirements for

M.S. degree in Geology

C. E. Prouty
Major professor

Date 4/6/80

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DOLOMITIZATION IN THE
NORTH ADAMS OIL FIELD,
ARENAC COUNTY
MICHIGAN

By

Ronald Glenn Richey

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Geology

1980

ABSTRACT

Dolomitization in the North Adams Oil Field appears to be mainly epigenetic and is the result of fluids moving up through fractures into the Dundee. This is shown by the generally high degree of dolomitization between 80 and 160 feet below the top of the formation. This coincides with natural rock porosity as shown by well logs. Dolomite also seems to be concentrated along the length of the main field which is interpreted to be a fault, and also along the smaller field interpreted to be an anticline. Finally, there appears to be a small amount of dolomite associated with the overlying Bell Shale which may have been a source of both Mg^{2+} and Fe^{2+}. This dolomite occurs just below the top of the Dundee formation.

ACKNOWLEDGMENTS

I wish to express my gratitude to Dr. C. E. Prouty, Committee Chairman for his advice and time, given in this study. I wish also to thank Dr. D. F. Sibley and Dr. J. W. Trow for their review of the thesis text.

Also, I would like to thank my mother, Ethel Richey and my aunt, Eleanor LaVean for their help in typing this work.

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INTRODUCTION

The Dundee (Devonian) is one of the major sources of oil in Michigan. Production appears associated with at least some type of dolomitization.

Attention has been called to the diagenetic origin of dolomite in various areas (Prouty, 1948, Cohee and Landes, 1958; Adams and Rhodes, 1960; Deffeyes, Lucia and Weyd, 1965; Illing, Wells and Taylor, 1965; Bathurst, 1971). Each of the studies has certain special conditions under which dolomite is formed. Some studies have indicated certain dolomites in the Michigan Basin as diagenetic in origin (Lasemi, Y. 1969; Newhart, R.E., 1976; Dastanpour, M., 1977; Syrjamaki, R.M., 1977). In other studies within the Basin where dolomite is shown to be epigenetic in origin (Landes, 1946; Powell, 1950; Jodry, 1954; Egleston, 1957; Tinklepaugh, 1958; Paris, 1977; Dastanpour, 1977; Hamrick, 1978; TenHave, 1979, Hyde, 1979) there is the question as to the source and movement of the dolomitizing fluids. The diagenesis of shales produces water, Fe and Mg (Boles and Franks, 1979), during illitization. The Bell shale which overlies the Dundee may have served as a source of Ferroan dolomite. Another likely source is from fluids which have picked up Mg from the dissolution of more deeply buried dolomites. Syrjamaki (1977) has shown that this dissolution has happened in the Lower Ordovician in the area of the Albion-Scipio oil field. Probably this dolomite would be less iron rich.

It is the principal purpose of this study to investigate the distribution and characteristics of any dolomite present to possibly determine the origin(s) of the dolomite in the North Adams field.

That there is dolomite in this Field has been shown by Landes (1946) and Jackson (1958), both using simple acid tests to show a general presence or absence of dolomite. With x-ray diffraction analysis, it is possible to do a much more detailed study and show vertical and lateral variations in the dolomite. Structural maps are to be used to compare the dolomitization to structural changes.

Petrographic analysis of grains stained for ferroan dolomite was done to indicate the possible source of the dolomitizing fluids.

The North Adams field (Figure 4) was chosen for the following reasons: (1) Reconnaissant work by Landes (1946) and Jackson (1958) shows that dolomite is present; (2) The field shows a different orientation than those done in the past, most other fields showing general NW-SE orientations instead of NE-SW; (3) Samples are available, along with at least a short section of core; and (4) This field is midway between West Branch (TenHave, 1979) and the Kawkawlin (Hyde, 1979) fields and should either reinforce or else change conclusions found in these fields.

It is hoped that the results found in this study will be helpful in finding and developing other lineartype fields and also in developing general conclusions about this type of dolomitization.

Previous Work

In a study of the relationship between porosity and secondary dolomite, Landes (1946) looked specifically at the dolomitization in the Adams oil field. The study related dolomitization to oil occurrence. Jackson (1958) tried to relate structure to dolomitization by looking two dimensionally at the structure of the top of the Dundee and dolomitization. Jackson differentiated dolomite from limestone using a simple acid test. In all three fields Jackson studied, including the North Adams, structure and dolomitization were related.

Several studies using Dolomite/Calcite ratios have been done to determine local variations in dolomitization. Powell (1950) used a wet chemical method in testing the Pinconning field, a field having about the same orientation, but smaller than, the North Adams. Jodry (1954) used the titration method in testing the fields in Mecosta County, specifically looking at secondary dolomitization. Tinklepaugh (1957) also used the titration method, looking at Dundee dolomitization along fold axes in structures in the central Michigan Basin. She found correlation between structure and dolomitization. Dastanpour (1977) started the current trend of using x-ray diffraction to find Dolomite-Calcite ratios in his study of the Dundee and Traverse formations in the Reynolds's Oil

Field, and concluded that the Dundee dolomite was of both early (diagenetic) and later (epigenetic) origin, whereas the Traverse was of epigenetic origin. Finally Hamrick (1978), Walker Field, TenHave (1979), West Branch Field, and Hyde (1979), the Kawkawlin Field, were all recent studies of the Middle Devonian, using the x-ray diffraction method. TenHave and Hyde's works both showed good correlation between structure and dolomite. Hamricks also showed this, but also showed a trend of diagnetic dolomite to the west end of the field.

Regional semi-quantitative dolomitization studies were made in the Middle Ordovician by Newhart (1976), Lower Ordovician by Syrjamaki (1977), and on the Traverse by Runyan (1976). These studies show the presence of early diagenetic dolomite to the west. A regional depositional and stratigraphic study of the Middle Devonian was made by Gardener (1974).

STRATIGRAPHIC FRAMEWORK

The Dundee studied in this field is overlain by the Traverse Group and underlain by the Detroit River Group (Figure 1). These three make up the Middle Devonian in Michigan.

The Traverse Group as described by Cohee and Underwood (1945) lies conformably on top of the Dundee. The Traverse Group is divided into three units, the Traverse Formation at the top, the Middle Traverse limestone, and the Bell Shale at the base. Cohee (1947) described the Traverse in eastern Michigan as interbedded argillaceous limestones and shales with a little pure limestone. The general trend is for the Traverse to become more calcareous to the west.

The Dundee as used in this paper includes everything from the base of the Bell Shale down to the top of the Detroit River. Ehlers and Radabough (1939) on the basis of surface work divided the formation into the Dundee at the base and Rogers City above. These divisions are based on faunal differences and they are almost indistinguishable lithogically. Any subsurface work must either treat them as one unit or divide them arbitrarily. According to Cohee (1948),

STRATIGRAPHIC SUCCESSION IN MICHIGAN

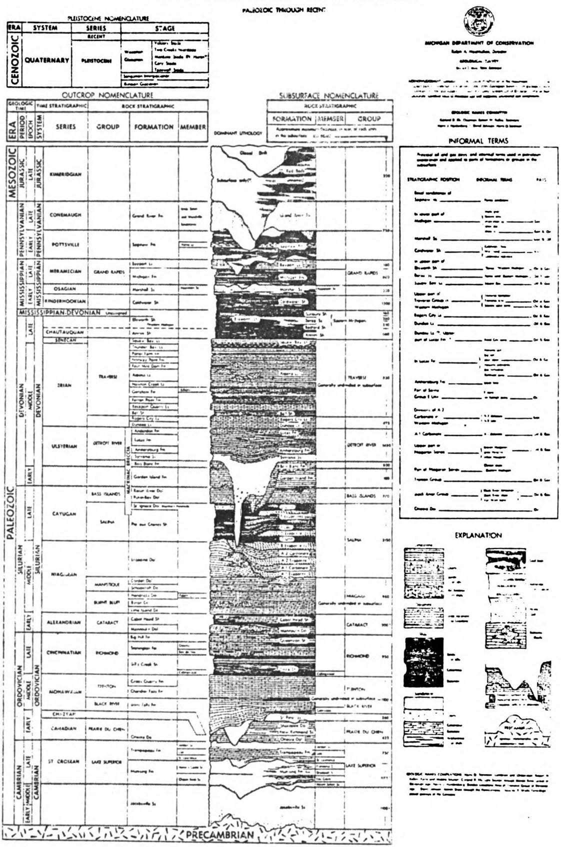


Figure 1

the Rogers City-Dundee is typically a dark brownish-buff dolomitic limestone to dolomite. Tinklepaugh (1957) showed that dolomitization is the locallized result of replacement of marine limestone.

The Detroit River Group is mainly limestone with some anhydrite, becoming dolomitic, and more anhydritic in western Michigan (Tinklepaugh 1957).

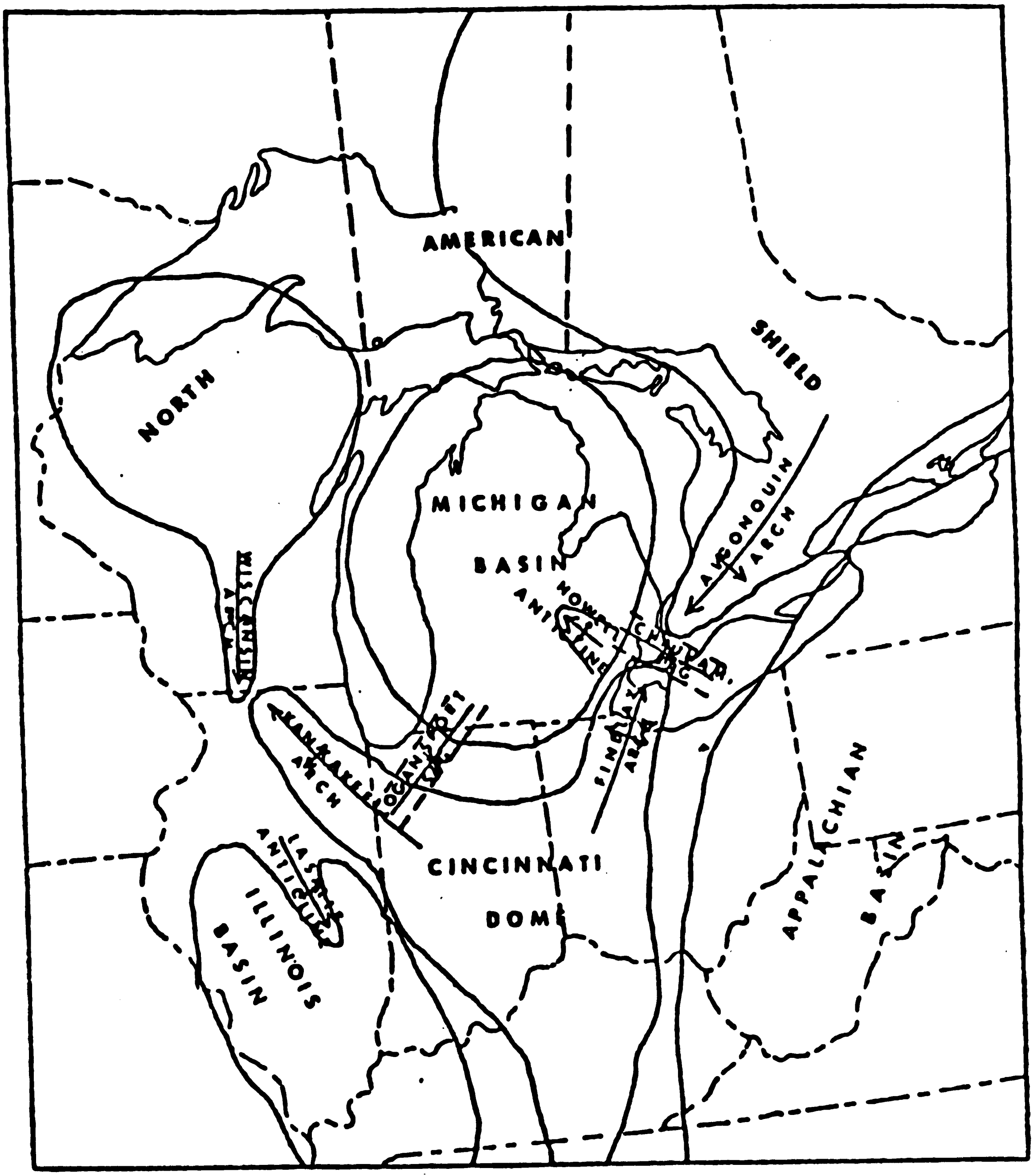
STRUCTURAL FRAMEWORK

The North Adams field lies nearly in the center of the Michigan Basin, with the true center directly to the west. Arches rim the basin, the Wisconsin Arch to the West, Kankakee Arch to the Southwest, the Findlay to the Southeast and the Algonquin Arch to the east (Figure 2).

The problem of the origin of the Michigan Basin has been addressed by many workers whose conclusions vary appreciably as to both time and mechanics of development.

Newcomb (1933) and Pirtle (1932) proposed that the Basin formed in the Precambrian-Keweenawan disturbance. Kirkham (1937) attributed settling to the movement of magma in the crust. Lockett (1947) believed that the Basin settled because of the load of sediments produced from Precambrian mountains that surrounded the Basin. Cohee and Landes (1958) believed that the Basin came into being in the late Silurian, continuing on and off into the late Mississippian. Hinze and Merritt (1969) using gravity and magnetic measurements believed the Basin was the result of a Precambrian rift zone (Keweenawan).

Paleozoic intrabasinal structures (Figure 3) are


AMERICAN
SHIELD
NORTH
MICHIGAN
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ARCH
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CINCINNATI
DOME
ILLINOIS
BASIN
APPALACHIAN
BASIN

Figure 2.

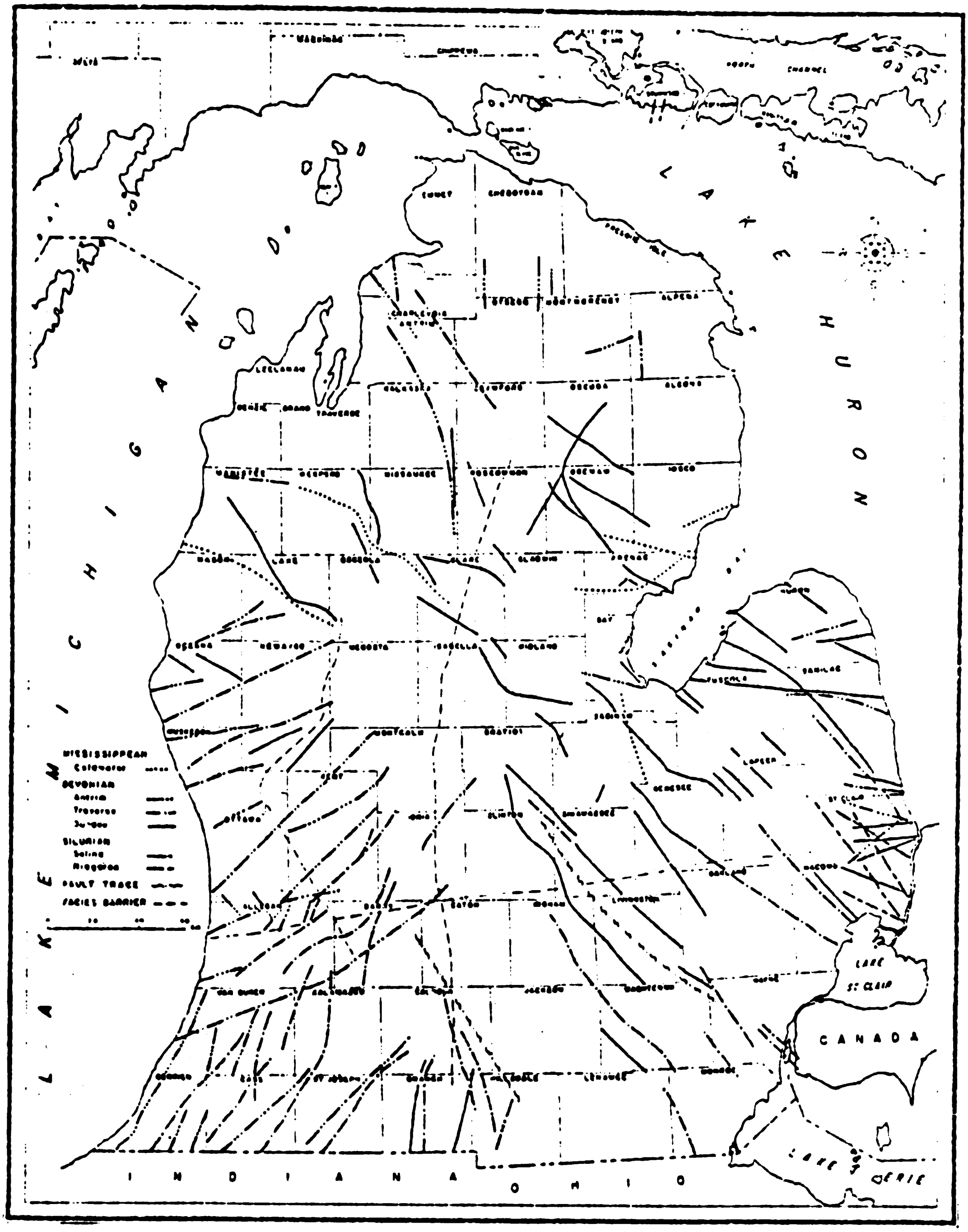


Figure 3.
Major Structural Trends in the Michigan Basin
(compiled by C. E., Prouty, 1971)

generally thought to be the result of movement of Precambrian basement rocks producing near-vertical faults. Prouty (1976a, 1976b)believes lineaments taken from LANDSAT imagery represent shear faults with lateral movement, and whose azimuths define a wrenching model responding to stresses directed from the east-southeast; further, it is considered that most basinal folds (other than saltfilled and possible radial folds) are genetically related to the mechanics of the wrenching tectonics (Figure 3).

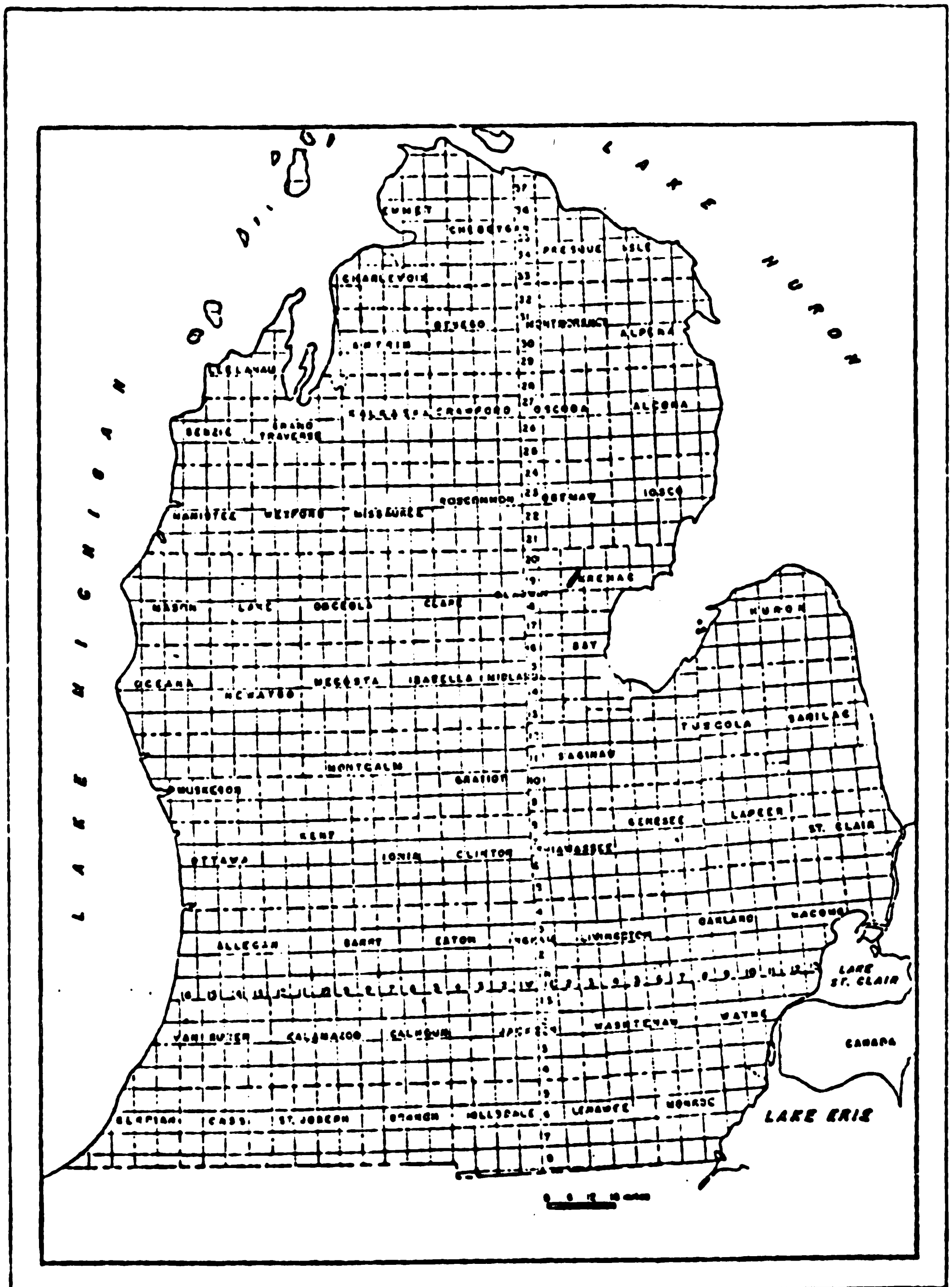
THE NORTH ADAMS OIL FIELD

Location:

The field is located in the eastern part of the Arenac County, sections 11,14,15,22,23,24,25,26,27 of Adams Township (T 19N, 3E). The field can be divided into two separate fields; one to the northwest following a probably fault zone, about 3 miles long and up to 1/2 mile wide and referred to herein as the Main Field; southeast following an anticline about 3/4 mile in diameter, referred to herein as the Southeast Field (Figure 8).

Developmental History:

The first discovery well in the southeast field, the Shearer #1, was drilled in section 26, in May 1938, into the Traverse. Initial Production was 68 Bbls, increased to 83 Bbls with acidation. The first well in the Main Field, the Yenior #1 section 22, completed July 1940, produced 500 Bbls, 2,500 Bbls after acidation. At first both fields were called "Adams", but as it became obvious that they were two separate fields, the Main Field was designated to be North Adams. Because almost all the production came from the North Adams, present day reports put the Adams production into the North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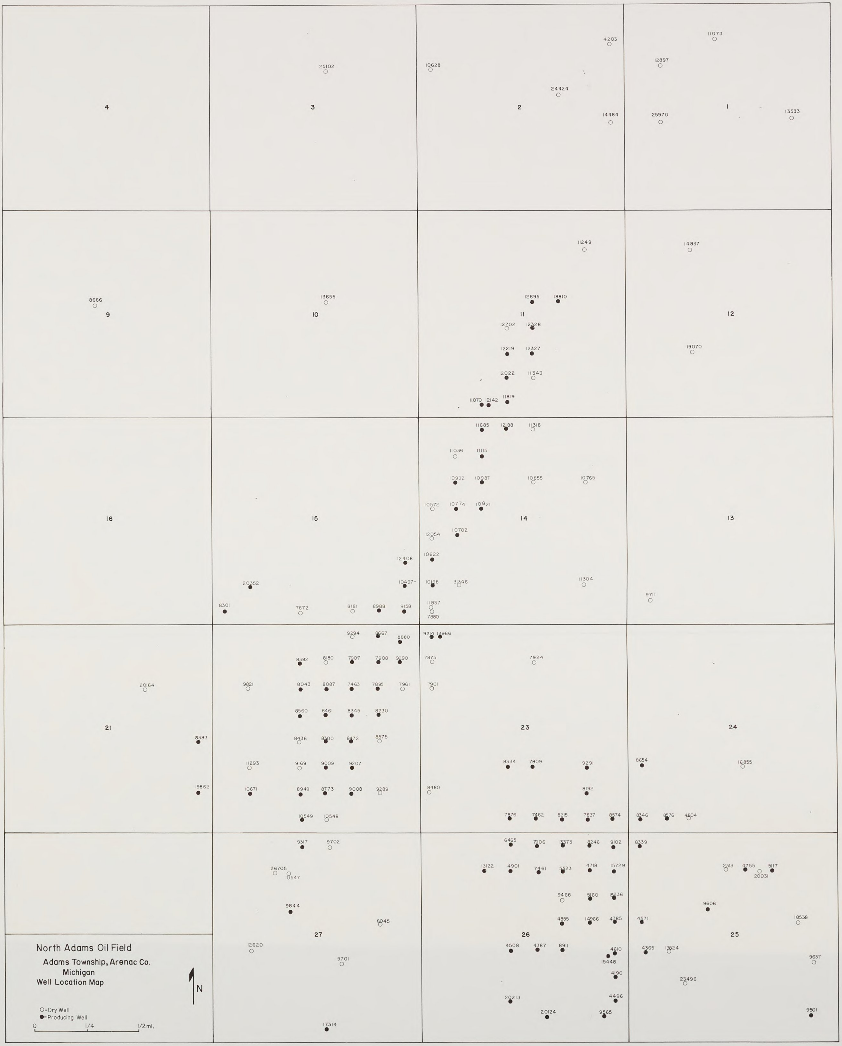
LAKE HURON
CHARLEVOIX
PRESQUE ISLE
ALPENA
ALCONA
ARENAC
HURON
BAY
TUSCOLA
SANILAC
SAGINAW
GENESEE
LAPEER
ST. CLAIR
OAKLAND
MACOMB
WAYNE
LAKE ST. CLAIR
CANADA
LAKE ERIE
OCEANA
MONTCALM
KENT
OTTAWA
ALLEGAN
BARRY
EATON
ST. JOSEPH

Figure 4


North Adams Oil Field
Adams Township, Arenac Co.
Michigan
Well Location Map
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O=Dry Well
●=Producing Well
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1/4
1/2 mi.
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18538
12620
4508
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8911
4610
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4365
13824
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20213
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9565
9501
17314


North Adams Oil Field
Adams Township, Arenac Co.
Michigan
Isopach of the Traverse Formation
Contour Interval 5 ft. and 25 ft.
○=Dry Well
●=Producing Well
0 1/4 1/2 mi.
N

Adams figures and call the field collectively, the North Adams. Most of the drilling was completed by 1942, with a final 50 producing wells and 510 proven acres. To the end of 1977 when 18 wells were still pumping, a total of 9,385,156 Bbls of oil and 1,280 mcf gas had been produced, for an 18,402 Bbls recovery per drilled acre (National Oil Scouts and Landmen's Association Year Book, 1939,42,77).

For most wells, pay was in the top 2-10 feet of the Dundee, although at the edges of the field pay was down to 90 feet below the top.

Structure:

Structure maps are based on formation tops as given on driller logs. Any logs that were incomplete or otherwise questionable were not used. Logs were verified where possible by comparing formation top designations with actual cuttings. Wells used are located on the base map (Figure 6). Driller's designations are tabulated in Appendix I. To fully interpret structure and timing of structural events, three maps have been constructed; the structure on top of Dundee and top of the Traverse; and an isopach map of the Traverse.

The Dundee structure map (Figure 7) shows both parts of the field, the Southeast Field (sections 23,26) and the Main Field (sections 11,14,22). The Main Field is very complex with alternating highs and lows. The Southeast Field on the other hand, is very simple with the least closure to the E-SE, covering sections 13-15,22-27. The orientation is basically W-NW, E-SE, nearly right angles to the Main Field.

The Traverse structure map (Figure 8a) although similar to the Dundee does have several faults that do not show up in the Dundee structure. These faults are similar in orientation to the Southeast Field, or nearly perpendicular to the Main Field. They are all parallel to each other and divide the main structure into cross-blocks, each of which appears to have moved in the left-lateral sense with some indication also of some vertical component.

Isopach:

The isopach of the Traverse was constructed in order to determine when faulting and folding occurred. It would appear very unlikely that the Southeast Field structure had been formed or was forming during Traverse time, as there is a lack of thinning over the structure. In fact there are several highs. The isopach map of the Main Field is much less conclusive, as there is thickening and thinning along its length. This may be due to differential compaction with the faulting occurring after deposition of the Traverse. It would appear much more plausible that all the tectonism occurred at the same time rather than separately, for each of these closely-related structures.

Deformation Model:

Moody (1973) developed a model (Figure 5) based on regional fault orientation studies which can be applied to explain structures formed in the Michigan Basin (Prouty, 1970, 1976a). To produce these structures, forces probably came from a general eastward direction reactivating shear faults in the basement complex and creating the faults and related shear folds in the Paleozoic rocks. (Figure 3). Harding (1974) showed, using a clay model, that en echelon faults with related fold deformation structures are produced with wrench-type forces. This may show why there is a thickening in the Traverse isopach over some of the structures. They may be produced by deformation rather than sedimentation. They also may have been produced by differential solution or by dolomitization shrinkage.

Hydrocarbon production vs structure:

Dundee production in the southeast field follows the high very closely, with original pay thickness about 9 feet at the center of the anticline, decreasing towards the edges. The pay in the Traverse was much less with most wells deepened to the Dundee.

Production along the Main Field is much less typical. As wells in the center of the structure had pay at the top of

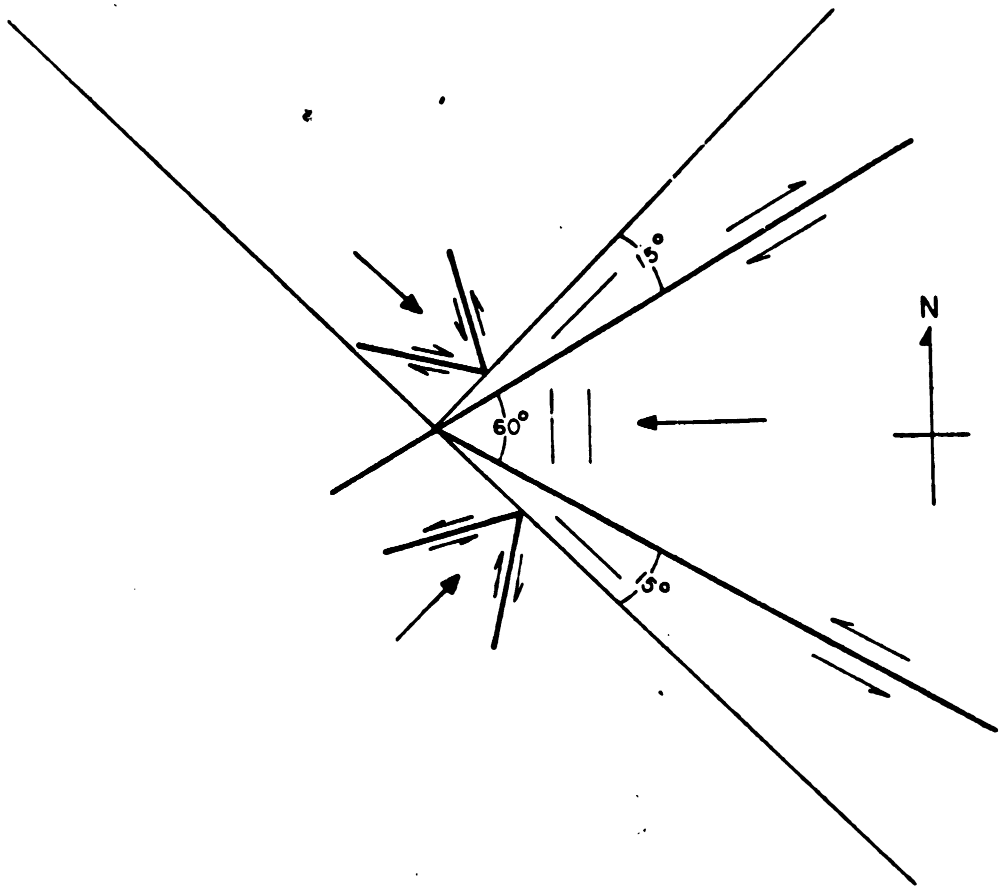


Figure 5.--Faults and Folds of a Wrench Deformation Model
(constructed by J. D. Moody, 1973)

the Dundee but were not drilled through the pay, and because two wells on the edge of the field had oil cut water at 90 feet below the top of the Dundee, the pay was interpreted to be 90 feet thick (National Oil Scots and Landmens Association Year Book, 1942). More drilling in the southern most part of the field showed production that was very complex, with pay found at more than one level, or at least at levels other than the Dundee top.

X-RAY ANALYSIS

X-ray Diffraction:

The x-ray diffraction technique was developed in the late 1950's (Tenet and Berge, 1956), and has been used in such studies of carbonate rocks as Weber (1967); Gunatilaka and Till (1971); Badiozamani (1973); Folk and Land (1975); and Supka (1977). This method has many advantages over other methods. Chemical methods are based on the amount of Ca and Mg, and can be influenced by the presence of other carbonate minerals. Thin section point counts can be very accurate but accuracy depends on the number of points counted. For example: with a mixture of 10% of one component and 90% of another, 400 points much be counted to achieve an accuracy of + or - 3%, or 900 points to achieve + or - 2% (Pettyjohn, Potter, and Siever, 1972).

Lumsden (1979) has shown that an accuracy of + or - 3% or better, can result using x-ray diffraction. Samples used in this study were analyzed several times and found to vary from the mean by less than 3%. The accuracy of this method is limited by several factors: (1) The background is not constant over the range of values measured. (2) The peaks are not totally centered over one point and using the area under the curve might improve accuracy but would be very time consuming. (3) Probably the greatest source of error is the fact that there is a range of crystal sizes. It is assumed when using this method that all crystals are the same size. This is never true. What compounds the error is the fact that there can be a bimodal distribution of grain sizes between calcite and dolomite. Also, there may be a difference between the sample crystal size and the crystal size in the standard (Jenkins and Devries, 1968). (4) There are other errors associated with the equipment but these are probably insignificant.

Method:

The method used consisted of measurement and comparison of the peaks of calcite and dolomite. By finding their relative height and comparing the ratios against a series of samples of known composition, the composition of the sample of unknown composition can be found (Tenet, 1956).

As has been stated above, a source of error is introduced in this method because of nonuniformity of the peaks. Samples that are poorly packed, allowing more randomness in the grain orientation will tend to have broader, flatter peaks. To overcome this somewhat, there was an attempt to make packing uniformly tight for all samples.

Samples:

Well cuttings from 38 wells, nearly all of which were cable tool samples, were chosen. The choice of wells was based mainly on getting the best distribution without using wells that were poorly sampled and/or contaminated. Cable tool wells were chosen over rotary wells because of the better quality of cable tool cuttings, with less caving and better depth control.

Samples were then separated into 20-foot intervals, with 4 grams weighed per sample. Samples were crushed, using mechanical grinding for 10 minutes per sample.

X-Ray Procedure:

Samples were packed into a sample holder and placed into the goniometer. Equipment used was a G.E. x-ray diffraction goniometer. X-rays were produced using the Copper K alpha radiation with a nickle filter, at 50 KV and 10 MA. The calcite peak at $30.96^{\circ}2$ theta and the dolomite peak at 29.40° were found, counted for 100 seconds and recorded. Because of small errors introduced in poor orientation of the sample holder, etc. the true peaks in most cases varied a little from their predicted angle. There was an attempt in each case to take readings on the true peak by manually setting the angle at maximum peak height. Background readings were taken at 28.0°. Each sample was x-rayed twice, at two different spots on the sample, and the results were averaged.

Calibration Curve:

A calibration curve was constructed using standard samples already prepared (Dastanpour, 1977). The curve when plotted, showed that the peak height ratio virtually matched the true dolomite/calcite ratio, with no corrections being indicated.

ISODOLIC MAPS

Dolomite maps are based on percentages as calculated by ratios. With the exception of the three samples noted in the appendix all values are based on 20 foot intervals. The three samples noted are based on samples less than 20 feet and are used only because of lack of good data in the center of the field. These values are meant only to show minimum dolomite values. All plots use a 5% isodolic contour interval which is based on the accuracy of the data. Well logs mentioned in the following are Gamma Ray-Neutron logs, and are listed in the Appendix.

Lateral Variation:

0-60 Feet below top of Dundee (Figure 9-11): All well logs show that these intervals have little porosity, with a single exception, a log next to the field which shows some porosity from 0-20 feet. Dolomitization only can be seen to occur along the main structure, particularly in the producing zone. Even in wells that were not analyzed for dolomite because of lack of cuttings or because they just penetrated into the Dundee, the Dundee was called dolomite in driller logs. Where dolomite is found there are some very high values but laterally dolomitization is rather restricted.

60-80 Feet below the top of the Dundee (Figure 12): All mechanical logs show this zone to be tight. No wells penetrated this deep in the center of the Main Field. In spite of this there has been some dolomitization. Two wells over the Southeast Field show the first indication of dolomitization in this structure.

80-100 Feet below top of Dundee (Figure 13): In this zone there is a transition from the tight, impermiable lithology above, into a very porous zone, as indicated by logs. In the Southeast Field there are 5 wells with 10% or greater dolomite. This is the first interval with a high dolomite value, 70%, which may indicate a small crossfault. It appears that dolomitization continues on to the north of the Main Field.

100-120 feet below top of the Dundee (Figure 14): All mechanical logs show this zone to be very porous. Dolomitization is laternally the most continuous of any levels studied, with at least a 15% isodol around both fields. Well #13655 has only 1% dolomite showing. Although dolomitization is continuous on-structure, off-structure there has been little or no dolomitization. It appears dolomitization continues both to the North and South of the Main Field.

120-160 Feet below top of Dundee (Figure 15,16): Well logs show that porosity decreases from that in the above level, although it still exists. Control is less for these maps but they were included to show the high levels of dolomitization, (up to 75%), not necessarily right on structure, but adjacent to it, possibly indicating cross faults. Dolomitization on the southeast structure is decreasing with 7% dolomite, the high value at 140-160 foot level.

Figure 9

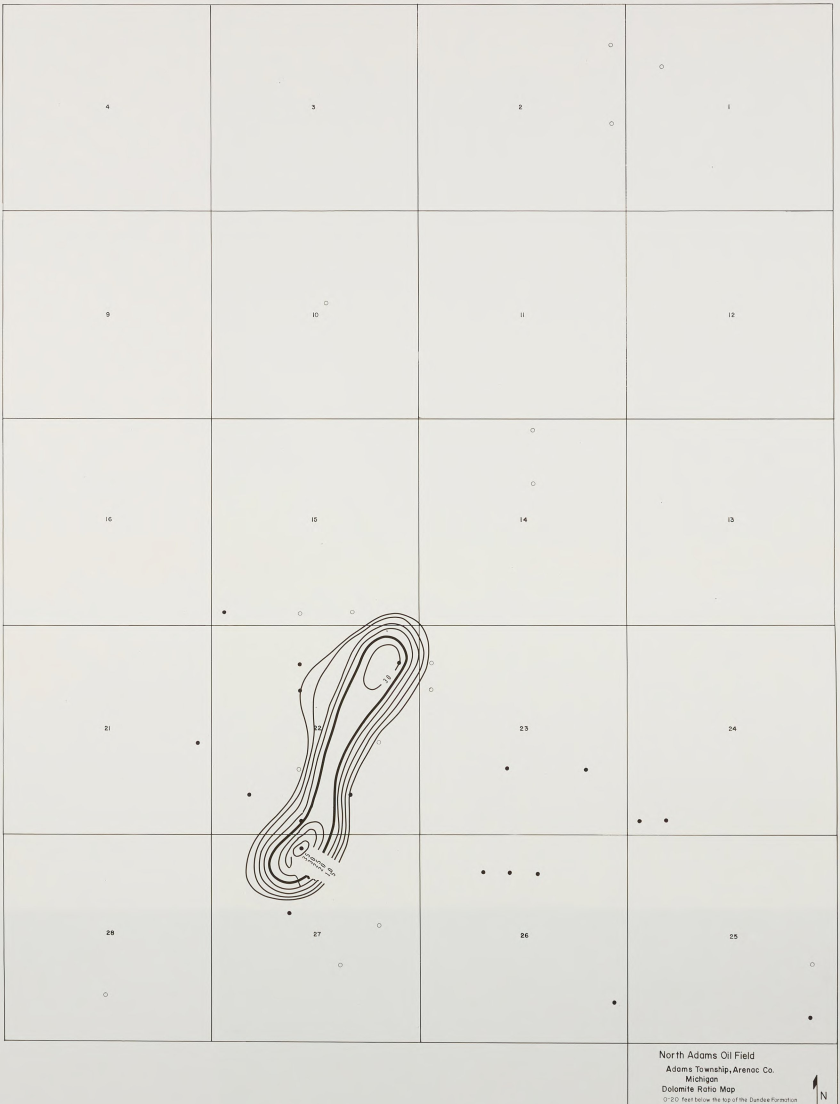
Map of

Dolomite Percentages

0-20 Feet

Below top of the Dundee

5% Contour Interval



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North Adams Oil Field
Adams Township, Arenac Co.
Michigan
Dolomite Ratio Map
0-20 feet below the top of the Dundee Formation
=Dry Well
=Producing Well
0
1/4
1/2mi.
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Figure 10

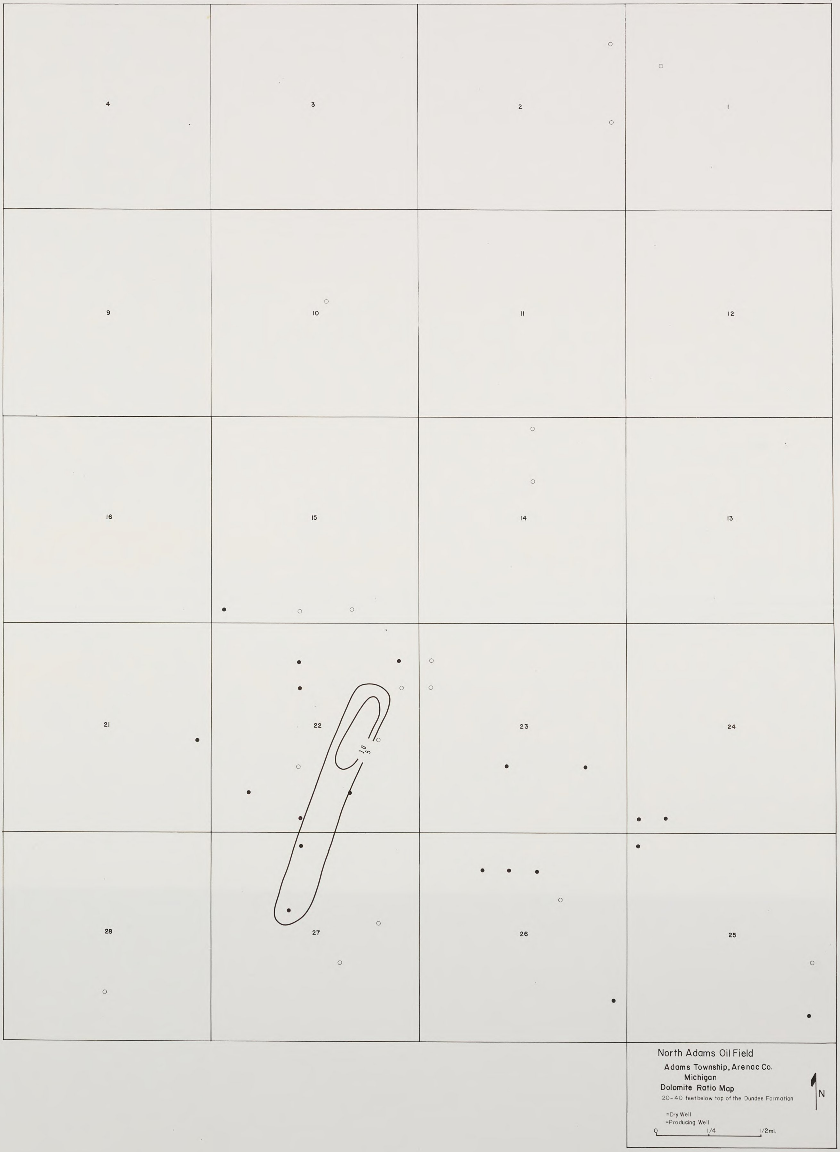
Map of

Dolomite Percentages

20-40 Feet

Below Top of the Dundee

5% Contour Interval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North Adams Oil Field
Adams Township, Arenac Co.
Michigan
Dolomite Ratio Map
20-40 feet below top of the Dundee Formation
N
=Dry Well
=Producing Well
0
1/4
1/2 mi.

Figure 11

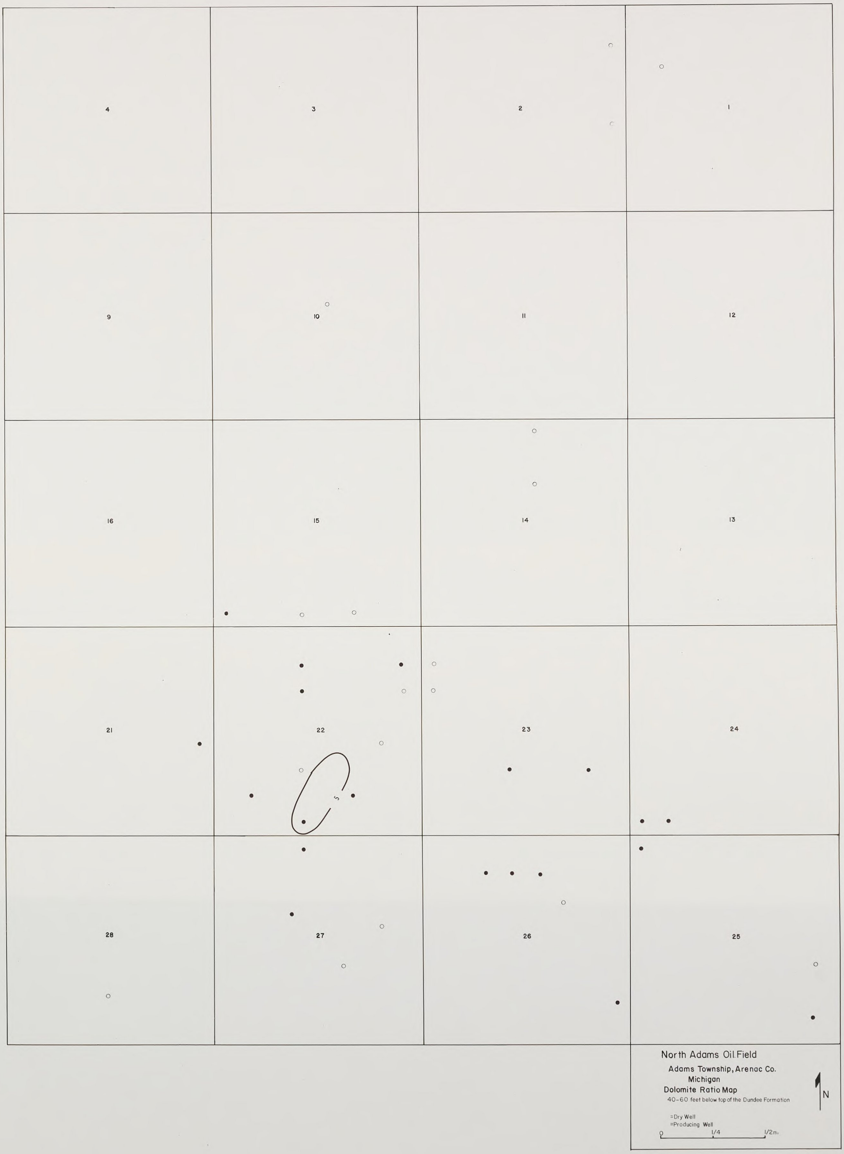
Map of

Dolomite Percentages

40-60 Feet

Below Top of the Dundee

5% Contour Interval



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North Adams Oil Field
Adams Township, Arenac Co.
Michigan
Dolomite Ratio Map
40-60 feet below top of the Dundee Formation
N
=Dry Well
=Producing Well
0
1/4
1/2mi

Figure 12

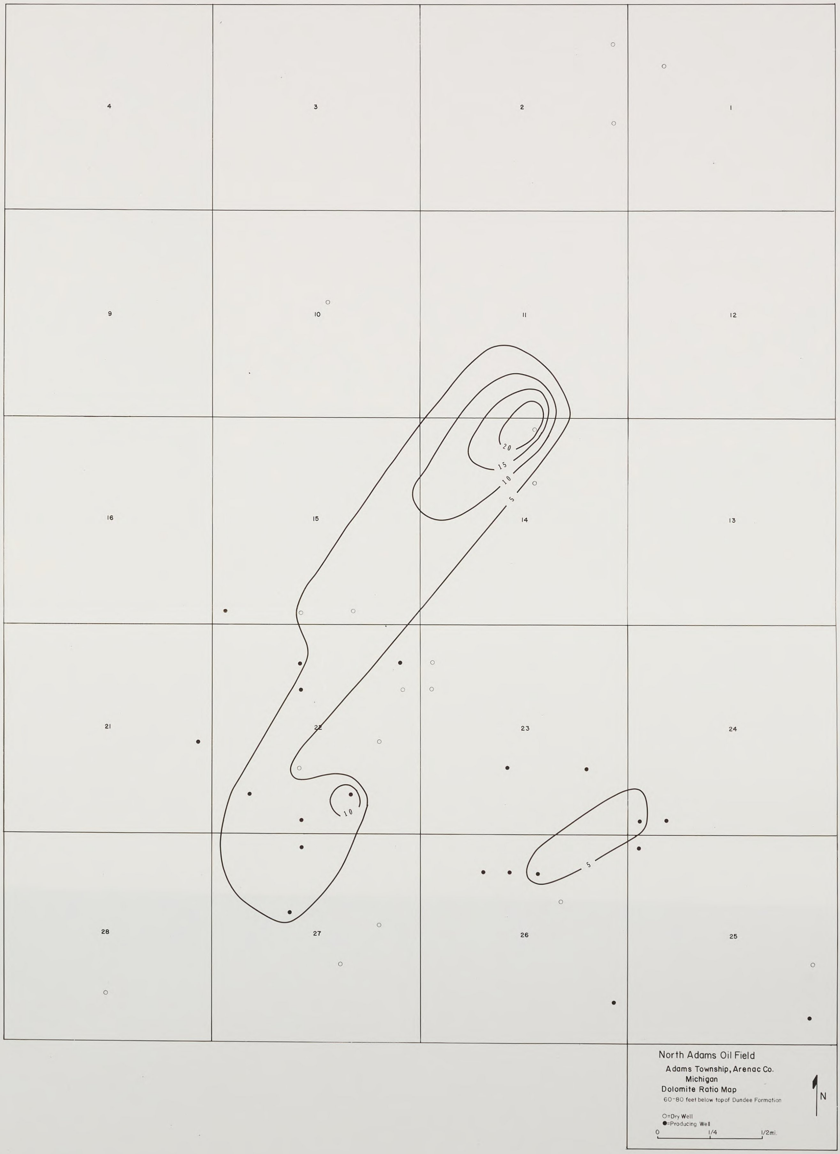
Map of

Dolomite Percentages

60-80 Feet

Below Top of the Dundee

5% Contour Interval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North Adams Oil Field
Adams Township, Arenac Co.
Michigan
Dolomite Ratio Map
60-80 feet below top of Dundee Formation
○=Dry Well
●=Producing Well
0
1/4
1/2mi.
N

Figure 13

Map of

Dolomite Percentages

80-100 Feet

Below Top of the Dundee

5% Contour Interval

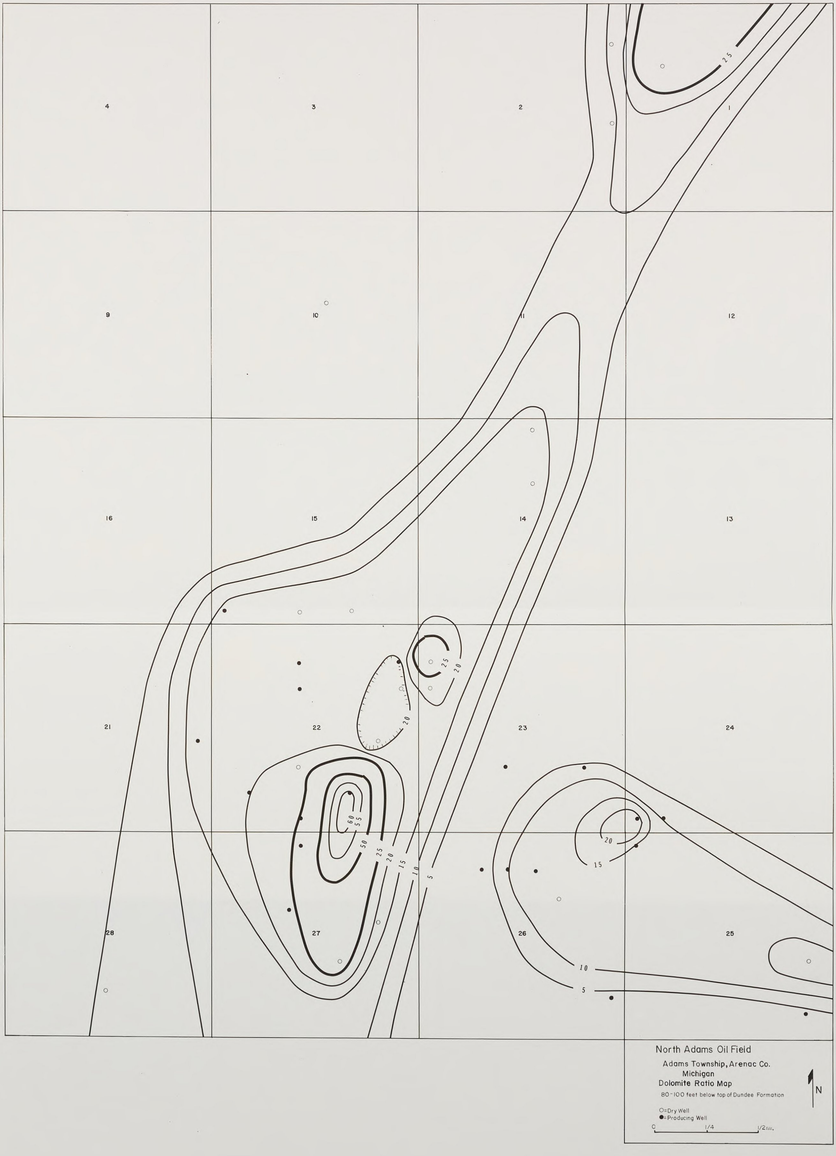

4
3
2
1
25
9
10
11
12
16
15
14
13
21
22
23
24
25
20
60
55
50
25
20
15
10
5
20
15
28
27
26
25
10
5
North Adams Oil Field
Adams Township, Arenac Co.
Michigan
Dolomite Ratio Map
80-100 feet below top of Dundee Formation
N
○=Dry Well
●=Producing Well
0
1/4
1/2 mi.

Figure 14

Map of

Dolomite Percentages

100-120 Feet

Below Top of the Dundee

5% Contour Interval

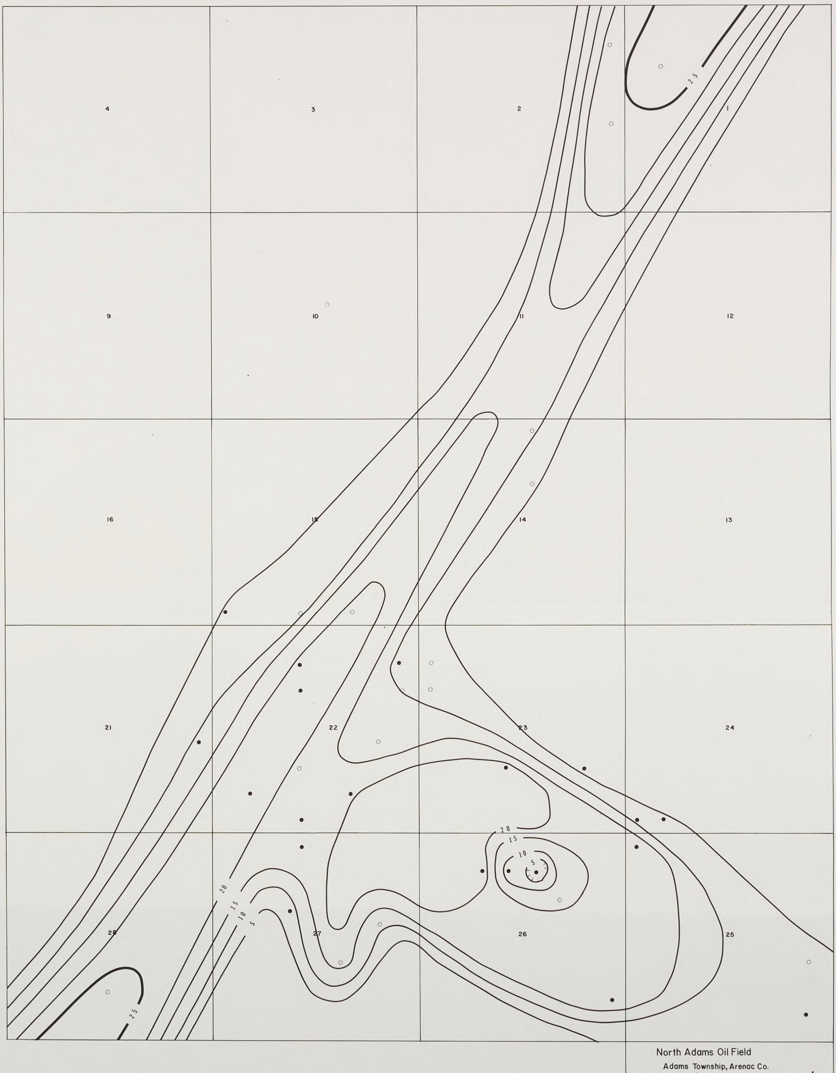

4
3
2
1
9
10
11
12
16
15
14
13
21
22
23
24
28
27
26
25
25
20
15
10
5
25
North Adams Oil Field
Adams Township, Arenac Co.
Michigan
Dolomite Ratio Map
100-120 feet below top of the Dundee Formation
○=Dry Well
●=Producing Well
0
1/4
1/2mi.
N

Figure 15

Map of

Dolomite Percentages

120-140 Feet

Below Top of the Dundee

5% Contour Interval


4
3
2
1
9
10
11
12
16
15
14
13
21
22
23
24
27
27
26
25
50
45
40
35
30
25
20
15
10
5
75
North Adams Oil Field
Adams Township, Arenac Co.
Michigan
Dolomite Ratio Map
120-140 feet below top of the Dundee Formation
N
O=Dry Well
●=Producing Well
0
1/4
1/2mi.

Figure 16

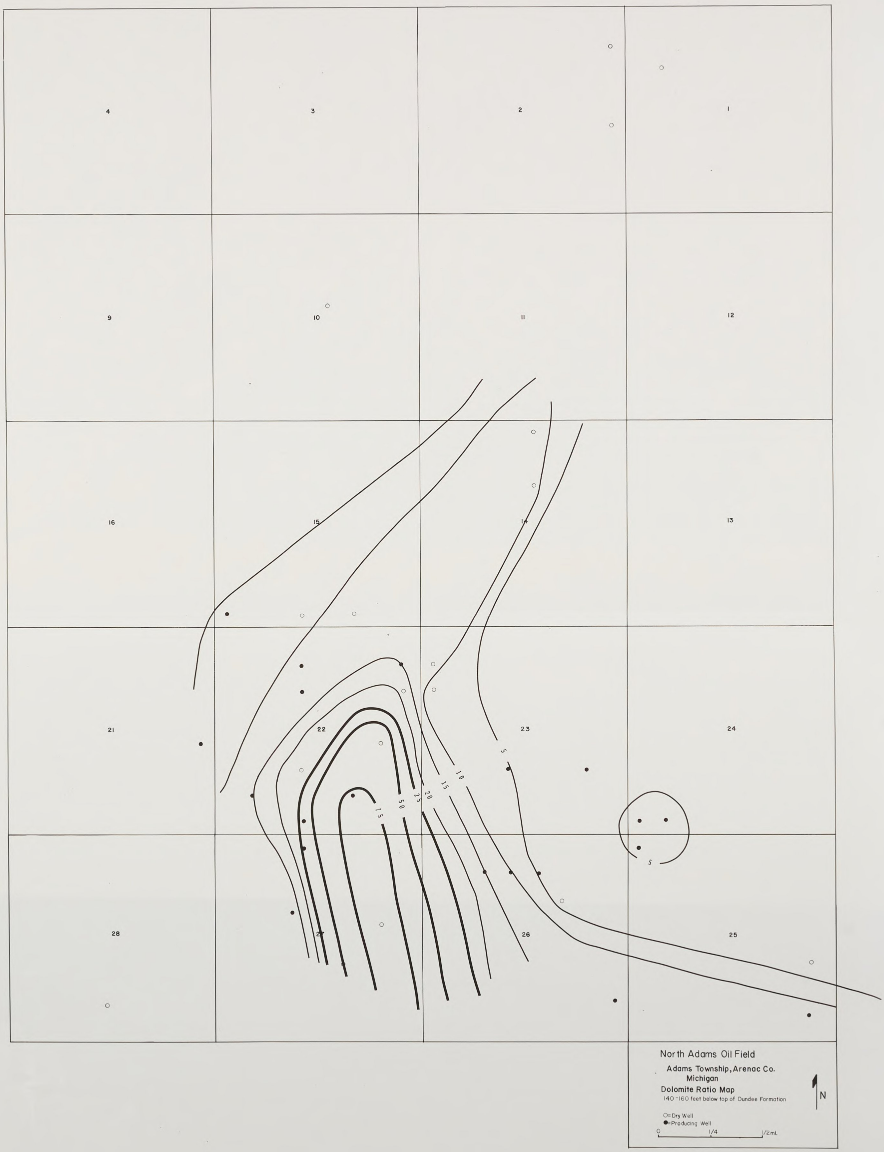
Map of

Dolomite Percentages

140-160 Feet

Below Top of the Dundee

5% Contour Interval


4
3
2
1
9
10
11
12
16
15
14
13
21
22
23
24
28
27
26
25
5
10
15
20
25
50
75
5
North Adams Oil Field
Adams Township, Arenac Co.
Michigan
Dolomite Ratio Map
140 -160 feet below top of Dundee Formation
O= Dry Well
●= Producing Well
0
1/4
1/2 mi.
N

VERTICAL DOLOMITIZATION VARIATION

In order to determine what effect the structures had on vertical dolomitization, two groups of wells were chosen and averaged. Ten wells that are on or adjacent to the Main Field, and eight wells over the center of the anticline were used. Also a single well that was well off both structures were used to show dolomitization in an off-structure position (Appendix III).

The resulting graphs (Figures 17,18), show that vertical dolomitization was affected by the structures. The well off-structure has a high of 3.9% dolomite over the 120 feet that the well penetrated. The average of all wells shows that overall, dolomitization follows porosity, as shown by mechanical well logs. The logs show the upper 80-90 feet to have a low porosity, with much higher porosity below this. The average of all wells shows that the top 80 feet never averages more than 5% dolomite per interval, while the lower 80 feet never averages less than 10%. Dolomitization on the structures is very similar between the two fields, except for the fact that at every interval dolomitization in the Main Field is greater than that on the Southeast Field. Finally, it can

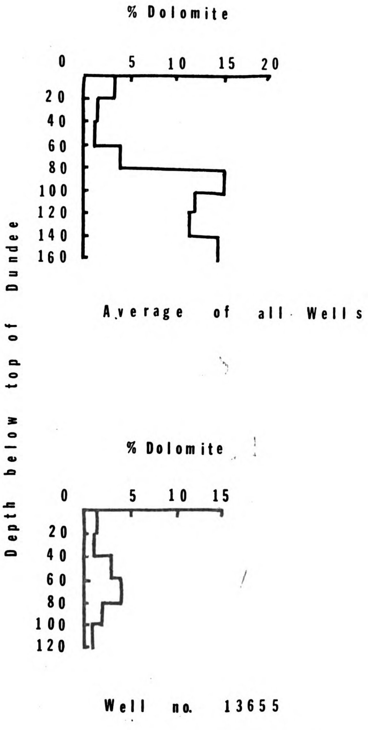

% Dolomite
0
5
10
15
20
20
40
60
80
100
120
140
160
Average of all Wells
Depth below top of Dundee
% Dolomite
0
5
10
15
20
40
60
80
100
120
Well no. 13655

Figure 17

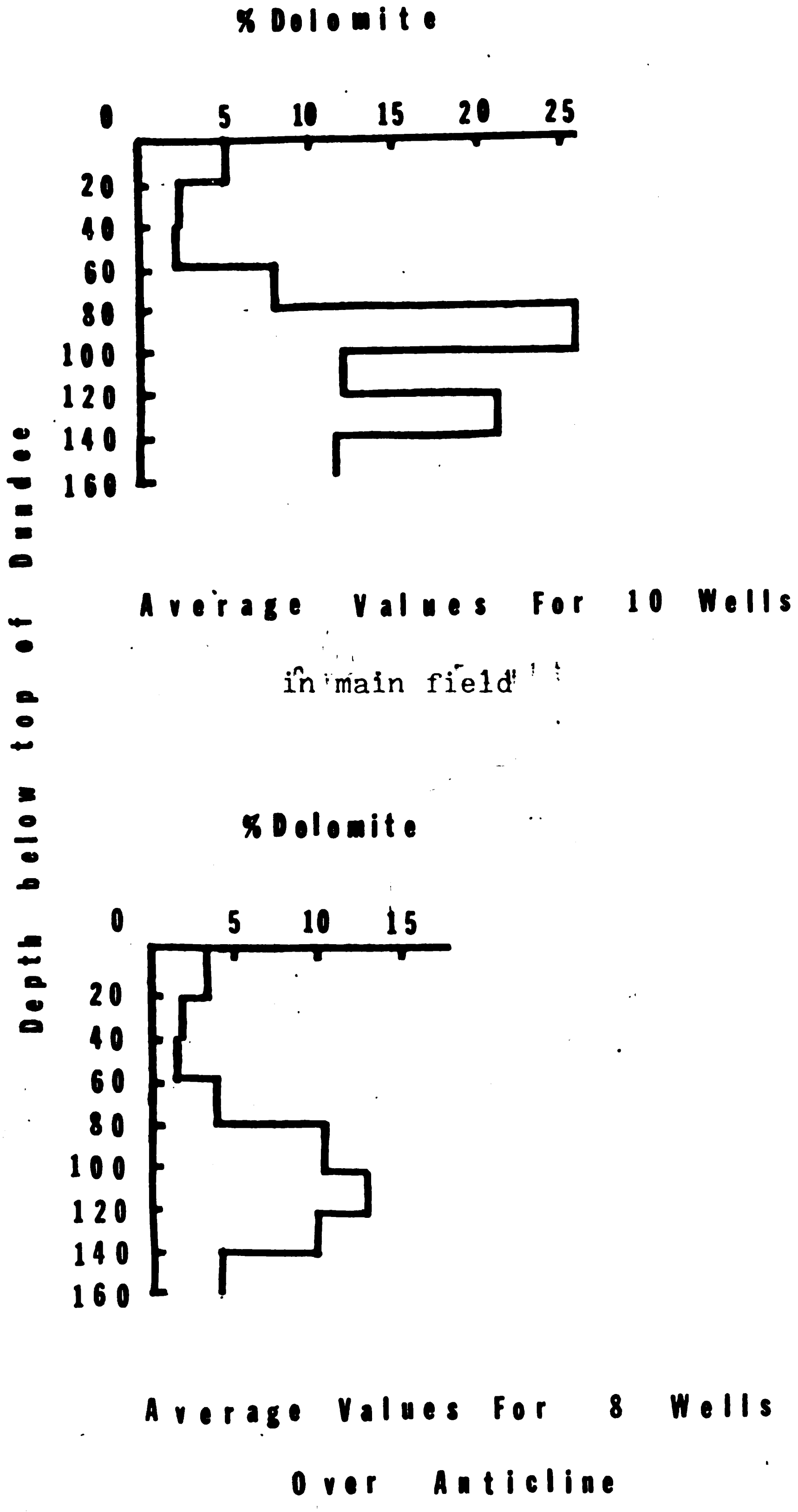

% Dolomite
0
5
10
15
20
25
20
40
60
80
100
120
140
160
Depth below top of Dundee
Average Values For 10 Wells
in main field
% Dolomite
0
5
10
15
20
40
60
80
100
120
140
160
Average Values For 8 Wells
Over Anticline

Figure 18

be seen that the average top 20 feet has nearly twice as much dolomite as either of the next two intervals (20-60 feet).

PETROGRAPHY

Core:

There was one core that was available for study. This core, from the Bolger and Rose State Adams #1 in section 14, (permit #10572), was from 96 1/2 to 99 feet below the top of the Dundee. This well, although not a producer, was very close to the fault. Of the 2 1/2 feet, 8 slides were prepared and stained.

The thin sections show that the original sediment was almost entirely a wackestone, with a fine micritic matrix. Interbedded are a few thin, grainstone beds with longitudinally-oriented fossils showing current flow. The types of fossils preserved are crinoids, brachiopods, ostracods, corals, and bryzoans, indicating an open marine environment. Pellets were also found in both thin sections and grain mounts. In the thin sections the cement is nonferroan calcite which, because of is blocky rather than elongate crystal habit, is interpreted to be fresh water-deposited, low-magnesium calcite (Longman, 1980). Stylolites are very common and tend to occur in swarms. They are mainly of the sutured type. Much

of the original fabric of the rock has been recrystallized as can be seen by the large amounts of neomorphic spar. This spar can be seen to be preferentially recrystallizing some beds over others.

There has been a degree of dolomitization which varies in amount throughout the slides. The occurrence of dolomite can be divided into three different associations, stylolites, in the matrix, and in the pore space. The greatest concentration of dolomite occurs along stylolites where it appears to either have crystallized from solution moving along the stylolite or from selective dissolution of calcite along the stylolite. The crystals are slightly larger than those found in the matrix, and are euhedral. This problem will be discussed later. The dolomite in the matrix is evenly distributed. Dolomite grain size is very small, and crystals tend also to be euhedral.

By far the largest dolomite crystals occur in the larger pores. These crystals are grown together and are euhedral. When stained for iron these crystals are the only ones that can be seen here to be even slightly ferroan. Those that did stain have a faint, rather thick zone, that has some iron. The faintness of this zone indicates that there is only a little iron compared to the ferroan dolomite discussed later. These crystals have clear rims and cloudy centers.

Well cuttings:

The well cuttings used in this study were prepared as grain mounts and stained. Two wells, one with high dolomite and one off-structure were divided into 20 foot intervals as they were for x-ray analysis. Cuttings from four producing wells, from within the producing zones were also prepared.

Well #8045 contained the highest percent dolomite of any interval in any well, with 85% between 140-160 feet. In this interval none of the dolomite is ferroan. Dolomite changes going upward become almost totally ferroan at the top. In the top 20 feet there is even a little ferroan calcite. Well #4203 shows the same thing. Also there is one instance where ferroan dolomite, in the top 20 feet, fills an unbroken ostracod. Unlike the West Branch field, these wells have virtually no chert (Ten Have, 1979).

Those grain mounts prepared from cuttings in the producing zones are all very high in ferroan dolomite. There are a few crystals that show zoning with high iron at the edges. These crystals are euhedral and probably grew in open pore space. Nearly all the original rock has been either dissolved or recrystallized with the rare exception of a few spots of micritic matrix. These cuttings all have a lot of opaque material, most of which is organic, but in reflected light, some can be seen to be pyrite. There is one piece of shale that contains "inclusions" of ferroan dolomite.

MODEL OF DOLOMITIZATION

All dolomitization models depend on chemical, pressure, or temperature regimes that differ from those in the typical environment of carbonate deposition. In determining whether or not the dolomite found in this area is early diagnetic, only chemical changes need to be considered. Differences in temperature and pressure at the near surface are not known to be important.

In order for dolomite to be produced there must be a mechanism whereby it will replace calcite. Several possible models have been proposed, based mainly on observations of dolomitization in modern sediments.

Most of these models depend on a high Mg/Ca ratio. This has been found in several places where dolomite is now forming, and seems to always be associated with hypersaline waters. In the sabka-type environment (Illing et al, 1965) it can be seen that high degrees of evaporation of sea water produce evaporites, particularly anhydrite and gypsum. As both of these minerals incorporate Ca into their structure, there is a loss of Ca from the fluids, raising the Mg/Ca ratio. When the ratio becomes high enough dolomite replaces the calcite. There are other variations such as dolomitization by seepage reflux (Adams and Rhodes, 1960), or by a density gradient (Deffeyes, 1965), but both of those depend only on evaporation, and hypersaline waters.

Another type of model depends on the mixing of marine water with phreatic water (Badiozamani, 1973; Land, 1973; Folk and Land, 1975). This mixing produces a fluid which is supersaturated with respect to dolomite, but understaurated for calcite.

This model depends on the presence of both sea and fresh water in the sediment for a length of time long enough for dolomitization to occur. Badiozamani (1973) showed that dolomite can be produced with a mixture of 5-30% sea water with fresh water. There needs to be a great deal of mixing in order to replenish the Mg in solution when it is being removed by dolomitization.

All the above models depend on an emergence of the land above sea level. In the western part of Michigan there are interbedded evaporites in the Dundee showing that there may have been a sabka type of environment in that area (Dastanpour, 1976). However, evaporites are not found in the Dundee of central or eastern Michigan. There is a blocky calcite cement from which one might infer a fresh water origin (Bathurst, 1971). Given that the rock was originally deposited in marine water and later there was fresh water indicates that probably at some time in between there was a mixing of the two. Assuming this to be the case, it would be expected that the mixing would have come before the deposition of the Bell shale as this would probably stop descending fresh water. As was shown by the isopach of the Traverse (Figure 8b), it appears the structures in both fields were not in existence in Dundee time. In order for most of the dolomite to have been formed by the mixing of fresh and sea water, the pattern of dolomitization would not have followed the structures. As it did follow the structures it is doubtful that it was the result of the Dorag model (Badiozamani, 1973).

There is another possibility that, as in the Bahamas, there was dolomitization by hypersaline brines, but with a loss of evaporites. This is shown, as above, to be unlikely because the dolomite follows the structure too closely.

If the dolomite is not early then it would have to be later epigenetic, probably at the same time the structures formed. There are two main possible sources for the dolomitizing fluids, either from below, or from the shales above.

It has been shown (Boles and Franks, 1979) that the diagenesis of shales at about 100°C causes Smectite and K^+ to change to Illite:

$$3.93K^{+} + 1.57\ KNaCa_2Mg_4Fe_4Al_{14}Si_{18}O_{100}(OH)_{20} + H_2O$$

Produces

$$K_{5.5}Mg_2Fc_{1.5}Al_{22}Si_{35}O_{100}(OH)_{20} + 1.57\ Na^{2+} + 3.14\ Ca^{2+} + 4.38\ Mg^{2+} +$$

$$4.78\ Fe^{2+} + 24.66\ Si^{2+} + 570\ ^{2+} + 11.4\ (OH)^{-} + 15.7\ H_2O$$

$$K^{+} + \text{Smectite} + \text{Water} + \text{Illite} + Na^{2+} + Ca^{2+}\ Mg^{2+} + Fe^{2+} +$$

$$Si^{2+} + O^{2+} + OH + \text{Water}$$

This reaction depends on the presence of potassium and Smectite. The original amounts of these two components will affect how much of the products are produced. The iron produced is reduced iron, Fe^{2+}. Potassium Ferrocyanide, the stain used in this study, specifically stains for this reduced iron (Evamy, 1963). It has been shown (Evamy, 1969), that reducing conditions are required for the substitution of Fe for Ca in calcite; under oxidizing conditions, the reduced iron is not available. As iron content in the dolomite found in this study increases to its maximum at the top of the formation, it would appear that the bulk of dolomitization at the top of the formation occurred under reducing conditions.

There are still a few problems with this model. Hower and others (1975) showed that the shale tends to act as a closed system for Illite, Mg, Fe, and Si. Yeh and Savin (1976) showed using O^{2+} isotopes that SiO_2 definately appears to stay in the shale. Little or no silica was found in this study. However Fe and Mg were found. Boles and Franks (1979) pointed out that although bulk chemical analyses show little change in Fe, Mg or Si with depth, significant amounts can be released from the shales without apparent change in bulk chemistry.

There is evidence that there is slightly more total dolomite in the top 20 feet of the Dundee compared to the amount of dolomite found from 20 to 60 feet. The difference is small, about 4% at the top, to about 2% below, but is very consistent. This tends to show that any fluids produced from the shales either were not able to do much dolomitizing, or else they were lost quickly down the fault and other fractures where they mixed with other fluids. The latter seems more likely as seen by the ferroan gradient in dolomite in wells along the fault.

The fact that dolomitization is greater with depth, and also the lack of ferroan dolomite at depth would tend to show that not all dolomite was the result of shale diagenesis. In well #8043 the interval from 140 to 160 feet had no trace of ferroan dolomite, with a total of 84% dolomite. None of the dolomite found in the core, with the exception of that found in large pore openings, was ferroan either. This would seem to mean that the main dolomitizing fluids were nonferroan and probably came from below.

Syrjamaki (1977) showed that approximately 350-500 feet of the Prairie du Chien dolomite has been lost in one place in south-central Michigan, presumably by dissolution. It is conceivable that deeply buried dolomite could become dissolved, and the solution could then move upward and re-precipitate the dolomite. If this were the case the dolomite should be greatest where there was the greatest movement of solutions, mainly in areas of high permeability.

There are many ways to get good permeability in limestone. Hyde (1979) stated after studying a core from the Kawkawlin field, that much porosity seemed to be related to dissolution of both fossils and matrix. There is also porosity produced by faulting and resulting breccia. Jackson (1957) indicates brecciation in core from the Dundee in the Pinconning field. When folding occurs, as in this field, there are usually joints formed. Dolomitization itself may form porosity.

In this field there are some very good avenues for the movement of dolomitizing fluids, particularly along the faults. As shown in (Figure 13), the greatest degree of dolomitization occurs along the main structure. The highest values found anywhere were in the pay zone (Appendix II). Also there appears to have been lateral movement along highly porous beds, as shown by well logs, resulting in high average dolomite values from 80-160 feet below the top, with much lower values from 0-80 feet. Finally there has been dolomitization along the anticline. Possible the solutions were hotter or otherwise less dense than the surrounding original fluids causing them to move into the highest permeable zone that they could. This might explain why only the axis of the anticline was dolomitized; also the anticline is likely fault related with fracture porosity and permeability present.

Finally there is the problem of the dolomite found along stylolites. There are several possible interpretations. One is the concentration of dolomite because of dissolution of calcite but not of the dolomite. The fact that the dolomite grains are larger than those found in the matrix might be explained by dissolution of very small dolomite grains and reprecipitation of the larger grains. The stylolite might act as a local pathway for these fluids. Another interpretation could be that later solutions moving through the rock would flow along stylolite surfaces because of the clay, and the dolomite could then be deposited. Another possibility is that solutions moved along stylolite surfaces at the time the stylolite was forming. There is no way to prove or disprove any of the above possibilities, given what has been observed in this field.

SUMMARY OF DOLOMITIZATION WORK DONE IN THIS AREA

(1) Early diagenetic dolomite:

This type of dolomite was found almost entirely in the west part of the state. Newhart (1976) has shown in his regional study of the Middle Ordovician that, at least during Middle Ordovician time, the Wisconsin arch was emerging and the resulting uplift in west Michigan allowed subareal exposure of the carbonates and resulted in dolomitization. Runyon (1976) showed that in the Traverse, clastics in the carbonates increased to the west. In Hamrick's (1976) study of the Walker Field, it was shown that in the west end of the field dolomite increased greatly and did not follow structure, indicating that there is a diagenetic dolomite. Dastanpour (1977) showed that there was diagenetic and epigenetic dolomite in the Reynolds field in the Dundee but only epigenetic in the Traverse. The Dundee dolomite in this field was associated with anhydrite.

Generally this type of dolomitization results in much greater degree of dolomitization. Sections with 60 to 100% dolomite are most common. This dolomite tends to follow large, broad areas and is not influenced by local small structures.

(2) Structurally controlled, epigenetic dolomite:

This type of dolomite is associated with the faults and folds that occur throughout the Michigan Basin. Landes (1946), looking at the North Adams field, and Jackson (1957) looking at the North Adams, Pinconning and Deep River fields, were able to determine that dolomitization directly on top of Dundee structures was greatest with little or no dolomite off structure. Later with x-ray techniques, it became possible to show in more detail along which paths the dolomitization occurred. Hyde (1979) was able to show, using petrographic studies of core, that dolomite followed natural porosity laterally, presumably along bedding. TenHave (1979) showed the same thing using porosity as given by Gamma-ray Neutron logs. Dastanpour (1977) was able to show that although the Dundee below, showed diagenetic dolomite, the Traverse dolomite still appeared to be epigenetic. These studies all showed that dolomitizing fluids appeared to follow vertical permiability, produced by their respective structures. Because of the distribution of the dolomite, greater lower in the Dundee, the source of fluids is generally assumed to be from a more deeply buried formation, possibly the Prairie du Chien as was stated earlier. Possibly some type of trace element distribution work could be done to solve this problem.

The degree of dolomitization of this type is generally much less than diagenetic dolomite. Where there has been found to be good porosity, values most commonly range from 10 to 30% dolomite over 20 foot intervals, although in a few instances they ranged much higher. Probably the thing that is the most different about this type of dolomite over the other two types is the lack of lateral continuity. Away from structures this type of dolomite does not occur.

All fields of this type appear to fit the Moody (1973) wrench deformation model. In eastern Michigan there is a remarkable similarity in the field orientations. The West Branch, Deep River, and Kawkawlin fields all have a WNW-ESE orientation. All are broad anticlines with wrenching causing them to curve slightly south on their east ends. The North Adams and Pinconning fields are oriented NNE-SSW, and are virtually parallel in their orientation.

(3) Dolomite resulting from the diagenesis of shales:

The diagnesis of shales produces the least degree of dolomitization, with generally less than 5% found over the 20 foot interval next to the shale. This study was the first to specifically mention this type of dolomite although data in other studies show its presence. Tinklepaugh (1957), using chemical methods observed that total iron content in the area she studied was greater in the 5 feet next to the Bell Shale than in the 20 feet next to the shale. Iron concentration did not appear to follow the structure. TenHave (1979) used luminesence and observed that there was more iron in the interval from 0 to 20 feet from the Bell Shale than in any interval from 20 to 170 feet below the base of the shale. Young (1955) in his study of the Stony Lake oil field found no relationship between dolomite and structure, but found that there was more dolomite from 0-3 feet than from 0-10 feet from the top of the Traverse Limestone. Both Hamrick (1978) and Dastanpour (1976) showed the same for the Traverse, with slightly higher dolomite percent averages at the top and bottom of the limestone, where it was in contact with the Antrim and Bell Shales respectively. Both TenHave (1979) and Hyde (1979) observed this for the Dundee capped by the Bell Shale. Possibly some of the "damming effect" observed may be the result of this kind of dolomitization.

GENERAL CONCLUSIONS

From the preceding analysis the following can be concluded:

(1) Dolomitization appears to be mostly epigenetic.

(2) There are two potential sources of dolomitizing fluids, the Bell shale, and from fluids derived from lower formations.

(3) In the top 160 feet of the Dundee, overall dolomitization decreases upwards showing the Bell shale was probably not the main source of fluids.

(4) Dolomitization is highest on the main structure and in crossfaults.

(5) Dolomitization highs on the Southeast Field follow anticlinal highs.

(6) Laterally moving fluids follow pre-existing planes ot permeability as shown by Gamma-Ray Neutron logs.

(7) There is dolomite associated with stylolites which may have formed in one of several ways.

APPENDIX I

LIST OF WELLS USED IN STUDY, ARENAC COUNTY

Adams Township, T19N, R3E

Permit No.	Traverse Group Top	Traverse Group Thickness	Dundee Top
Section 1.			
11073	-1288	790	-2078
12879	-1304	802	-2106
13533	---	---	-2101
25979	-1287	800	-2087
Section 2.			
4205	-1313	782	-2097
10628	-1312	810	-2122
14484	-1289	816	-2105
24424	-1311	800	-2111
Section 3.			
25102	-1322	815	-2137
Section 9.			
8666	-1327	792	-2119
Section 10.			
13655	-1314	758	-2072
Section 11.			
11249	-1308	804	-2119
11343	-1306	806	-2112
11819	-1322	784	-2116
11820	-1319	803	-2123
12022	-1323	788	-2111

Permit No.	Traverse Group Top	Traverse Group Thickness	Dundee Top
Section 11.			
12142	-1320	796	-2116
12219	-1316	788	-2104
12327	-1316	788	-2104
12328	-1320	781	-2101
12695	---	---	-2119
12702	-1306	819	-2125
18810	-1321	800	-2121
Section 12.			
14837	-1271	831	-2102
19070	-1276	840	-2116
Section 13.			
9711	-1274	812	-2086
Section 14.			
7880	-1322	790	-2112
10198	-1316	784	-2100
10572	-1317	804	-2121
10622	-1308	790	-2098
10702	-1315	786	-2101
10774	-1318	776	-2094
10765	-1196	896	-2092
10821	-1322	792	-2114
10855	-1311	794	-2105
10932	-1320	775	-2095
10987	-1313	792	-2105
11036	-1309	797	-2106
11115	-1321	788	-2109
11304	-1298	790	-2088
11318	-1280	818	-2098
11685	-1292	806	-2098
11837	-1332	790	-2122
Section 15.			
7872	-1298	794	-2092
8181	-1310	785	-2095
8301	-1284	795	-2089

Permit No.	Traverse Group Top	Traverse Group Thickness	Dundee Top
Section 15.			
8988	-1300	793	-2093
9158	-1245	838	-2083
10497	-1250	843	-2093
12408	-1312	790	-2102
20352	-1296	784	-2080
Section 17.			
7943	-1364	792	-2163
8784	-1196	812	-2008
14579	-1220	798	-2018
Section 20.			
4507	---	---	---
Section 21.			
8383	-1315	782	-2097
19862	-1303	789	-2092
20164	-1309	787	-2096
Section 22.			
7463	-1306	775	-2081
7895	-1306	785	-2091
7905	-1302	775	-2097
7907	-1307	798	-2105
7908	-1309	771	-2080
7961	-1335	756	-2091
8043	-1314	780	-2094
8044	-1311	777	-2088
8087	-1309	784	-2093
8180	-1320	775	-2095
8230	-1297	754	-2051
8300	-1313	764	-2077
8345	-1315	772	-2087
8382	-1306	780	-2086
8436	-1311	782	-2093
8461	-1310	794	-2104
8472	-1313	773	-2086
8560	-1315	786	-2101

Permit No.	Traverse Group Top	Traverse Group Thickness	Dundee Top
Section 22.			
8575	-1311	776	-2097
8667	-1229	856	-2085
8773	-1305	765	-2070
8880	-1339	747	-2086
8949	-1312	770	-2082
9008	-1313	766	-2079
9009	-1310	765	-2075
9207	-1304	774	-2078
9821	-1301	785	-2086
9169	-1305	783	-2088
9289	-1301	781	-2082
9290	-1305	790	-2095
9294	-1312	790	-2102
9821	-1301	785	-2086
10548	-1302	772	-2074
10549	-1308	787	-2095
10671	-1308	783	-2091
11293	-1299	793	-2092
Section 23.			
7462	-1261	785	-2055
7809	-1270	792	-2062
7837	-1261	---	---
7875	-1293	803	-2096
7876	-1269	793	-2062
7901	-1299	797	-2096
7924	-1277	800	-2077
8192	-1270	---	---
8215	-1268	795	-2063
8334	-1176	884	-2060
8480	-1308	774	-2082
8574	-1272	794	-2066
9214	-1294	805	-2099
9291	-1269	797	-2066
13966	-1251	875	-2126
Section 24.			
4804	-1247	815	-2062
8654	-1247	786	-2060
8346	-1269	794	-2063

Permit No.	Traverse Group Top	Traverse Group Thickness	Dundee Top
Section 24.			
8365	-1252	---	---
8576	-1271	796	-2067
16855	-1279	815	-2094
Section 25.			
4365	-1252	---	---
4571	-1245	---	---
4755	-1270	---	---
5117	-1273	---	---
8335	-1268	795	-2063
9501	-1271	803	-2074
9606	-1264	802	-2066
9637	-1270	798	-2068
13824	-1222	854	-2076
16010	-1262	797	-2059
18538	-1273	---	---
20031	-1270	790	-2060
23496	-1266	---	---
Section 26.			
4190	-1272	---	---
4387	-1254	---	---
4496	-1275	806	-2081
4508	-1284	---	---
4610	-1268	---	---
4718	-1262	---	---
4785	-1259	795	-2054
4855	-1192	876	-2068
4901	-1264	797	-2061
5160	-1260	801	-2061
5523	-1264	795	-2059
6465	-1181	---	-2062
7461	-1264	797	-2061
7906	-1268	788	-2056
8246	-1265	801	-2066
8911	-1183	---	---
9102	-1264	799	-2063
9468	-1270	791	-2061
9865	-1280	809	-2089
13122	-1200	852	-2052

Permit No.	Traverse Group Top	Traverse Group Thickness	Dundee Top
Section 26.			
13373	-1255	---	---
15236	-1275	786	-2061
15448	-1264	806	-2070
15729	-1269	789	-2058
20124	-1286	---	---
20213	-1293	---	---
44966	-1256	813	-2069
Section 27.			
8045	-1307	929	-2236
9377	-1219	890	-2109
9701	-1307	800	-2107
9702	-1313	782	-2095
9844	-1304	778	-2082
10547	-1276	824	-2100
12625	-1310	787	-2097
17314	-1336	810	-2046
26705	-1297	789	-2086
Section 28.			
10390	-1356	807	-2163
11258	-1404	771	-2175

Wells in Pay zone:

Permit Number	Feet Below Dundee Top	Percent Dolomite
9377	0-9	92.6
8230	43-45	99.1
9290	1-3	90.4

APPENDIX II

DOLOMITE PERCENTAGES

Permit Number	0-20	2-40	40-60	60-80	80-100	100-120	120-140	140-160
4203	3.3	1.8	1.1	1.3	10.9	20.2	3.5	---
4496	4.4	1.6	1.0	2.4	4.6	19.1	11.7	14.7
4901	3.0	1.2	1.4	2.0	15.1	7.5	8.0	---
7461	3.5	1.7	1.6	8.7	12.8	4.4	7.2	---
7872	3.4	1.3	1.2	5.4	15.3	9.4	8.6	---
7875	2.6	1.4	1.5	3.1	25.5	9.6	8.6	12.3
7901	2.0	1.7	1.3	4.2	22.5	8.9	5.4	6.9
7961	4.7	1.5	1.3	3.6	13.9	9.7	14.7	18.2
8043	5.8	---	3.8	9.7	----	---	---	---
8045	2.8	2.6	1.3	1.4	18.8	14.7	31.5	84.6
8181	3.1	2.1	1.9	6.2	17.6	3.7	7.9	8.3
8301	---	---	---	---	18.7	7.0	7.0	7.4
8334	3.8	2.4	.8	1.8	.7	22.9	10.4	5.2
8335	3.7	3.2	1.3	3.2	14.2	17.1	10.9	---
8346	2.4	.9	.9	5.9	24.1	7.5	10.8	5.2
8382	2.6	2.4	1.0	1.9	16.2	22.4	---	---
8383	4.3	1.6	.9	1.2	15.9	13.6	9.1	---
8575	3.3	1.1	1.3	2.2	12.9	13.3	12.0	60.5
8576	2.8	1.6	.9	2.1	5.9	6.7	13.9	7.0
9008	2.6	1.4	2.6	10.1	70.4	---	---	---
9169	4.0	2.7	.5	1.8	20.7	15.5	77.2	---
9291	4.2	2.8	1.4	1.4	7.0	4.7	2.4	2.6
9390	---	---	---	---	3.2	4.6	---	---
9468	2.9	---	---	---	3.4	14.1	9.0	3.1
9501	4.4	2.1	2.0	4.4	4.5	6.0	7.1	13.0
9637	3.6	3.2	1.3	3.2	14.2	17.1	10.9	---
9701	2.2	1.4	1.8	4.8	34.1	20.2	7.7	---
9844	4.4	1.4	6.1	5.3	21.3	9.8	8.9	6.1
10390	3.1	---	---	2.3	6.2	29.6	20.8	---
10549	20.9	7.3	---	---	---	----	---	---
10671	2.4	1.2	1.6	7.3	---	---	---	---
10855	2.9	2.0	2.0	1.0	15.3	6.8	7.8	10.8

Permit Number	0-20	2-40	40-60	60-80	80-100	100-120	120-140	140-160
11318	1.1	1.4	3.6	20.0	18.7	12.5	9.8	10.7
12879	4.5	1.5	.5	1.9	25.4	22.4	3.5	----
13122	---	1.2	1.2	2.6	.9	22.6	8.3	----
13655	1.2	.7	2.9	3.9	1.9	1.1	---	----
14484	1.9	1.4	.9	2.9	1.7	29.6	13.1	----

APPENDIX III

List of Wells Used in Dolomite Averages

Main Field:	Anticline:
7875	4901
7901	7461
7961	8334
8043	8335
8181	8346
8382	8576
9008	9291
9169	13122
10549	
11318	

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North Adams Oil Field
Adams Township, Arenac Co.
Michigan
Structure top of the Dundee Formation
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O=Dry Well
●=Producing Well
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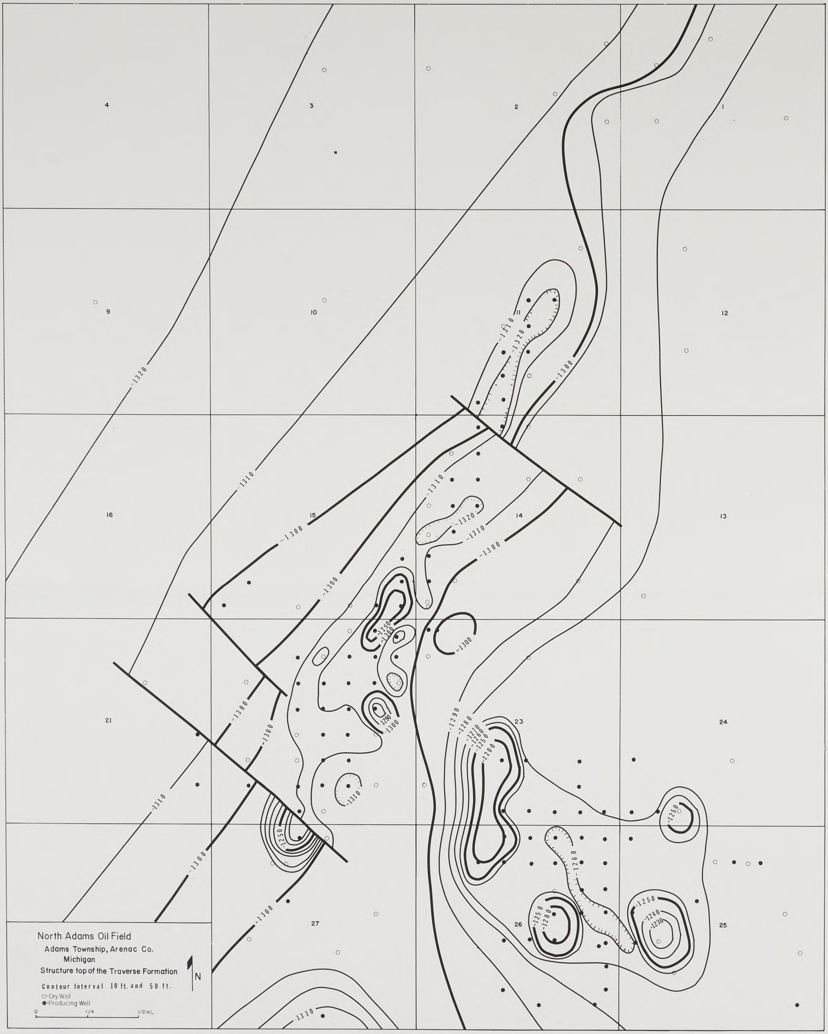
North Adams Oil Field
Adams Township, Arenac Co.
Michigan
Structure top of the Traverse Formation
Contour Interval 10 ft. and 50 ft.
O=Dry Well
●=Producing Well
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