A REGIONAL STUDY OF THE MIDDLE DEVONIAN DUNDEE DOLOMITE IN THE MICHIGAN BASIN

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ABSTRACT

A REGIONAL STUDY OF THE MIDDLE DEVONIAN DUNDEE DOLOMITE IN THE MICHIGAN BASIN

By

Alfred T. Bloomer

In the Michigan Basin a considerable number of oil and gas fields produce from porous zones in dolomitized limestones. The Devonian system in the Michigan Basin consists of five groups; the Traverse, Casenovia, Detroit River, Onesquethaw, and the Deer Park. This thesis deals with the Casenovia group which consists of the Dundee and the Rogers City limestone formations. These formations are lithologically similar and very difficult to distinguish in the subsurface. Therefore, they will be referred to as one unit; the Dundee.

This study confirms that the Dundee dolomite is for the most part restricted to the center of the Michigan Basin, and that it is from this dolomitized carbonate rock that the Dundee hydrocarbons are produced. Here the Dundee is a clastic, brecciated, burrowed, brown to black, petroliferous, locally dolomitized limestone. Porosity within the Dundee interval is secondary. The proposed mechanism for dolomitization of the mid-basin Dundee is

seepage refluxion. The writer believes that the mid-basin Dundee was deposited in a supratidal environment.

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Alfred Travers Bloomer

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Mobil Oil Corporation, Oklahoma City Division, through the efforts of Mr. R. M. Berry, loaned the writer 1200 mechanical logs which were essential to this study. Dr. J. H. Fisher of McClure Oil Company supplied the writer with two Dundee cores which were necessary to this investigation. The writer is grateful to these men and their respective companies.

Not the least of my gratitude is due my wife, Carol, for her patience, assistance, and understanding.

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CHAPTER I

INTRODUCTION

History and Description of the Michigan Basin

The Michigan Basin has been recognized since the work of Douglass Houghton, who in 1840 was the first state geologist of Michigan. James Hall in 1843 published a geologic map showing the circular pattern of the subcrops beneath the glacial drift. The extensive cover of Pleistocene glacial deposits, which in places reaches a thickness of nearly 1300 feet, restricted the amount of subsurface data available prior to the 1930's. Since that time extensive oil and gas exploration has been undertaken in the basin, providing valuable subsurface information.

The Michigan Basin is a roughly circular, gravity-sag, intracratonic basin (Figure 3). It is frequently referred to as the type example for an autogeosyncline as classified by Marshall Kay (1951). The basin includes the Southern Peninsula and the eastern part of the Northern Peninsula of Michigan, eastern Wisconsin, north-eastern Illinois, northern Indiana, northwestern Ohio, and western Ontario. This represents an area of 122,000 square miles, part of which is covered by Lakes Michigan, Huron, and St. Clair (Cohee, 1965). It is bounded on the south and southeast by the Kankakee and Findlay Arches, which are the northern extensions of the north-south trending Cincinnati Arch. The east side of the basin is defined by the Algonquin Axis and the Findlay Arch. The Wisconsin Arch borders the basin on the west and the Laurentian Shield forms the north and northeastern boundaries.

The basin is filled with Paleozoic rocks which reach a maximum thickness of about 14,000 feet. The depocenter of the basin migrated throughout the Paleozoic system. During Dundee time the depocenter was in the Saginaw Bay area where the interval reaches a thickness in excess of 400 feet (Figure 4).

The basin began its greatest subsidence during the late Silurian-Salina time. This is indicated by a deepening and thickening of the Salina sediments basinward (Prouty, 1969). The structures in the Michigan Basin generally trend northwest-southeast. Dr. Harold Scott (1969) pointed out the similarities in tectonic development between the Illinois, Williston, and Michigan Basins. The Mississippian shows a period of the most extensive structural development in these basins.

Purpose of Study

The major purpose of this investigation is to describe the lithology and porosity of the middle Devonian Dundee rocks in the Michigan Basin. Further, it is the writer's intention to determine the depositional and environmental conditions which were present in the Basin during Dundee time. It is also of primary interest to determine the mechanism(s) of dolomitization within this mid-basin middle Devonian interval, and its effect, if any, on the porosity. This information will be obtained by lithologic analysis of samples taken from the Prosper and Porter fields. A lithological analysis will also be made of two Dundee cores obtained from the McClure Oil Company. Mobil Oil Corporation loaned 1200 mechanical logs which were essential to completion of this thesis.

It is the hope and purpose of the writer that the information gained from this study will shed additional light on Middle Devonian-Dundee sedimentation.

Selection of Wells and Picking the Dundee Interval

The Dundee limestone is overlain by the Rogers City limestone in the Michigan Basin. These formations are lithologically similar and are very difficult to distinguish macroscopicly and on radioactivity logs. Therefore, here they will be referred to as one unit; the Dundee.

Two hundred fifty radioactivity logs were used in preparation of the regional structure contour map. The regional isopach map was prepared from only those logs containing the entire Dundee interval. The wells selected are represented by an "O" on the maps and are listed by county in the Appendix.

The Bell shale forms the base of the Traverse Group which overlies the Dundee. It serves as an excellent marker bed since it lies between two carbonates, and it shows up clearly on the radioactivity logs (C.S. 1 & 2).

The Detroit River Group lies immediately beneath the Dundee. The upper part of this group is characterized by an extensive series of anhydrite beds. The writer picked the top of the first anhydrite as the base of the Dundee interval.

CHAPTER II

STRATIGRAPHY

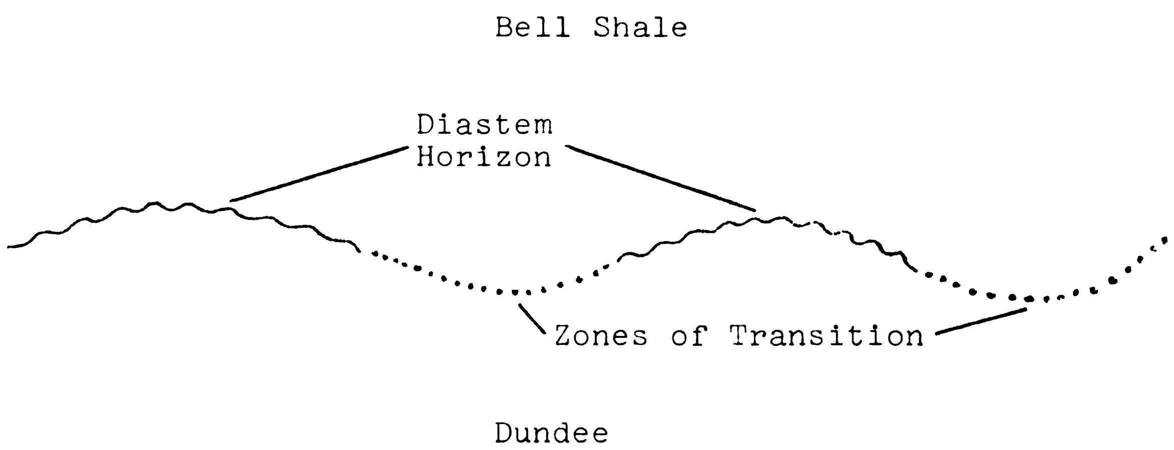
Very little geologic work has been published on the Bell shale which overlies the Dundee. Since this shale is so closely associated with Dundee production, the writer feels that a knowledge of this formation is necessary for understanding the Dundee.

Bell Shale

The Dundee unit is overlain by the Bell shale except in the extreme western and southwestern part of the basin. The Bell formation is generally described as a dark gray to black, calcareous shale containing crinoid stems. The writer examined two McClure Oil Company cores, the White Est. #1, SE SW SE, Section 18, Township 17 North, Range 8 West and the Nadco-Woods, Alderman-McCoy, Section 1, Township 21 North, Range 6 West, to lend more detail to the above description. In these cores the crinoids at the top are scattered, and varying in size. Moving down in the section they occur in beds normal to the core section and are size sorted. The shale shows evidence of conchoidal fractures and parting parallel to bedding. Pyritization is often in evidence along the afore-mentioned lines of parting.

A close examination of the shale in these cores indicates that the crinoid content decreased in the basal part of the shale interval. The shale also becomes less argillaceous and more calcareous toward the base, where it grades into a dolomitic rock, thus marking the top of the Dundee. This zone of transition is also marked by what appears to be an erosional rill that is pyritized along its boundaries.

Newcombe (1930) and Landes (1951), among others, proposed a regional disconformity across the basin at the base of the Travers Group, between the Bell shale and the Dundee. The writer, on the other hand, suggests that the depositional surface in the mid-basin area at the close of Dundee time was irregular with large isolated pools of water standing in the lower areas. At the beginning of post-Dundee shale deposition, areas that were under water yielded a thin transitional zone like the one mentioned in the previous paragraph. The rill channels are the result of tidal run-off channels or small rivulet channels that cut across the Dundee depositional surface. Similar rill zones may be observed within the Dundee unit itself. The higher rill horizon may have led Landes and Newcombe to recognize a regional disconformity. Due to the time interval inferred by the transitional zones, the writer prefers to interpret this break as a diastem horizon with the local zones of transition reflecting lower areas. A regional diagrammatic representation of this mid-basin diastem horizon is given below.



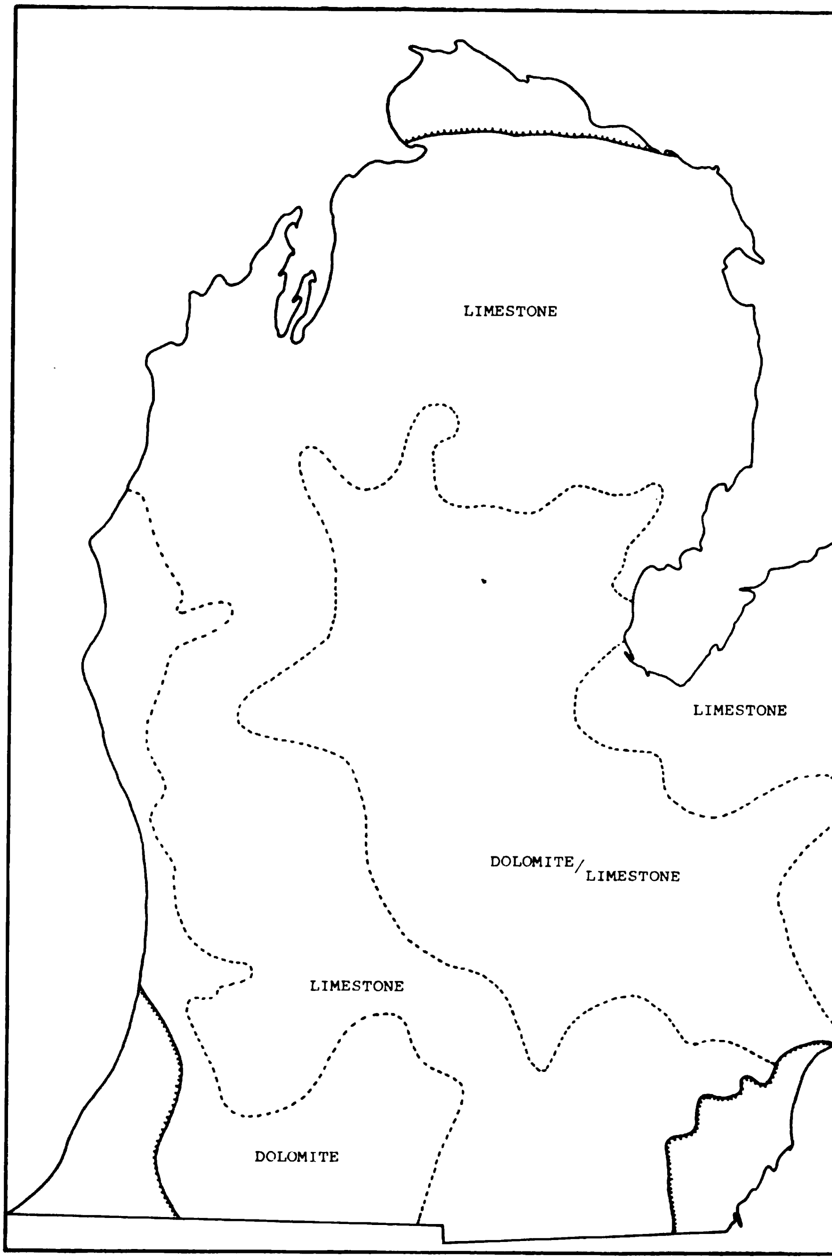
The distance between crests likely varied from a few tens of feet to as much as a mile. The maximum relief probably never exceeded a few feet.

A depositional model is presented later that explains the origin of the diastem between the Bell shale and the Dundee.

Examination of radioactivity logs yielded two criteria suggesting that the source of the Bell shale was to the north-northeast. Referring to Cross Sections 1 and 2, it is noted that the shale is thickest to the north-northeast and pinches out to the south-southwest. Secondly, it is noted that in well number 6 of Cross Section 1, the shale interval has a calcareous bed passing through it. This calcareous zone migrates from high in the shale in the northeast to low in the shale, eventually merging into the Dundee to the southwest. The writer believes that this calcareous intertongue and the pinching out of the shale suggest a generally transgressing sea from the north-northeast which deposited the overlapping Bell shale (C.S. 1).

Dundee Unit

The Dundee interval underlies most of the Southern Peninsula. The outcrop and subcrop pattern is shown in Figures 3 and 4. The Dundee interval is commonly described as a buff to brown-grey, fine to coarsely crystalline limestone. In the central portion of the basin, it is a mixture of dolomite and limestone, and in the far central western region and the southwestern region it is predominantly dolomite (Figure 1). It is the dolomite zone in the central basin that is of primary interest. Knapp (1956) indicates that "The Dundee in the east and northeastern areas of the Michigan Basin is a marine limestone, predominantly tan, containing oolites and stylolites and with a more varied fauna in the peripheral areas." He further states that "In west-central Michigan in a belt extending north and south, is a so-called 'primary' dolomite, crystalline, even-textured, predominantly tan and lacking in recognizable fossils except for occasional stromatoporoids." He considers this to be the characteristic lithology of the Dundee.



LITHOLOGY OF THE DUNDEE INTERVAL

SCALE: 0 12 Miles

FIG. 1

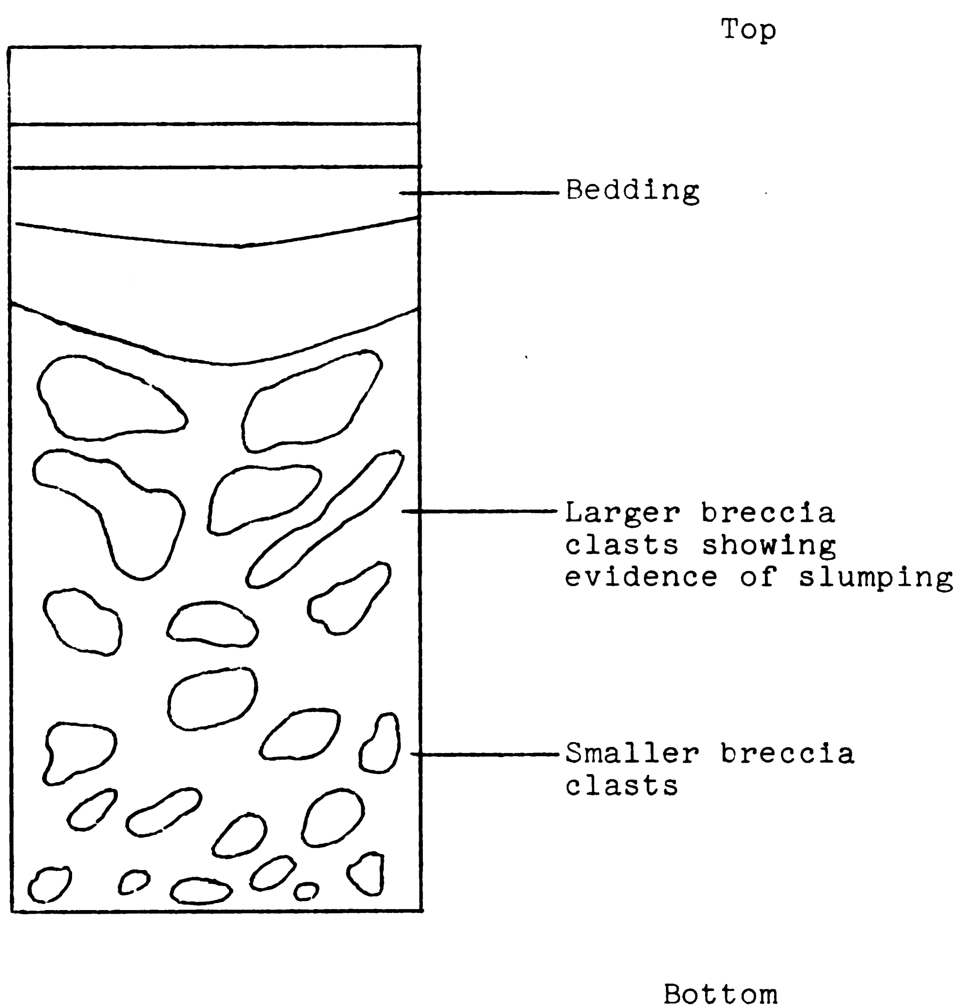
After Cohee & Underwood (1945)

The writer examined the White Est. #1 and the Nadco-Woods, Alderman-McCoy cores, and researched previous literature on the Dundee to compile a more detailed description of the mid-basin Dundee. Here the Dundee is a clastic, in places brecciated, possibly burrowed, brown to black, petroliferous, locally dolomitized limestone. The Dundee in this area contains stromatoporoids, brachiopods, coral, and scattered crinoids. It is fractured, usually normal to bedding (Plate VIII). Scattered stylolites, containing black residue, roughly parallel to bedding are also in evidence. Cores also show the presence of anhydrite nodules (Plate VII) along with tabular crystals of gypsum lining many of the vugs.

The afore-mentioned brecciation occurred in zones at various intervals within the Dundee unit. A single breccia zone is diagrammatically represented on the following page.

The Dundee breccia zones are much like those referred to by Beales and Oldershaw (1969). A series of photographs were taken from a 2.7 foot interval in the White Est. #1 core to substantiate this similarity.

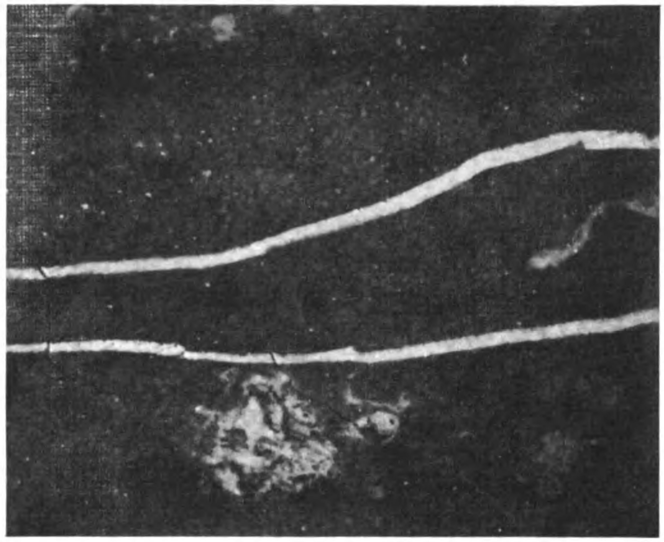
The bedded sequence and the breccia molds are outlined with white in the photographs on pages 12, 13, 14, 15, and 16. The breccia molds range in size from 4.0 to 0.5 centimeters. The matrix is a dark, finely crystalline dolomite. Clasts are lighter colored, and



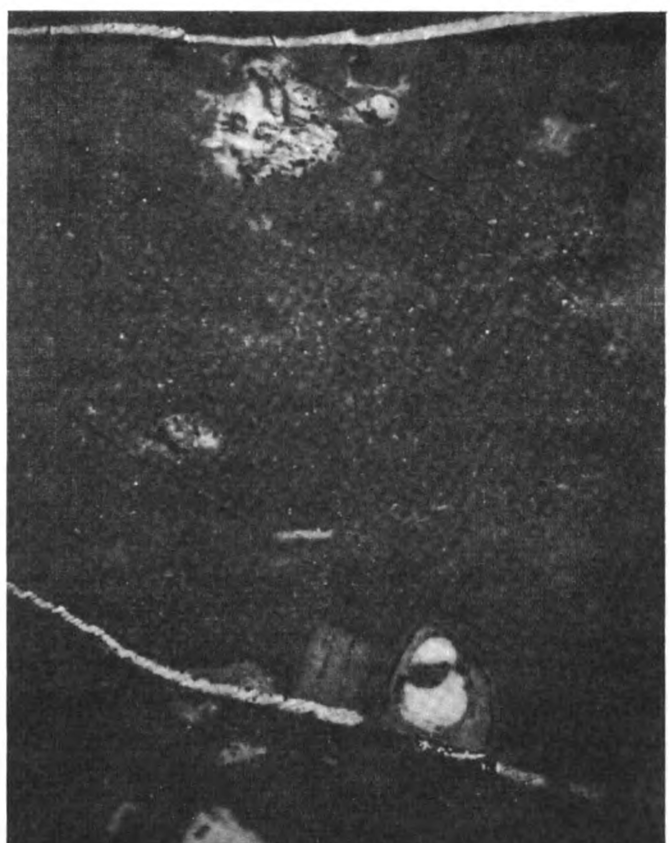
generally, a slightly coarser, crystalline dolomite. Due to their similarity to the matrix lithology and uniform recrystallization, the individual clasts are generally difficult to recognize. It is immediately apparent from Plates I, II, III, IV and V that the top beds are relatively flat lying and that the fragments generally begin to slump lower in the section (Plate III). Plate III also shows a brecciated breccia fragment. The size of the fragments becomes smaller at the base of the breccia

Plate I

Figure A and B indicate the upper part of a single breccia zone showing the laminae outlined in white.



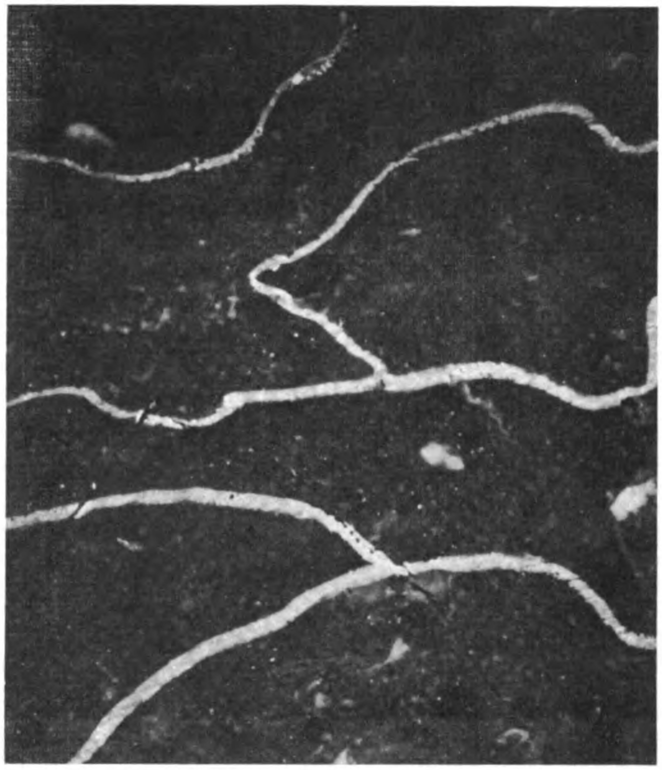
¼x Fig. A



¼x Fig. B

Plate II

Figure A and B show the larger clasts, outlined in white. These clasts are beneath the laminae.



¼x Fig. A

¼x Fig. B

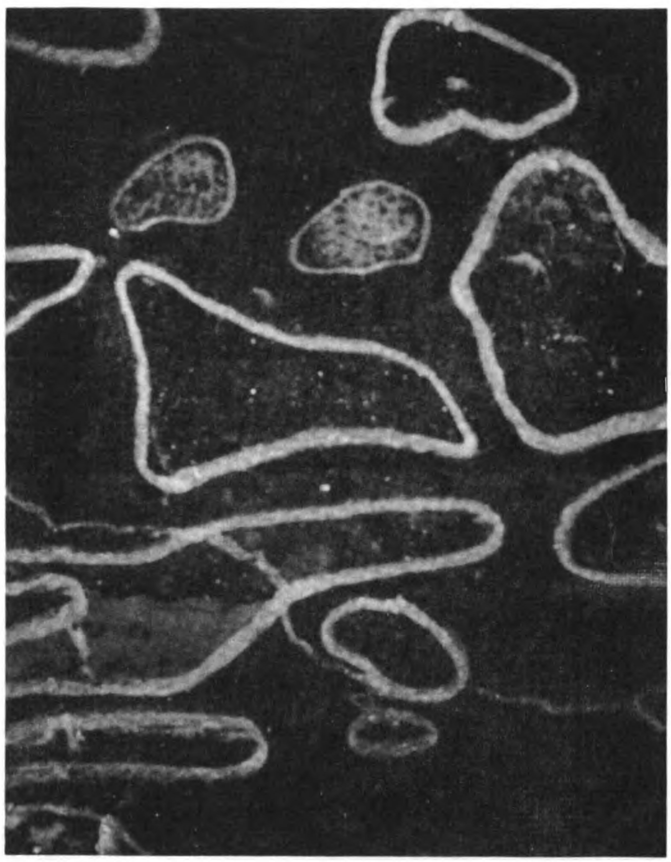
Plate III

This plate shows the clasts in the breccia "zone" as they begin to slump. Note the large fossil clast, as well as the brecciated breccia fragment.

¼X

Plate IV

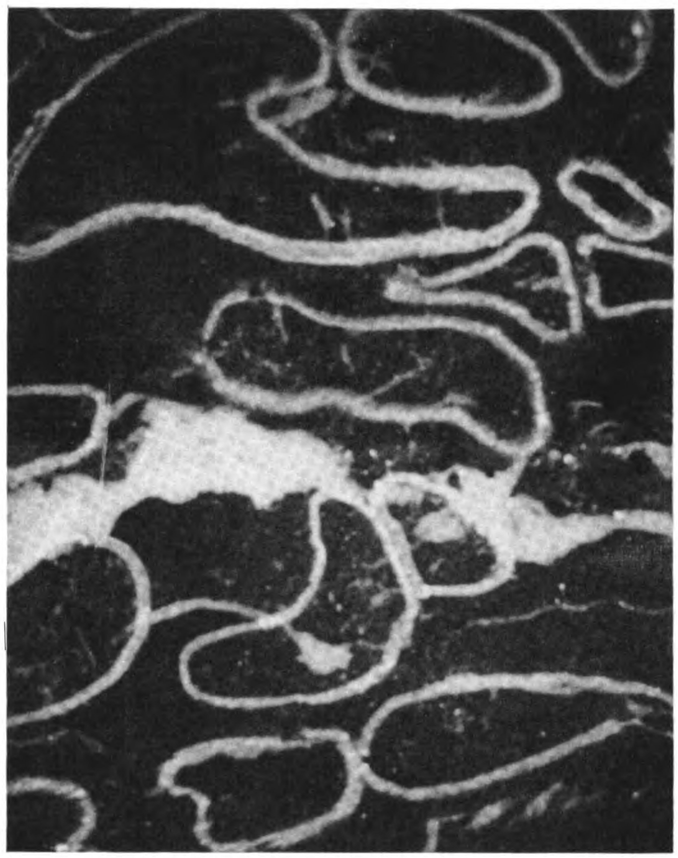
This plate shows the beginning of the decrease in size of the clasts.



$\frac{1}{4}$X

Plate V

This plate shows the smallest breccia clasts at the base of the breccia "zone". Note the white dolomite vein that crosses the zone.



¼X

section. Presumably this is the zone that Beales and Oldershaw (1969) called a solution breccia. This breccia may have formed from the solution of an evaporite or possibly a calcite bed or both, which occupied the space immediately below what is now seen as the brecciated zone. Overlying rock subsided, slumped, or caved into the void caused by solution. The smaller fragments in the basal part of the breccia zone probably broke off from the overlying rock first. As the caving continued these fragments in the base of the void would be broken up and rounded even more. Beales and Oldershaw (1969) point out five characteristics that support a solution origin for the breccias that they studied:

1. the repetition of angular breccia-moldic porosity in beds
2. the complex dolomitization of the box-work texture and intervening strata
3. the local sag and collapse of some layers
4. the restricted variety of the faunal content
5. the presence of brecciated breccia fragments (suggestive of repeated precipitation and solution)

The Dundee breccia falls closely within the first four of these five characteristics. The writer noted only one brecciated-breccia fragment within this zone (Plate III).

The Dundee interval shows five types of porosity in the mid-basin area of the Southern Peninsula. Geologists have recognized in several Dundee wells angular vugs, which are often lined with white dolomite crystals. The writer suggests that this type of porosity is the result of the selective solution of breccia clasts mentioned previously. The more coarsely crystalline clasts appear to be more porous, making them susceptible to this differential selective solution (Plate II, Figure B). It should also be noted that some of these clasts are actually fossils or fossil fragments (Plate III). Many of these brecciated fossils have the initial porosity which favors solution. The pin point porosity observed within the White Est. #1 core also appears to be a product of the differential solution of these breccia clasts. In Plate VI, Figure A the zones of pin point porosity are outlined in white. Consistent with the writer's observations Deffeyes, et al. (1964) pointed out that in pelleted lime muds the pores are intergranular whereas in the dolomitized equivalent the sand size pellets and shells are commonly differentially leached to form vuggy porosity.

Another common origin of porosity in Dundee rocks is the solution of fossils inherent within the interval (Plate VI, Figure B). The solution of these fossils leaves

Plate VI

Figure A shows a zone of pin point porosity. Figure B shows porosity by fossil solution.

¼x Fig. A

¼x Fig. B

vugs of various sizes and shapes. The vug in Plate VI, Figure B is rounded and about 1.5 centimeters in diameter.

Solution of anhydrite nodules is still another type of porosity recognized in the Dundee. Plate VII shows a circular white anhydrite nodule that is 2 centimeters in diameter. Below it is a golf-ball size vug that the writer believes is the result of the dissolution of such a nodule. The writer bases this conclusion on the proximity of the vug to the nodule, as well as the vug's size and circular shape.

Replacement anhydrite in itself neither creates nor destroys porosity unless, as is quite common, earlier interparticle, intercrystalline, or vuggy void spaces are engulfed by a solid replacement crystal. However, replacement anhydrite is commonly dissolved later to produce anhydrite mold vugs (Murray, 1964).

Fractures present in the Dundee are also avenues of migrating brines and/or hydrocarbons. These fractures are secondary and probably structurally controlled. White crystalline dolomite frequently forms along these fractures (Plate VIII).

Most of the porosity at or near the top of the Dundee is thought to be due to waters percolating through the rock during a period of emergence. Solution of the limestone was not uniform; in some places the uppermost Dundee is honeycombed and in other places it is only

Plate VII

This plate shows an anhydrite nodule, along with a vug that resulted from the solution of such a nodule.

¼X

Plate VIII

This plate shows a typical fracture pattern in the Dundee.

¼X

slightly leached. In most places the initial porosity in the uppermost few feet of the Dundee was increased several fold at the time of leaching. Here and there within the Dundee interval, layers of greatest susceptibility, probably those with enough initial permeability to permit percolation, are several feet beneath the Bell shale. In this case the principal reservoir is there instead of at the top, directly beneath the shale seal. This lower zone of porosity in the Dundee is localized. Investigation has shown that this zone was very fossiliferous, which might account for the porosity. It seems evident that the fossil content of the basal Dundee decreases. This may be due to the saline environment at the close of Detroit River time.

Some of the possible mechanisms causing the leaching of the Dundee have been pondered:

1. Subaerial exposure and descending ground water prior to the deposition of the Bell shale.
2. Refluxion of hypersaline brines prior to the deposition of the Bell shale. In this instance leaching would had to have been contemporaneous with dolomitization.
3. Hydrothermal solutions which originated lower in the geologic column and migrated upward along fractures. These solutions would have been dispersed along the Bell shale-Dundee

interface. These solutions may have contributed to some dolomitization within the Dundee unit.

4. Flow of ground water at the interface of the Bell shale and the Dundee, as well as ground water flow along permeable avenues within the Dundee unit.

Since the best Dundee porosity is concentrated in the upper few feet of the interval, the writer favors mechanism (1). Each of the remaining mechanisms could have contributed to the porosity independently or in conjunction with any or all of the others.

CHAPTER III

HISTORICAL RÉSUMÉ OF DOLOMITE

Large amounts of petroleum have been and will continue to be produced from dolomitic strata in Michigan. A maximum of triumphs and a minimum of trials require that we learn as much as possible about the conditions under which these strata were deposited. These conditions had an effect on the formation, migration, and accumulation of petroleum in the subsurface reservoirs with which the state has been endowed.

The mineral dolomite has been known as such since 1779 when Arduino named it in honor of the French chemist Dolomieu (Siegel, 1961). Arduino made the first attempt to explain the formation of "magnesium limestones." He attributed these rocks to the pneumatalytic alteration of pre-existing calcite limestones in an area of volcanic activity. In 1916 Van Tuyl published an excellent review of the dolomite problem. He treated most of the theoretical possibilities with equal care, including some of the features of the scheme now accepted by most geologists.

Although much has been written about the origin of dolomite, only a brief résumé of the history and present status of the problem, specifically related to the Dundee, will be given here.

The terms primary and secondary are most often employed to signify the suspected genesis of any dolomite. Primary implies that the dolomite in question has been laid down as such without alteration (Fairbridge, 1957):

1. as a straight-out chemical precipitate
2. as an organic secretion
3. as a clastic accumulation

Regarding case (2), there is no evidence in favor of a direct organic source of dolomite, but there is plenty of evidence in favor of organically precipitated magnesium-rich calcite (Fairbridge, 1957). For case (3) there is no problem, since dolomite sands and breccias presuppose an earlier dolomite. Thus, a clastic dolomite is not really primary at all, but a detrital rock (Sander, 1951); Rodgers, 1954). As for case (1), evidence indicates that although many theories have been proposed to explain the formation of particular dolomites, it has never been demonstrated unequivocally to have been precipitated in nature directly from solution, nor has dolomite ever been formed in the laboratory under simulated sedimentary conditions (Krauskopf, 1967).

Secondary is a term covering all other forms of dolomite genesis. For the marine realm, it may cover all dolomites. Within its scope, these are all the "metasomatic" or "diagenetic" and "epigene" dolomites, alternatively "replacement" and "leached" dolomites. The "metasomatic," "diagenetic," or "replacement" classes may be subdivided further into the "contemporaneous," "penecontemporaneous," and "subsequent" types. With a reasonably slow rate of accumulation, i.e., the time element, replacement can take place directly on the sea floor (Goldich and Parmelee, 1947).

Diagenetic dolomites can be found in the form of layers or lenses with obscure stratification. They have slight porosity and fine-grained texture with xenoblastic grains of irregular form, which are filled with dust-like inclusions. Relict structure is commonly evident, and the fauna ordinarily remains in the form of molds (Chilingar, 1956). The epigenetic dolomites result from alteration of completely lithified limestones by downward percolating meteoric solutions or rising hydrothermal solutions. Epigenetic dolomites are cavernous, having obscure stratification, patchy distribution, non-uniform grain size, and relict structure. Chilingar (1956) noted that "the Ca/Mg ratio of epigenetic dolomites varies widely over short distances, both vertically and horizontally."

Although there is little agreement as to the mechanics of secondary dolomitization, there is general agreement that the parameters involve ph, salinity and temperature. One particular mechanism for dolomitization of limestone advanced by Adams and Rhodes (1960) is of particular interest to the writer, since it can be applied to the Dundee. Their hypothesis of seepage refluxion has been well received and appears to explain a fair quantity of dolomite in the geologic record. According to this hypothesis, loss of water by evaporation lowers the water level in a marine lagoon, thereby increasing the concentration and specific gravity of the remaining brine. The heavier brine sinks and migrates into the lowest depressions in the sedimentary basin. These highly concentrated brines are chemically potent solutions with a temperature near 35°C, a pH of 9.0 or higher, and have nearly neutral redox potentials. The Mg/Ca ratio is much higher than normal sea water. This refluxing hypersaline brine is much denser than the connate water in the limestone substrate and displaces it, migrating down through the limestone. The limestone is dolomitized by this hypersaline solution. Dolomitization is terminated as these solutions lose magnesium and gain calcium, thus reducing the Mg/Ca ratio of the primary brine. Loss of heat to the cooler limestone, and lowering of the ph by CO_2 in connate water also helps to end the dolomitization.

CHAPTER IV

DEPOSITIONAL MODEL

The abundance and widespread distribution of major sedimentary dolomites indicate that these rocks are likely products of a common, relatively simple natural process. In order for a limestone to become dolomitized, the following requirements must be fulfilled (Deffeyes, *et al.*, 1964):

1. A water having a Mg/Ca ratio larger than the ratio that would be in equilibrium with both calcite and dolomite must be available.
2. This water must flow through the limestone, because magnesium transport by diffusion is inadequate to explain most dolomite occurrences.
3. The rate of production and flow of the high-magnesium water must be adequate to dolomitize the rock in the time available.

A discussion of the chemical processes involved in displacing the calcium by magnesium is beyond the scope of this study. The other problems are essentially geological and yield to geological analyses.

For the most part geologists agree that the Middle Devonian sediments of Michigan are a part of a typical evaporite cycle. Krumbein and Sloss (1963) point out that black shales or siltstones, as in the Middle Devonian of the Michigan Basin, may intervene between the normal marine and penesaline stages. The ideal evaporite cycle as applied to Michigan's Middle Devonian by the writer is:

NORMAL MARINE	Traverse Group
Bell Shale	
PENASALINE	Dundee formation
SALINE	Upper Detroit River
PENESALINE	Lower Detroit River Lucas formation

The normal marine state is characterized by biomicrites and other fossiliferous limestones indicative of open circulating marine waters. The penesaline stage includes finely laminated dolomitic micrites often interbedded with anhydrite and dolomite, with anhydrite replacements and vug fillings. The saline stage begins with massive anhydrite beds and progresses upward to intercalaticns of salt and anhydrite. Following the recession of the late Silurian sea from the basin, there was a period during which no great amounts of sediment were deposited, or if deposited, they were subsequently removed by erosion (Cohee, 1965). The Devonian Period was especially a time of sea transgressions and regressions. The Dundee was deposited in the latter part of Middle Devonian time when the basin was not isolated (Cohee, 1965).

Based on the writer's observations, he proposes that the central-basin Dundee was deposited in a somewhat restricted supratidal environment. Further, it is believed that the Dundee is not time equivalent. As the Dundee sea transgressed and regressed, the supratidal zone migrated accordingly. Since this supratidal flat was only awash during spring tides and storm conditions, limestones accumulated more slowly and were denser than those forming on the rapidly growing modern oceanic banks. These limestones were reworked giving the section its clastic appearance and also fossil orientation. Sorting is fair to poor but locally, where currents were strong enough, the sorting is good. Other criteria suggesting a supratidal environment during Dundee time are burrows as well as evidence of calcitic mudcracks. Examination of the core further shows the presence of rill channels, which are consistent with the environmental interpretation given here.

Two "lows" on the east were probably the major avenues for the storm tides as they encroached upon the supratidal zone. The isopach map (Figure 2) reflects the position of these supratidal inlets. One inlet suggested in the vicinity of Saginaw Bay was also considered an inlet by Briggs (1958) and by Briggs and Pollack (1968) during upper Silurian (Salina) evaporite sedimentation. The other, the Chatham Sag, is located southeast of Michigan. The influence of this structure was noted by Fettke (1948) in the Ordovician and by Briggs (1958) and Majedi (1968) in the upper Silurian and middle Devonian.

The supratidal zone was irregular, with large pools of water trapped in the lower areas. This irregular surface at the end of Dundee deposition explains the diastem and the local zones of transition between the Dundee and the Bell shale. Those areas that were under water show a thin zone of transition between the carbonate and the shale, while the mounds exposed to air yield a diastem horizon.

The material supplied from the various sources is reworked by the tides and organisms inherent in the sediment. This reworking is characterized in the deposit by the occasional presence of streaky and irregular bedding. The principal source of material was wave cut off shore, as well as shore zone sediment. The color of sediments is variable but generally dark due mostly to intercrystalline oil stain. Reducing conditions that existed a few feet below the depositional surface, along with fecal deposition, further contributed to the darker color.

In a supratidal area the ground water flow would be very close to the surface. Presumably, this ground water flow was the mechanism causing the solution breccias mentioned previously and some of the early porosity.

A model for dolomitization by seepage refluxion was published by Adams and Rhodes (1960), which the writer has applied in this study. As the supratidal zone was subject to long periods of subaerial exposure, evaporation would have played a significant role. Evaporation takes place from the capillary water held in the exposed sediment. As a result, gypsum is precipitated in these supratidal sediments. The initially precipitated gypsum would be changed to anhydrite as a result of increased heat and pressure after burial. The hypersaline brines that are produced eventually become heavy enough to displace the connate water and reflux slowly downward through the slightly permeable carbonates of the supratidal deposits. The writer suggests that the proposed supratidal flat was somewhat isolated by a barrier on the east, giving the zone a very shallow saucer shape. This explains why the brines would have migrated to the center producing the dolomite configuration in the basin, as we see it today (Figure 1). Water flowing in from the open ocean as well as fresh water replaces that lost by refluxion and evaporation. Circulation is maintained by this influx of sea water and the outflow of fresh water from cratonal streams.

Typical hypersaline water contains about 0.25, 0.01 and 0.002 molecule of Mg^{2+}, Ca^{2+}, and total CO_2 per kilogram of solution, respectively. It thus contains one hundred times as much magnesium ion as total CO_2 carbon. Weyl (1960) has shown that such waters should dolomitize by utilizing the carbonate in the limestone and replacing half its calcium with magnesium. The hypersaline reflux mechanism combines a source of high-magnesium water with a natural driving force to move this water through the sediments. The only environmental requirements necessary are a seasonally or fairly continuous dry climate, so that evaporation may exceed precipitation, and a nearly flat sediment surface near sea level to provide a supratidal environment of sufficient areal extent. Although the evidence does not prove unequivocally that the Dundee was dolomitized by this proposed mechanism, the writer suggests that the mechanism was adequate for the time available. It should be pointed out that seepage refluxion is probably not the cause of all the mid-basin Dundee dolomitization. Another probable mechanism responsible, in part, for the dolomitization is the upward migration of hydrothermal solutions along fracture patterns. The North Adams field in Arenac County and the Pinconning field in Bay County are examples of a Dundee limestone that has been dolomitized by such a mechanism.

There is no uniform shape to a supratidal flat. Thicknesses of sediment vary with the rate of subsidence in the area. The best chance for preservation is where there is rapid subsidence and/or rapid transgression over the tidal flat covering the flat with marine shales or muds, i.e., the Bell shale. This appears to be the most common relationship in preserved such flats.

CHAPTER V

STRUCTURE AND THICKNESS

Structure contours at the top of the Dundee interval show more than 3,000 feet of relief (Figure 3). The structure contour map further shows an average regional dip of approximately 35 feet per mile. The dominant structural trends in the central basin area are generally northwest-southeast, whereas around the margin of the basin, trends in other directions are noted. These marginal trends appear to be somewhat radial. The "radial structures" are not in evidence on the isopach map (Figure 4) indicating that they were probably post-Dundee in origin. Similar "radial-like" structures were pointed out by Asseez (1967) in the lower Mississippian.

An intrabasinal system of gentle folds has a relief ranging from a few tens to a few hundred feet, and the northwest-southeast trends parallel the axis of the slightly ovate basin (Cohee, 1945). The age of the folding is not entirely clear. Pirtle (1932) believed that the folds originated early in basin development and were controlled by fold trends or structural weakness within the basement rocks. He suggested that folding continued during successive periods of geologic history and that compression was most intense in post-middle Mississippian time. The structural traps were formed, or at least enhanced, at this time. Jodry (1957) described evidence for a probable pre-Devonian tectonic fabric with essentially no relation to the post-Mississippian basin folds. He concluded that although the older fabric is not readily apparent in the Devonian rocks, it affected the environment in which the Traverse Group and older sediments were deposited. Conspicuous faults appear to be scarce, and the central basin area lacks the lithologic and tectonic complexities known to characterize the basin margins.

The Howell anticline, the major anticlinal fold in the basin, extends northwest-southeast through Livingston County into Shiawassee County. There is no isopach evidence for the Howell anticline during Dundee time. It was undoubtedly structurally formed earlier, but during Dundee it was ironed out by sedimentation. Newcombe (1933) described faulting on the west flank of the Howell anticline, which he pointed out as being responsible for displacement of beds on its southwest flank. Ells (1969) showed the structural development of the Howell anticline at different stages from the Ordovician to lower Mississippian, including the Dundee.

The deepest part of the Dundee structure conforms to the present structural basin. The Dundee isopach shows a thickness in excess of 400 feet in the Saginaw Bay area, which suggests this area was structurally low at the time of deposition. Cross Sections 1 and 2 further show basinal thickening of the Dundee. In addition, Cross Section 1 shows "local" basinal structure in the Saginaw Bay area.

The irregular distribution of Dundee rocks is apparent upon initial observation of the isopach map. However, there is an indication of lineation from Livingston County northwest through Shiawassee, Gratict, on up into Missaukee County. The interval is absent in the extreme southwestern part of the state, and in most of western Michigan it is less than 100 feet thick. Thinning suggests the configuration of the basin changed from time to time during Dundee deposition. Dr. J. H. Fisher (1969) published a series of maps showing how the depocenter of the basin migrated in Paleozoic time. During the Ordovician he showed the depocenter northeast of the Saginaw Bay area, with a shallow extension to the northeast across Manitoulin Island. In Silurian-Salina time the depocenter was near the southwest end of Saginaw Bay. An isopach of total Devonian sedimentation shows the depocenter northwest of Saginaw Bay, while the writer's Dundee isopach shows the depocenter conforming closely with Saginaw Bay. Comparing Fisher's (1969) complete Devonian isopach with the writer's Dundee isopach, one sees how the depocenter migrated within the Devonian period.

Periods of non-deposition and the presence of broad structural features during Dundee time are also possible explanations for the thinning.

CHAPTER VI

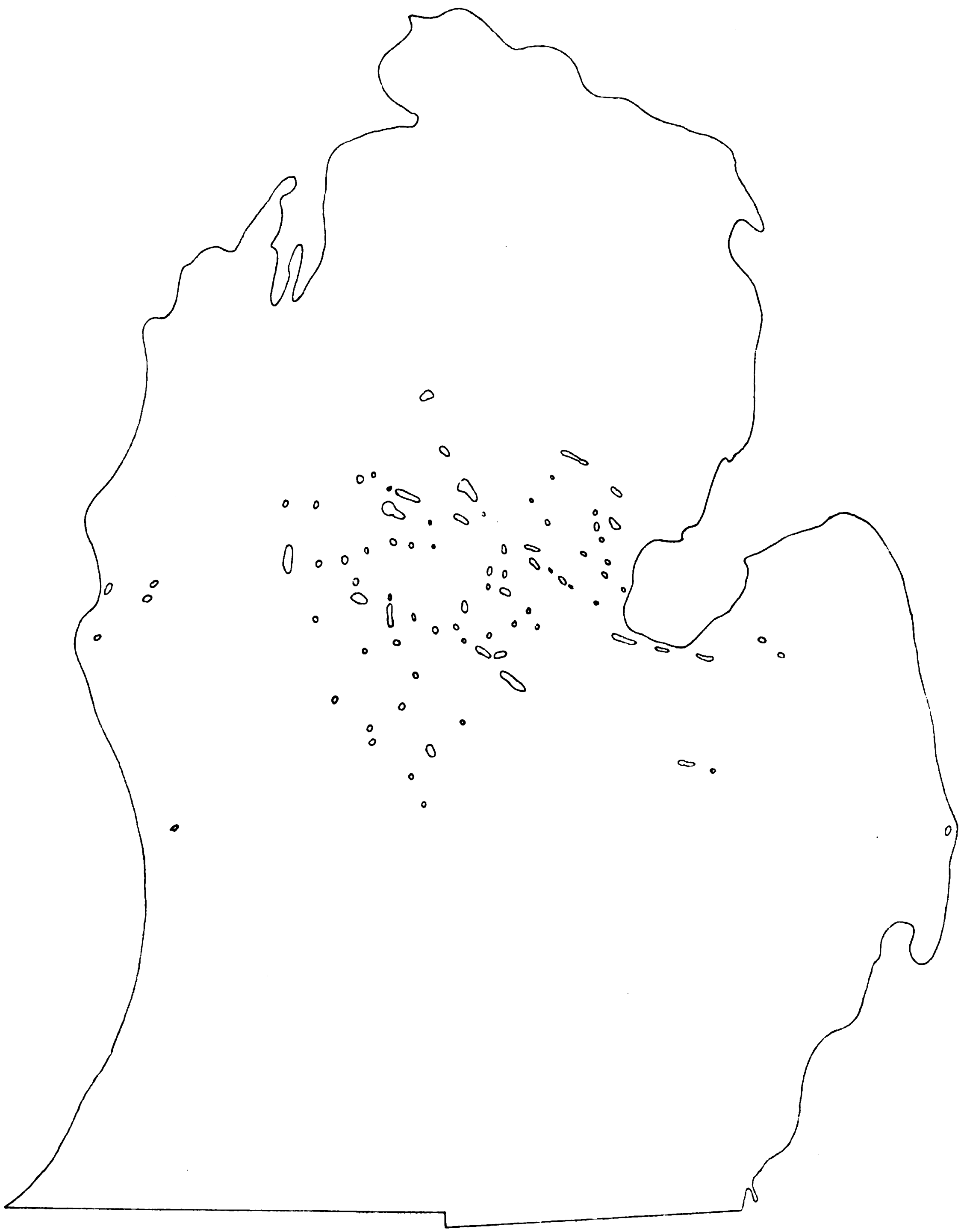
DUNDEE PRODUCTION

Oil production in the Michigan Basin began at Petrolia, Ontario, in 1858; but production in volume began with the discovery of the Muskegon field on the west side of the basin and the Mt. Pleasant field near the center of the basin in 1928. Since that time more than 200 oil fields and more than 100 gas fields have been discovered in the basin. According to figures published by the Michigan Geological Survey, the Dundee interval through 1967 has produced over 325 million barrels of oil and 49 billion cubic feet of gas. Even though Dundee production has decreased since 1947, it still leads all other Michigan formations in the production of hydrocarbons. This decrease in Dundee yield may be due to a lesser heritage of hydrocarbons per cubic mile of sediment or because the production is from carbonate with erratic porosity. Geophysical exploration is made difficult by the thick cover of glacial overburden. In any event exploration techniques are not at present able to reverse the downward trend of Dundee production.

Oil and gas in the Dundee occurs in anticlinal folds, and along the flanks, in zones of secondary porosity in the upper part and in zones of initial porosity lower in the section. The greatest production is from well developed zones of secondary porosity that are generally lenticular and are two to twenty feet thick. Wells from zones of initial porosity have low initial yields and low total recoveries. Most of the oil produced in the central part of the basin is from the Detroit River and Dundee rocks. Figure 2 shows the distribution of Dundee production within the basin.

The source of the Dundee hydrocarbons has been of interest to petroleum geologists. The most apparent source of the oil appears to be from the overlying black, organic Bell shale. It is believed that as this overlying shale was compacted, the hydrocarbons were squeezed downward into the porous zones of the Dundee. It is also known that there is very little Dundee production in the western part of the state where the Bell shale is absent. Here production apparently comes from lower permeable zones within the Dundee referred to earlier. This could be due to a lack of source rock or simply a lack of an effective seal. The writer believes that it is equally probable that the source of the hydrocarbons is from within the Dundee interval itself. From information gathered in the core it is evident that the Dundee contains abundant organic material, and that in the areas studied it contains intercrystalline oil stain throughout the interval. This stain is so persistent within the core, that it appears logical to the writer that migration from without the Dundee could not account for all of it. However, early pre-consolidation migration from some source outside the Dundee could place intercrystalline oil throughout the Dundee. The writer is not able to state that the one source is predominant over the other; he does believe that both contributed significantly to the Dundee reservoir. It is probable that migration from within the Dundee was early, while migration from the overlying Bell shale came much later after Dundee lithification.

The Dundee is primarily a limestone deposit that has undergone dolomitization locally. It is from these dolomites that the majority of Dundee oil is produced. Probably much undiscovered oil is contained in Michigan rocks of this type. Allegedly "dry" domes, tested by one or two wells near the crest, may contain oil in a belt of local dolomitization porosity on the flanks. It is suggested that in regions where oil is known to occur in reservoirs of this type, the exploration not be confined to the tops of the anticlines, and that the samples be analyzed for $MgCO_3$ content. A dry hole in which the limestone samples contain more than an average amount of $MgCO_3$ should encourage exploration laterally in the hope of finding true dolomite.



DISTRIBUTION OF DUNDEE OIL & GAS FIELDS

PRODUCING AND ABANDONED - 1967

SCALE: 0 6 12 MILES

FIG. 2

CHAPTER VII

CONCLUSIONS

The close of Dundee time was marked by the deposition of the Bell shale by a transgressing sea from the east.

From the maps prepared and from the data obtained by analyzing the Dundee rocks in the mid-basin, certain conclusions may be drawn:

1. The Dundee is a clastic, in places brecciated, burrowed, brown to black, petroliferous, locally dolomitized limestone.
2. Porosity within the Dundee is secondary but is not related to the chemical process of dolomitization.
3. Fossils, evaporites, mudcracks, solution breccias, rill channels and reworked sediments all suggest a supratidal depositional environment.
4. The structure contour map shows the Dundee to have a concentric-ovate distribution, with northwest-southeast trending intrabasinal structure.
5. The isopach contour map shows an irregular Dundee distribution, with the thickest

accumulation in the Midland and Bay County areas.

6. The major mechanism for Dundee dolomitization was seepage refluxion of hypersaline brines.

In these supratidal sediments no one sedimentary process or fabric is exclusively diagnostic. Fortunately there are many diverse fabrics which as a group indicate the distinctive aspect of the environment. The quality of any one of these as a potential reservoir rock depends on continuity of a porous matrix. At any one time and locality supratidal sediments of one fabric type may be fairly continuous but more commonly they are interrupted by the formation of other impinging supratidal fabrics, by meandering channels, and by irregular low-profile topography (Roehl, 1967).

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APPENDIX

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
ALCONA					
22-26N-9E	William Atchinson #1	721	874	1159	497
20-27N-8E	State Hawes #1	900	675	1085	428
23-27N-9E	Edwin S. York, *et al.* #1	760	598	810	212
27-27N-6E	Quart #1	870	1145	1407	262
ALLEGAN					
17-3N-11W	Herman Edwards, *et al.* #2	800.5	1194.5	1229.5	35
28-3N-15W	Keith Bushee #1	709.5	882.5	920.5	38
ALPENA					
9-29N-5E	Turtle Lake Club #1	884	538	766	228
5-31N-9E	Ford Motor Co. #1-5	684	+380	+184	196
ARENAC					
11-18N-4E	M.C. Grashaw #1A	625	2065	--	--
5-19N-3E	State-Adams #A-1	767	2191	--	--
26-19N-3E	Hasty G-1	740	2104	--	--
16-19N-4E	Josephine Kozira #1	738	2017	--	--
5-20N-4E	Metzgar #3	819	1643	--	--
26-20N-7E	Van Horn #1	610	2647	--	--

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
BARRY					
23-1N-7W	Ernest Farley #1	848	1125	1157	32
17-1N-8W	Mary Puttman #1	979	1111	1146	35
3-4N-8W	Greta McClellan #1	869	1568	1604	36
20-4N-8W	J. M. Allerding #1	850	1483	1525	42
34-4N-10W	Jack Janose #1	781	1344	1386	42
20-4N-7W	Schaibly #1	869	1573	1606	33
BAY					
19-14N-3E	C. L. Duel #1	661	2985	--	--
1-14N-4E	Kaiser #5	587	2138	--	--
BERRIEN					
1-6S-19W	Schlutt #1	645.5	--	53.5	--
CALHOUN					
27-1S-5W	Donald E. Cushman #1	951	986	1182	196
14-3S-4W	Radee, *et al.* #1	1019.5	815.5	863.5	48
CASS					
14-6S-14W	Fancheon Kimmich #1	912	468	--	--
CHARLEVOIX					
7-32N-4W	Romaniak #1	833	167	257	90

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
CHEBOYGAN					
11-33N-1W	State-Nunda #A-1	834	218	311	93
1-33N-2W	Lewis A. Garred #1	783	177	267	90
CLARE					
6-17N-4W	J.D. & D.D. McKay	956	2933	3189	256
21-20N-4W	Mary Yake #1	1211	2821	2979	158
8-20N-5W	Francis T. Amstutz, *et al.* #1	1099	2678	2966	288
CLINTON					
27-7N-1W	Fickies #1	773	1972	2077	105
13-7N-2W	Henning #1	754	2043	2149	106
26-8N-2W	N.R. Irrer #1	716	2105	2219	114
35-8N-4W	Fred Watts #1	738.5	2189.5	--	--
CRAWFORD					
6-25N-3W	State Beaver Creek #1	1262	1942	2238	296
20-26N-2W	B. McClintic Trustee #1	1186.5	1903.5	2165.5	262
28-27N-1W	Consumers Lovell #1	1076	1629	1794	165
EATON					
2-1N-6W	Palmer-Miller Comm. #1	935	1155	1270	115

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
GENESEE					
29-6N-7E	Elmer A. Everson #1	850	1267	1478	211
12-6N-8E	E. J. Coffee #1	915	1231	1445	214
4-9N-8E	Hutchinson #1	827	1633	1868	235
GLADWIN					
19-17N-2W	State Beaverton #a-2	748.5	3096.5	3362.5	266
15-18N-1E	Heil #1	713.2	2331.8	--	--
6-18N-1W	S.I.Briggs #1	733.6	2979.3	--	--
36-18N-1W	McMahon #1	728.5	2757.4	2094.5	337.1
4-18N-2W	J.E. Mills #1	842	2976	3260	284
14-18N-2W	James A. Ogg B #1	793	2937	3204	267
19-18N-2W	Consumers and Bonninghausen #1	743	3002	--	--
30-19N-2W	J. Watson #1	888	2897	3177	280
16-20N-1E	State-Clement #A-1	817	27270	--	--
GRAND TRAVERSE					
9-25N-10W	Reu J. Lemcool	1101	1494	1691	197
GRATIOT					
23-10N-2W	Chester Cowdrey #1	705	2375	--	--
13-11N-3W	Melvin Gearig #1	769	2493	--	--

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
HILLSDALE					
20-5S-1W	Harry Alley #1	1128	542	--	--
34-5S-1W	Robertson #1	1113	552	--	--
19-5S-2W	Dallas Finegan #1	1118	462	--	--
HURON					
10-15N-10E	Andrew J. & Eliz. I Szidik #1	639	2117	2321	204
36-16N-12E	C. P. Scott #1	750	1870	2200	330
36-17N-10E	Schulze #1	625.5	2200	2480	280
INGHAM					
13-1N-2E	Dave Basore #1	963	752	830	78
16-2N-2W	F. W. Harkness #1	902	1525	1566	41
33-3N-1W	Nelson Whipple #1	915	1598	1660	62
IONIA					
15-5N-7W	Wildman #1	857	1708	1738	30
4-6N-8W	C. E. Burtle #1	707	1883	1908	25
IOSCO					
29-21N-5E	Erickson #1	763	2409	2667	258
20-21N-6E	Natl. Gypsum Co. #1	646.5	2488.5	2773.5	285
28-23N-5E	Mott #1	863.5	2276.5	2620.5	344

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
ISABELLA					
2-14N-3W	State Isabella B-4	728	2787	--	--
17-14N-5W	E.E. Courser & M.S. Wardrop #1	878	2772	2997	225
1-14N-6W	Herman Cook et us Unit A-1	876.5	2753.5	--	--
25-14N-6W	R.O. Rendell, *et al.* #1	984	2741	2937	196
23-15N-6W	Woodin & Forbes #1	927.5	2777.5	--	--
30-15N-6W	H.R. & L.A. Latham, *et al.* #1	1033	2744	--	--
17-16N-3W	Northwise Unit-Tract Well #2W	5794	2866	--	--
26-16N-5W	O'Rourke #1	896.5	3003.5	--	--
JACKSON					
14-1S-3W	Schultz-Canull Comm. #1	934	1161	1211	50
36-1S-3W	Campbell #1	1019.5	1155.5	1212.5	57
27-2S-2W	Reardon #1	976	989	1039	50
26-2S-3W	McConkey #1	963	917	962	45
32-3S-1W	Herman Gumper #1	983	812	--	--
19-4S-1W	Gumper #1	1136	514	564	50
9-4S-2E	Albert Baylis #1	963	742	817	75
5-4S-2W	Ford #1	1023	677	727	50
28-4S-3W	Dawson #2	1066	539	599	60

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
KALKASKA					
10-25N-8W	State-Springfield #1	1123	1992	2235	243
29-27N-5W	Ten Point Club #1	1176	1604	1769	175
11-28N-6W	State-Cold Springs #1	1271	1361	1559	373
KENT					
12-6N-9W	Leg #4	620	1765	1800	35
35-8N-9W	George Francisco #1	860	1970	2000	30
9-10N-11W	Free #1	907	1993	2083	90
LAKE					
5-19N-13W	USA #1	867	2008	2098	90
14-19N-13W	State-Peacock #1	874	2041	2138	97
30-20N-12W	State Newark #1	977	2111	2203	92
LAPEER					
6-6N-12E	Edward Ulatowski #1	841	977	1108	131
17-6N-12E	John Braidwood #1	913	902	1070	168
14-7N-11#	Bagley #1	926	1154	1321	167
10-8N-9E	Irving Thom #GG-1	790	1570	1672	102
6-8N-10E	State Mayfield #1	839	1536	1731	195
1-9N-10E	Andrew Roseltha Mathews #1	797	1631	1845	214

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
LAPEER cont.					
17-10N-10E	Theodore B. & Ann B. Lyon #1	827.5	1630.5	1895.5	265
28-10N-10E	Homer Nowlin #1	780	1603	1841	238
21-9N-11E	Wilder #1	824	1496	1695	199
LEELANAU					
6-30N-11W	Kirt #1	913	392	487	95
LIVINGSTON					
35-3N-4E	Martin J. McPherson #1	942	78	178	100
MACOMB					
10-3N-14E	Max & Helen Henning State #1	598	202	382	180
29-4N-13E	W. Payne-D. Gray #1	655	505	620	115
36-4N-14E	John Siefert #1	619	279	406	127
36-5N-12E	M.E. Lanphar & Co.	757	578	678	100
8-5N-13E	Ward #1	777	658	813	155
MANISTEE					
13-21N-17W	Joseph Gambs #1	606	994	1129	135
8-24N-13W	Robert & Cecelia Northrup, et al. #1	896	1344	1479	135
10-24N-14W	Consumers Power Co. #1	758	1134	1287	153

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
MASON					
9-17N-15W	Healey #1	708	1770	1937	167
7-18N-17W	Disposal Well #40	649	1401	1531	130
14-18N-17W	Jacobson #3	694.5	1523.5	1671.5	148
20-19N-17W	Paul P. Timby #1	678	1367	1497	130
MECOSTA					
2-13N-10W	Clare & Margret Whipple #1	968	2387	--	--
8-13N-10W	Wm. H. & Orpha P. Finch #1	929	2316	--	--
36-14N-8W	G. Delong #1	1025	2630	--	--
3-15N-7W	H.C. Phillips #1	1015	2810	--	--
23-15N-8W	R. Darling #1	1056	2694	--	--
9-15N-9W	W. Flanders & F. Wilkins, et al. #1	958	2477	--	--
2-16N-8W	Elgin Denslow #1	1177	2733	2873	140
13-16N-10W	Adair #3	1020	2459	--	--
MIDLAND					
12-13N-1E	Brine #56	644.9	2885.1	3210.1	325
21-13N-1W	Merton Emery #1	683.7	2679.3	3020.3	344
7-13N-2E	Brine #55	639.5	2795.5	3420.5	--
21-14N-2E	Salt #8	609.3	3002.7	3310.7	308
13-15N-1W	C & O #1	649	3015.5	--	--

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
MIDLAND cont.					
10-16N-1E	Rider #1	692	3076	--	--
1-16N-2E	Askevich #1	670	2726	--	--
MISSAUKEE					
16-21N-7W	Gibbs #1	1215	2770	--	--
20-21N-7W	Geo. & Clarice Meekhoff #1	1319.5	2669.5	--	--
23-22N-6W	State Aetna #1	1316	2694	3006	312
25-22N-7W	Jager #1-25	1184	2681	2761	80
32-22N-7W	Stroh & McBain #2	1193.5	2758.5	--	--
1-24N-5W	Faharney #7	1247	1875	2178	303
14-24N-5W	Horner #68	1168	1932	2127	195
MONTCALM					
9-10N-7W	Neilson #1	890.5	2374.5	2419.5	45
26-10N-7W	Goodenough #1	843	2327	2392	65
8-11N-8W	Bessie & Fernon Lee #1	956	2504	--	--
30-11N-8W	Christensen #1	930	2325	2380	55
5-11N-5W	E.N. Race #1	908.5	2336.5	--	--
MONTMORENCY					
30-30N-4E	Joe Carrier-Glen Pittenger-Leslie Cunningham #1	810	602	845	243

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
MUSKEGON					
21-9N-14W	Carl Wunsch #1	673	1577	1617	40
9-10N-14W	Leon Raison #1	700	1672	1728	56
15-10N-17W	McMahn #1	620.5	1447.5	1504.5	57
NEWAGO					
18-11N-12W	John Nyhof & Richard Dobbin #1	819	1991	2066	75
15-11N-13W	C.F. Seaman	803	1942	2017	75
10-12N-13W	Stanley J. Purcell #1	841	1939	2015	76
26-12N-14W	Sheridan Twp. #1	738	1877	1942	65
26-13N-14W	C. Siersema #1	890	1935	2000	65
OCEANA					
36-15N-17W	Peters #1	720	1665	1762	97
15-16N-16W	Everett Hill #1	885	1570	1720	150
OGEMAW					
1-21N-2E	State Horton #2	837	1678	2031	353
4-24N-3E	State Rose #1	1232.5	1762.5	2050.5	288
OSCEOLA					
29-17N-7W	Wm. H. Rountree, et. ux #1	1115.5	2809.5	--	--

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
OSCEOLA					
32-18N-7W	R. Wimmer, et al. #1	1056.5	2838.5	--	--
20-18N-10W	Dan Richards A-2	1141	2369	2614	245
30-18N-10W	Emma Fatum #3	1081	2361	2433	72
35-19N-8W	Arnold Yarhouse #1	1213	2832	2929	97
26-19N-10W	Carl Lindell #1	1197	2493	--	--
5-20N-7W	Chas. Stewart Mott Foundation #1	1213	2775	2859	84
17-20N-8W	Gerrit Kleinhess-elink #1	1304.5	2763.5	--	--
14-20N-9W	George Johnson-Ted Thomsen #1	1586	2719	2796	77
19-20N-10W	Lindberg #1	1168.5	2486.5	--	--
OSCODA					
32-25N-3E	State Mentor #1	1268	1732	--	--
OTSEGO					
13-29N-1W	St. Charlton BE #1	1280	1232	1480	248
16-29N-3W	State Otsego Lake #1	1429	1071	1331	260
2-29N-4W	Lake Horicon Dorp. #1	1402	998	1223	225

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
OTTAWA					
34-7N-13W	Reinhard Fenske #4-A	645	1487	1435	52
21-8N-14W	Heckel State #1	651	1539	1584	45
ROSCOMMON					
28-22N-2W	Leander J. Meldrum Est.	1180	2544	2835	291
34-22N-2W	St. Helen "C" #1	1203.7	2536.3	--	--
8-22N-4W	Ida H.P. Hooan #6	1136.8	2548.2	2738.2	190
23-24N-1W	North Mich. Land & Oil USAB #1	1168	1632	1972	340
SAGINAW					
21-10N-3E	F.G. & Allen L. Swartzmiller #1	601	2222	--	--
33-11N-3E	Robt. Gage Coal Co.	593	2319	2612	293
	L. Elbers #1	606	2504	2811	237
SANILAC					
8-9N-14E	Edward Donnelly #1	785	1225	1425	200
3-9N-15E	Chas. & Ethel Francis #1	757	491	685	104
31-9N-15E	Chas. & Arthur Kappler #1	768	922	1055	133
2-10N-15E	Robert E. Trowhill #1	716	709	924	215

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
SANILAC cont.					
9-10N-16E	Phillips #1 Sanilac 44 S.T.-Keglovitz #1	772	606	811	205
25-11N-12E	Ode #1	771	1684	1929	245
7-11N-14E	Felker-Mica Comm. #1	786	1399	--	--
7-11N-16E	Jerome G. Essenmacher #1	805.5	806.5	966.5	160
9-12N-13E	Phillips #1 Snover ST Leonard Wiswell #1	784	1381	1681	300
12-12N-14E	Phillips #1 Sanilac 76 S.T.-Detary #1	762	1171	1368	197
28-14N-12E	Linderman #1	776	1824	--	--
21-14N-15E	Ray J. Cleary #1	802	1273	--	--
SHIAWASSEE					
22-5N-2E	Dysinger #1	895	1485	1575	90
15-5N-3E	Scribner #1	871	984	--	--
	G.H.&S.L. Ferris #1	856.4	1309	1432	123
	Scribner #1	881	976	1193	217
ST. CLAIR					
11-3N-16E	Sharrow #B1-11	590	77	135	58
2-4N-15E	Dittman-Lopakiewicz	647	323	448	125
4-5N-15E	Stern *et al.* #1	704	426	561	135
7-6N-14E	Evans-Korth-Schmidt #1	792	693	818	125

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
ST. CLAIR cont.					
5-7N-13E	D.W. & V.M. Hull #1	789.5	1035.5	1195.5	160
11-7N-14E	D.J. Gleason #1	783.5	794.5	931.5	137
4-8N-16E	R.E. O'Conner et al. #1	721	225	324	99
TUSCOLA					
31-10N-8E	McCormick #1	770.5	1614.5	--	--
8-13N-9E	B.& L. Sattelberg #1	668	2092	--	--
16-13N-11E	Novesta Township, et al. #1	727	1868	2248	380
12-14N-9E	R.V. Dancey #1	654	2066	--	--
	C. & B. Montle #1	731	1724	2007	283
31-14N-11E	Lounsbury-Perry et al. #1	743	1777	--	--
VAN BUREN					
8-1S-14W	Pease #1	736	617	798	181
24-2S-15W	Tomcola Arendt Curtis #1	708	607	723	161
34-4S-14W	Kern #1	911	351	379	28
WASHTENAW					
22-1S-3E	R. & E. Wagner - C. Slocum #1	954.5	587.5	665.5	78

Location	Well Name	Elevation	Dundee Top	Detroit River Top	Thickness
WASHTENAW cont.					
12-1S-7E	Butler-Angell-Stroh #2	939	+287	+233	54
25-2S-3E	Goers #1	937	308	468	160
26-2S-7E	Knudt Jorgensen #1	768	+123	11	134
24-3S-7E	Wabash Railroad Co. #1	691	+336	+202	134
34-4S-4E	O.B. Bohnenstiehl #1	917	+90	18	108
16-4S-5E	W.P. Schowacko #GG-1	862.5	+266.5	+124.5	142
WEXFORD					
28-21N-9W	Davidson #1	1323	2577	2657	80
13-21N-10W	J.W. Stites #1	1347	2498	2585	87
27-21N-10W	State Cherry Grove A-1	1268	2490	2577	87
23-21N-11W	State Henderson #A-1	1346	2348	2440	92
32-22N-9W	Leeson & Sours #1	1303	2489	2572	83
9-22N-10W	Cummer Sons Cypress Co. #1	1411	2209	2301	92
20-24N-9W	State Liberty "A"-1	1014	2131	2221	90