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FACIES DEVELOPMENT AND POROSITY RELATIONSHIPS IN THE DUNDEE LIMESTONE OF GLADWIN COUNTY, MICHIGAN

by

Eric Lee Montgomery

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Science
Department of Geology

Western Michigan University
Kalamazoo, Michigan
April 1986
FACIES DEVELOPMENT AND POROSITY RELATIONSHIPS IN
THE DUNDEE LIMESTONE OF GLADWIN COUNTY, MICHIGAN

Eric Lee Montgomery, M.S.
Western Michigan University, 1986

The Devonian of the Michigan Basin was a time of
transgressive seas and extensive carbonate deposition
including coral and stromatoporoid buildups. Deposited
during the Middle Devonian, the Dundee Limestone
represents deposition in subtidal, intertidal, and
restricted environments. The Buckeye Oil Field, located
in south-central Gladwin County, is a combined
stratigraphic and structural carbonate trap which
produces from a series of intertonguing patch reefs,
fringing sand bodies, and "intertidal island" fenestral
zones. The major reef building organisms include
stromatoporoids, corals, calcareous algae, brachiopods,
and crinoids, with the stromatoporoids providing the
major framework. The patch reef facies is composed of
massive stromatoporoid boundstones which contain primary
intraparticle porosity. The fringing grainstone sands
are composed of coarse crinoid and brachiopod skeletal
debris which exhibit interparticle porosity. The
"intertidal island" zone found in the North Buckeye Field
is represented by a fenestral pelletal packstone.
ACKNOWLEDGEMENTS

This research was supported in part by grants from the Wiser Oil Company, The Graduate College, Western Michigan University, W. David Kuenzi Memorial Scholarship Fund, and the Western Michigan Subsurface Core Laboratory.

I would like to give special thanks to my advisor, Dr. William B. Harrison III, whose enthusiasm, dedication, and guidance made this project possible. I would also like to thank Dr. John D. Grace for his time and instruction with the x-ray machines; my colleagues, William Morse, William Henderson, David Skrocki, and Paul Horton, whose encouragement and friendship were invaluable; Tim Turmelle for his infectious propensity towards scholarship; Bill, Linda, and Sandy Harrison, whose house became a home; and last, my parents, Eleanore and Arkie, whose love and support have always been the guiding force in my life.

Eric Lee Montgomery
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INTRODUCTION

Statement of Problem

The Dundee Formation of the Michigan Basin has been a prolific producer of oil and natural gas since the 1930's, but no facies or diagenetic analyses using modern techniques and concepts have been reported. The application of modern facies and diagenetic models can aid in exploration and increase the chance of locating new oil and gas deposits within the Michigan Basin. The Buckeye oil field has produced over 25 million barrels of oil and is similar in its depositional environment to many other Dundee fields throughout the state. Understanding the processes which generated the depositional packages at Buckeye will aid greatly in future oil exploration within the Dundee rocks of Michigan. The objectives for this research on the Dundee Formation, Buckeye oil field, are:

1. Construction of an actualistic model of facies and depositional environments which existed during the Devonian at South Buckeye. A facies study would aid in the better understanding of the extent and distribution of oil in the various facies of the Dundee Formation.

2. Development of a field-wide porosity and permeability model for South Buckeye which has been chosen
as a site for secondary oil recovery by water flooding. This model could aid in the placement of water injection wells to maximize the potential for oil recovery within the field.

3. Construction of a model for the diagenetic history of the Dundee Limestone at South Buckeye and its relationships to type and percentage of porosity that can be used for examination of potential oil recovery within the area. A diagenetic study would greatly aid in locating porous and permeable zones in the rocks along with features and structures that enhance permeability across the field such as stylolitization and fracturing.

**General Setting**

The Buckeye oil field, located in south-central Gladwin County, T. 18 N., R. 1 W., Michigan, is a combined stratigraphic and structural trap, which produces from a variety of rocks deposited in carbonate environments (Figure 1). The Buckeye field is separated into two distinct oil reservoirs. The upper pool, North Buckeye, has produced over 20 million barrels of oil and the lower pool, South Buckeye, has produced over 5 million barrels of oil since its development in the late 1930's. The Buckeye field was originally discovered by Virgil Kirkham in 1936 using subsurface techniques and was named after Buckeye township where it is located.
Figure 1. Location of Buckeye Oil Field, Gladwin County, Michigan. From Addison, 1940.
Structural Setting

The Buckeye field is located on an anticlinal fold which parallels the major northwest-southeast structural trend in the central part of the basin (Figure 2). The axis of the south field trends northwest-southeast but the axis of the north pool is slightly transverse to the regional trend (Addison, 1940). It is not presently known how much structure was present before the sediments of the field were deposited and how much structure is simply due to the build up of carbonate over time. Isopach maps indicate that the shallow water facies on the fields had greater and faster carbonate deposition than the deeper water, open-shelf deposition found off the field. Limited structural data on the Dundee/Detroit River contact, due to low well control in the area, does not conclusively show the presence of a large structure before the field developed. It seems likely that both pre-Dundee structure and differential sediment accumulation operated to produce structural relief on the field. Some initial structure probably did exist to influence the depositional environment of the facies and shallow water deposition on the structure occurred at a greater rate than deeper water deposition (Wilson, 1975), so that the initial structure now appears more pronounced.
Figure 2. A Compilation of Major Axial Trends Gleaned From Maps of Specific Times in the Michigan Basin. From Prouty, 1971.
Climatic Setting

The Michigan Basin during the Devonian Period was located in a semi-arid to arid tropical environment closer to the equator than it is today (Dott and Batten, 1971; Figure 3). Evaporites deposited during Middle Devonian time indicate that arid conditions existed when the Dundee rocks were deposited. Paleoeologic evidence, the presence of stromatoporoids and corals, supports the conclusion that the Dundee Limestone of the Buckeye oil field was deposited in a warm, shallow, well circulated sea that transgressed across the basin from east to west.

Lithologic Character

The Devonian of the Michigan Basin represents deposition in restricted, open shelf, and clastic-influenced environments (Gardner, 1974). The Dundee Limestone was deposited from a sea which transgressed across the basin during deposition of the Kaskaskia sequence on top of the regressive carbonates and evaporates of the Detroit River group (Sloss, 1963). Prior to deposition of Dundee carbonates multiple sea-level changes or facies progradations and regressions produced nodular and mosaic anhydrites in lime muds of a sabkha-like environment. These anhydrites are interbedded with algal mat lagoonal carbonates and
Figure 3. Paleographic Setting of the Michigan Basin During Devonian Time. From Dott and Batten, 1976.
massive halite, beds forming the Lucas Formation (Gardner, 1974). Transgression of the Kaskaskia sea returned open shelf deposition to the basin in which the Dundee Limestone was deposited. Open marine conditions then existed in the eastern and central parts of the basin while restricted conditions prevailed in the western areas of the basin. Dundee sedimentation came to a close with the deposition of gray mud, from an eastern source area, which formed the Bell Shale of the Traverse Group (Gardner, 1974).

Stratigraphic Nomenclature

The present day stratigraphic nomenclature used to describe Dundee rocks from the Michigan Basin is disjointed and is not representative of the rocks deposited in the Dundee. The published nomenclature used today is taken from Cohee, 1944. The Dundee nomenclature was later reorganized by Gardner (1974), who redefined the Reed City and the Rogers City Members (Figure 4). The problem with nomenclature in the Dundee is that members are named as because of their stratigraphic position in the geologic column, by facies represented from the rocks, by their lithology, and by their geographical position within the basin. Because similar rocks can be found in different stratigraphic positions, can have different lithologies due to secondary
alteration, and can be located in different geographical areas within the basin, some rocks can belong to more than one member or have been incorrectly assigned to a member in which they do not belong. The Rogers City Member has been used to describe the upper zone of the Dundee Formation. This upper zone is an open shelf nodular micrite which can't be distinguished from similar rocks occupying lower horizons within the subsurface. The Reed City Member has been used to describe open marine and shallow water facies located in the western part of the basin that have been influenced by evaporite deposition and dolomitized. It has also been used to describe open marine rocks located throughout the basin that have been dolomitized but were not influenced by evaporites. It is proposed by this author that members should only be named from their facies which best describe the rocks themselves and not from their stratigraphic position, diagenetic lithology, or geographical location. The Rogers City Member should be used to describe all rocks deposited in the open marine facies whether they have been dolomitized or are limestone. New members need to be created to describe the shallow water facies represented by the stromatoporoid boundstone and fenestral/pelletal packstone rocks located at Buckeye and other Dundee oil fields throughout the state. The Reed City member should be used to describe
evaporites deposited in tidal flat environments deposited in the Dundee.

Previous Investigations

Published research on the Dundee Limestone and the Buckeye oil field is very limited. Although the Dundee has been a major oil producer throughout the state since the 1930's very little recent work has been published on its geology, paleontology, and geochemistry. Some of the earliest work was by C.F. Bassett (1935), who described the paleontology and defined stratigraphy of the Dundee. G.V. Cohee (1944), worked on the lithologic character and the stratigraphic relationships of the Dundee. The most recent research on the facies of the Dundee was performed by Gardner (1974), who described the Dundee as a biostromal shelf carbonate that contained a dark fine grained off-shore facies. This open shelf facies was deposited in a westward transgressing sea. A sabkha-lagoonal facies on the west records the retreat of evaporite deposition from the Michigan Basin. Gardner (1974) was the first researcher to interpret the lithologic character of the Dundee using the transgressive and regressive sequences described by Sloss (1963), and attempted to isopach lithologies from subsurface data. Lilienthal (1978) briefly described the lithology of the Dundee and correlated selected wells
throughout the state. Previously published research on the Buckeye field is limited to that of Addison (1940). He described production characteristics of the field, constructed structure contour maps of the area, and correlated pay zones throughout the field. However, he did not suggest interpretations of the paleocology, petrology, and geochemistry of the Dundee.

Method of Study

Field Methods

During various times in 1984 and 1985, oil well cores, core reports, drillers logs, and electric logs of Buckeye samples located at Mt. Pleasant, Plainwell, and Lansing, Michigan were collected. Three days were spent examining Dundee outcrops, collecting samples, and determining facies geometry and models in the Devonian outcrop belt of northern Michigan.

Laboratory Methods

Eleven oil well cores from South Buckeye and one from North Buckeye were examined using a binocular microscope to determine mineralogy, grain size, sedimentary structures, textures, fossils, cement-type, fabric, crystal shape, porosity, permeability, and nature of facies contacts. From these twelve cores, forty thin
sections were made for detailed analysis of grain fabric, porosity, and cement relationships. The thin sections were pressure impregnated with blue epoxy resin to highlight porosity and stained with Alizarin Red S. to highlight calcite mineralogy (Friedman, 1959). Thin section investigations concentrated on detailed analyses of the samples to gather data on porosity type, cement relationships, pressure solution formation, grain determination, and fossil identification. Drillers logs, electric logs, and core reports were then used to make contour maps, cross sections, and production maps that correlate depths, thicknesses, and facies at South Buckeye. Fluorescence microscopy was used to help determine grain contacts, rock textures, and cement types. X-ray diffraction and x-ray fluorescence techniques were used to calculate calcite/dolomite ratios and Sr content.
Because there is a close connection between depositional environment and nature of sediment deposited, understanding the processes that act on a pile of sediment will aid in the recognition of sedimentary features indicative of certain environments. Each sediment package or facies can be distinguished from others by its characteristic lithology, fossils, geometry, and sedimentary structures. Facies are important because their recognition provide the basis for an environmental interpretation of stratigraphic units. The distribution of facies can be interpreted because they are subject to controls imposed by geological setting, tectonics, and climate (Blatt, Middleton, and Murray, 1980).

Four major facies types have been recognized from the Dundee Formation located in Buckeye oil field. These facies consist of (a) stromatoporoid boundstone, (b) skeletal grainstone/wackestone, (c) nodular micritic wackestone/mudstone, and (d) fenestral/pelletal packstone. Although all four lithologies can be recognized to some extent in both the north and south fields, the south field is dominated by the stromatoporoid boundstone and skeletal grainstone/wackestone facies whereas the north field contains fenestral/pelletal packstones and some stromatoporoid boundstones. Both fields, as well as
areas off the producing field, contain thick sections of the nodular micritic wackestone/mudstone facies. The stromatoporoid boundstone, fenestral/pelletal packstone, and the skeletal grainstones facies all contain commercially produceable quantities of hydrocarbons. The nodular wackestone/mudstone facies has such low porosity and permeability that it is non productive in most areas. The carbonate rock classification used in this research was proposed by Dunham, 1962 (Figure 5).

**Stromatoporoid Boundstone Facies**

Economically the most important facies located at South Buckeye is the stromatoporoid boundstone facies (Figure 6). These boundstones are usually gray and are mostly limestone with up to 10% dolomite. Organisms which comprise the boundstones include massive and tabular stromatoporoids, corals, crinoids, and brachiopods, although the stromatoporoids provide the major framework for the deposit (Figure 7). Based upon abundance, size, and orientation of fossils, the boundstones can be interpreted as having been deposited in a patch reef environment (Figure 8). Various stages of reef growth are present in the South Buckeye patch reefs (Figure 9). Commonly stromatoporoids tend to dominate the central reef core and corals are usually found in pockets or predate the stromatoporoids. The reef mass is divided
### Classification of Carbonate Rocks According to Depositional Texture

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![Classification of Carbonate Rocks According to Depositional Texture](image)

Figure 5. Carbonate Rock Classification. From Dunham, 1962.
Figure 6. Stromatoporoid Boundstone Facies.

Figure 7. Stromatoporoid Boundstone Facies.
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Figure 8. Distribution of organisms in Devonian reef zones and off reef areas. From Krebs, 1974.

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between massive boundstones and debris filled pockets which differ in size and textures (Figure 10). The debris pockets range in texture from a wackestone to a grainstone and usually contain broken skeletal debris from corals, stromatoporoids, crinoids, and brachiopods.

Energy conditions within the patch reef were different depending upon position and orientation of the reef relative to the open water source of wave energy. Lower portions of the reef, below wave base, endure moderate energy conditions and growth forms tend to be of the bulbous and branching types (Figure 11). Crinoids, brachiopods, and some lower energy stromatoporoid forms occur in these zones. Higher energy forms, in the wave-affected zone, are typified by massive stromatoporoids and some corals.

Correlation of core information with initial production data indicate that there are 2 reef masses at
Figure 10. Debris pocket in stromatoporoid boundstone facies.

<table>
<thead>
<tr>
<th>GROWTH FORM</th>
<th>ENVIRONMENT</th>
<th>Wave Energy</th>
<th>Sedimentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delicate, branching</td>
<td></td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Thin, delicate, plate-like</td>
<td></td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Globular, bulbous, columnar</td>
<td></td>
<td>moderate</td>
<td>high</td>
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<tr>
<td>Robust, dendroid, branching</td>
<td></td>
<td>mod-high</td>
<td>moderate</td>
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<td>Hemispherical, domal irregular,</td>
<td></td>
<td>mod-high</td>
<td>low</td>
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<td>massive</td>
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<td>Encrusting</td>
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<td>Tabular</td>
<td></td>
<td>moderate</td>
<td>low</td>
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Figure 11. Growth form of reef building organisms. From James, 1983.

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Buckeye. One reef mass is located in the south-central area of the field and the other is located in the northwest portion of the field. Core data shows that the reefs grow to a maximum of forty feet while their horizontal extent ranges from a few feet to approximately a mile. The vertical growth of the reef was probably limited by the water depth because reefs can only grow in the photic zone and can't grow up to the water surface. Reef growth was halted when, either an increase in the subsidence rate or a rising sea level, caused the reefal organisms to fall below the photic zone and die.

The reason that reef growth was initiated at Buckeye, is still unclear but because elongated patterns of oil production can be identified within the Dundee, it is likely that some structural control exists in the field although insufficient information is available to determine this (Figure 12).

It is also possible that local conditions suitable for reef growth may have developed because of submarine lithification of sediment on a paleographic high. Combinations of low sedimentation rates, sediment stability, and high initial permeability of sediments, (Shinn 1982), could have caused submarine lithification to develop making the region favorable for reef development.
Figure 12. Map showing regional trend of Devonian oil fields modified from Gardner, 1974.
Porosity and Permeability

Porosity is both varied and abundant in the patch reef facies. Porosity values range from 1 to 21% in the patch reef boundstones and the average value is approximately 10%. Porosity types that occur include intraparticle, fracture, vuggy, and styloitic with primary intraparticle porosity inside the skeletal micropores of the stromatoporoids, the dominant type. The majority of the intraparticle porosity is primary and has not undergone dissolution shown by the still-intact configurations of the cell walls inside the stromatoporoids and corals (Figure 13). Some solutional enlargement of the pores is present in certain areas of the boundstones where cell walls have been partially dissolved or have been completely removed by fluids undersaturated with respect to calcium carbonate. Reduction of the porosity by cementation has also effected the boundstones to varying degrees. Percentages of cements range from near zero to almost 100% cementation. The primary intraparticle porosity found in the patch reef facies is geologically rare and will only be present under an unusual set of diagenetic circumstances. Longman (1981), has done extensive research on porosity formation and stated that "I know of no hydrocarbon reservoir where it contributes more than a
small percentage to the total production (p. 67)." In South Buckeye it is the main porosity type, contributing more than 75% of the total reservoir porosity. Other porosity types are styolitic, fracture, and vuggy. These are relatively minor and add more to the permeability than to the porosity in most cases. Fracture porosity, which occurred in the burial history at Buckeye, probably formed as a result of loading and unloading of the sediment. Styolitic porosity is found only in large sutured styolitic seams (Figure 14). Vuggy porosity, formed by dissolution of calcium carbonate, can
be locally important but is usually not extensive in its effect. The porosity classification (Figure 15), used in this research is that of Choquette and Pray, 1970.

The permeability in the patch reef facies is relatively uniform and usually falls in the range between 75-150 millidarcies. Permeability through the stromatoporoid zones is the result of several factors including pressure solution, fracturing, and dissolution. Pores within the stromatoporoids appear to be interconnected both horizontally and vertically and will certainly provide substantial permeability. Fluid and hydrocarbon migration should also be aided by the presence of styolitization and fracturing within this facies.
Figure 15. Classification of carbonate pore types. From Choquette and Fray, 1970.
Skeletal Grainstone/Wackestone Facies

The skeletal grainstone/wackestone facies at South Buckeye consists of skeletal grainstones that are gray and composed of calcite with small amounts, usually less than 10%, of dolomite (Figure 16). Skeletal debris which make up the grainstones is mostly from crinoids, brachiopods, and molluscs, although ostracod, foram, algae, and trilobite fragments are sometimes present. Crinoid ossicles are the dominant fossil found in the grainstones but locally brachiopods range from trace to almost 100% of the fossils present. Molluscs present include both bivalves and gastropods. Pellets are also a common constituent in some of the grainstones.

The geometry of the grainstones bodies is variable but often tends to be lens-shaped. Vertically they are usually limited to less than 10 feet, but horizontally their extent can be a few hundred feet.

The formation of grainstones occurs in several areas as a result of sorting processes in high energy environments. They commonly form as part of the reef flank deposits (Ginsburg, 1964). These types of deposits are associated with reef facies at Buckeye and contain abundant coral and stromatoporoid fragments. These types of grainstones can also form as beds of crinoid and brachiopods which live along the sides of reefs in lower
energy environments. Grainstones formed in this manner usually develop around the reefs in a circular pattern and are present as fringing sand bodies. The limit of the grainstones depends upon energy conditions and the vertical extent of the reef. Lastly, grainstones can form isolated sand bodies not associated with reef growth which become stabilized by crinoids and brachiopods (Figure 17). These beds develop in areas where hard substrates and suitable energy conditions exist. Grainstone beds form substrates which can support colonization by reef forming organisms. The above types of grainstones are all present at South Buckeye and have aided in the production of hydrocarbons within the field. Major grainstone accumulations are found surrounding both

Figure 16. Skeletal grainstone/wackestone facies.
reef masses and are present in the northeast area of the field not associated with any known reef mass.

Porosity and Permeability

Porosity values within the grainstones range from 2 to 7% and the average value is 5%. Major porosity types seen in this facies include interparticle and intraparticle with minor additions from moldic, styolitic, vuggy, and fracture (Figure 18). Grain shapes and smooth pore geometries indicate that much of the porosity seen in this facies is primary except where dissolution has occurred and removed cement between
adjacent grains. Intraparticle porosity is also commonly observed within skeletal grains of gastropods. Overall porosity within this facies is lower than in the patch reef facies but oil production, usually between 25 and 150 barrels of oil a day, is still significant due to the wide distribution of the grainstones.

Permeabilities values in the South Buckeye reef flank and fringing sand facies usually range between 5 and 50 m.d. Average permeability is thus lower than in the stromatoporoid boundstone facies but greater than in the nodular micritic wackestone/mudstone facies. Pores are connected in this facies and horizontal permeabilities should be sufficient for fluid and hydrocarbon migration although drainage will be slower than within the reef masses themselves. Stylolitization
and fracturing have secondarily increased permeability within this facies.

Nodular Micrite Wackestone/Mudstone Facies

The most volumetrically abundant facies present at Buckeye is the nodular micritic wackestone/mudstone facies. This facies consists of wackestones and mudstones which are dark gray in color, partially oil stained on the microscopic level, and composed of calcite (Figure 19). Grains which make up the open marine wackestones are skeletal debris and pellets. Common skeletal grains include crinoids, brachiopods, and stromatoporoid and coral debris can be locally abundant. Round pellets are common in this facies and are were probably formed as fecal pellets of burrowing organisms moving through the sediment. Fossil diversity and abundance is low in this facies compared to the stromatoporoid boundstone facies and the skeletal grainstone/wackestone facies. The most widespread structure seen in the open marine facies is the nodular texture that develops during diagenesis. Shinn, Halley, Hudson, and Lidz (1977), and Shinn and Robbin (1983), suggested that partial lithification of sediment on the sea floor could explain the nodular pattern which develops in this facies. Early lithification produces differential compaction around the semi-lithified clasts.
Figure 19. Nodular micritic skeletal wackestone/mudstone facies.

which causes the clay-size particles to squeeze out and around the carbonate clasts. This process is thought to occur fairly early in the burial cycle.

In modern sediments and their ancient analogs the geometry of this facies is both horizontally and vertically extensive although sedimentation rates are much lower in this relatively deeper water environment. Whenever water depths become too great for reef growth or at locations far remote from a reef mass, open marine deposition occurs. Energy conditions are usually low in this environment and wackestones and mudstones are the
common textures observed. This facies is typical of deposition which occurs in subtropical, shallow, well-circulated seas. Rocks reflecting this type of deposition are the most common and widespread lithology in the Dundee.

**Porosity and Permeability**

Porosity in the open shelf facies at Buckeye tends to be low and values commonly range between 2 to 3% (Figure 20). Porosity types found in this facies include vuggy, moldic, styolitic, and fracture. Primary porosity is lacking in this facies and secondary solutional enhancement is minor except in a few areas where vuggy porosity is locally significant. Other evidence for dissolution in this facies is indicated by the presence of small amounts of moldic porosity. The moldic porosity usually occurs in mollusc shells that were originally aragonite.

Permeability within the open marine wackestones/mudstones is also low although it has been enhanced due to burial processes. Permeability values across the field range from 0.1 to 200 m.d., but are usually less than 10 m.d. Permeability has been increased in this facies by styolitization and fracturing. Both large sutured styolites and microstyolitic swarms are common. These are usually oil
stained and provide pathways for fluid and oil migration. Although porosity and permeabilities are low in this facies, some water movement should occur though these rocks and may connect adjoining porous facies throughout the field.

Fenestral/Pelletal Packstone Facies

The facies which has produced the most oil and gas from Buckeye is the fenestral/pelletal packstone facies located at North Buckeye. This facies consists of pelletal and skeletal packstones which are buff to tan in color, oil stained, contain abundant fenestrae, and are composed of calcite with dolomite ranging from 5 to 10 percent (Figure 21). Organisms which lived in this fenestral/pelletal packstone facies consisted of a large variety of molluscs including numerous gastropods and
bivalves, various forms of algae, and probably a few species of worms. Other fossils commonly found washed into this facies are stromatoporoids, corals, crinoids, and brachiopods. However, the major grain which makes up the packstones is pellets.

Structures found within this facies include tidal laminations, small algal mats, and fenestrae, which indicate a shallow water, intermittently exposed environment. The buff to tan color most likely indicates an oxidizing environment that was at least periodically exposed. This facies is most commonly developed in tidal
flat environments (Tebbutt, Conley, and Boyd, 1965). Laminations, which represent fluctuating energy conditions in a shallow water tidally influenced environment, can be seen in some of the cores in the North Buckeye field. Algal-like structures, which develop in very shallow water conditions, are also present at North Buckeye. The dominant and most abundant sedimentary structure present at North Buckeye and at the southeastern end of South Buckeye is fenestrae. Fenestrae can form from the decay of algal films in cryptalgal sediments, by lateral migration of water and/or gas, burrowing by organisms, plant roots, gas evolution, dessication, and lithification (Tebbutt, Conley, and Boyd, 1965; Logan, 1974). Fenestrae at North Buckeye are generally laminoid or irregular in shape. Laminoid fenestrae are commonly formed by decay of algal material (Logan, 1974), and sinuous vertical fenestrae are usually formed by decay of algal material, activities of burrowing organisms, and by gas evolution (Tebbut et al., 1965; Logan, 1974). Fenestral form and size along with the presence of pellets indicates that some of the fenestrae of the laminoid type were formed due to the decay of algal material but the majority of the fenestrae are very similar to fenestrae found in modern Bahamian tidal flats formed by burrowing organisms (Personal Communication, R.N.Ginsburg, 1986). Samples containing
fenestrae were subjected to resin epoxy casting under a vacuum and showed a intricate network of tubes very similar to those formed by burrowing organisms.

Evidence for the existence of burrowing activities in exposed areas comes from a study performed by Ginsburg and Hardie (1975). They found that burrowing in recent Bahama tidal flat sediments occurred in areas exposed as much as 70% of the time. Evidence of intensive burrowing is present in a few cores from the southeastern end of South Buckeye (Figure 22). This area probably represents a high on the sea floor where shallow water deposition occurred before patch reefs developed at South Buckeye.

The geometry of this facies is quite extensive both horizontally and vertically where the controlling factor is water depth. The facies is generally uniform throughout except at the edges where slightly deeper water deposition occurs and burrowing activity is less intensive. Energy conditions acting on this facies would be variable although it would be less than the reef and grainstone areas but greater than the conditions acting on the deeper water open shelf environment.

Because of the position of Buckeye in the facies tract of the Michigan Basin (Gardner, 1974), these shallow water facies cannot be part of a near shore environment. Their offshore position and limited areal extent suggests the presence of an island setting.
Figure 22. Fenestral/pelletal packstone facies.

Although the formation of an fenestral/pelletal packstone facies not associated with a shelf edge is unusual in the geologic record, conditions were apparently favorable for the development of the facies in the Middle Devonian of the Michigan Basin. Sedimentary structures and the presence of freshwater cementation indicate that water depth was very shallow at times and exposure occurred periodically during deposition of this portion of the Dundee. Exposure was probably only intermittent because mud cracks, evaporites, and other dessication features are missing and would be present if long periods if
exposure occurred. Formation of this facies began when subsidence rates or changes in sea level caused reef growth to cease and shallower water conditions to develop. Drastic changes would not have been necessary for the development of this facies because reef growth had to be near the water surface, in the photic zone, so that a slight drop in the water level could cause shallow water tidal-like deposition to occur.

**Porosity and Permeability**

Porosity values in the fenestral/pelletal packstone facies usually range between 10 and 15%. Porosity types found in this shallow water facies include fenestral, vuggy, moldic, fracture, and styolitic. Fenestral porosity represents the dominant type and is thought to be mostly primary in origin. Shapes of fenestrae from core samples and from resin epoxy casts show that some of the original burrow wall structure is intact and has not undergone dissolution (Figure 23). Some fenestrae have lost their original shape and size indicating that the porosity has been enlarged by solution. The presence of moldic porosity also indicates that some dissolution has taken place within this facies.

Permeability in the fenestral/pelletal packstones has the highest values found in the Buckeye oil field. Values range from 150 to 1800 m.d. and normally fall
between 300 and 400 m.d.. This high permeability is a result of the connective character of the fenestrae due to both the nature of the organisms which created the burrows and the fact that secondary solutional enhancement has affected certain parts of the reservoir and enlarged the fenestral pores.
DIAGENESIS

Carbonate rocks which form at or near the earth's surface often change or are altered from their original mineralogy and texture as depth of burial increases and chemistry of burial fluids change. Rocks deposited at Buckeye are no exception, and have been modified by the many complex processes which occur during diagenesis. Much of the initial porosity and permeability was either increased by dissolution, like in the fenestral/pelletal packstone facies, or has been reduced by cementation, like rocks from the patch reef facies. Crystal forms have been altered from the orthorhombic form of aragonite to the more stable trigonal shape of calcite. Trace element chemistry has also been altered in the rocks from Buckeye to where percentages of Sr, Mg, and other ions have been increased or decreased dramatically. Processes occurring during diagenesis in the Buckeye oil field have been varied and repetitive in nature. Major carbonate diagenetic processes that have acted on rocks from Buckeye oil field include cementation, dissolution, styolitization, fracturing, and hydrocarbon migration. Models of diagenetic environments used in this report are those described by Longman, 1980 (Figure 24).

The most unusual aspect of the diagenesis at the Buckeye oil field is the presence of intraparticle
Figure 24. Major diagenetic environments in shallow subsurface. From Longman, 1980.
porosity preserved inside stromatoporoids and the preservation of fenestral porosity within the "intertidal island" packstones. Although these diagenetic effects are geologically rare, they formed as a result of various combinations of complex processes which can be identified and correlated into a relative time sequence.

Compaction and Marine Cementation

The first diagenetic processes to act on the rocks deposited at Buckeye were compaction and early cementation. Compactional processes can begin with as little as 100 meters burial (Shinn and Robbin, 1983), and tend to squeeze unlithified sediment and grains together causing loss of porosity, flattened burrows, and deformation of pellets and other soft grains. Because open porosity, pellets, and non-deformed burrows can be seen in cores from Buckeye, early cementation must have impeded compactional processes within the rocks. Four different cementation generations have been recognized. The first cements which formed in the Buckeye rocks were aragonitic and high Mg calcite fibrous marine cements (Figure 25). This cement is only present in the patch reef facies where it is randomly distributed in small amounts on walls of stromatoporoids and corals. Because the original aragonite and high Mg calcite has been neomorphosed to low Mg calcite, indirect evidence, such
as the presence of non-planar intercrystaline boundaries, undulose extinction, and crystal size and shape (Tucker 1981), must be used to identify marine cements. The presence of relic fibrous textures in the heavily cemented zones in the skeletal micropores of the stromatoporoids suggests that the low-Mg blocky calcite cements were once fibrous aragonite. X-ray fluorescence spectrometry analysis indicates that an unusually high percentage of Sr, from approximately 1500 to 4000 p.p.m., exists within the heavily cemented zones of the stromatoporoids. Bathurst (1975) and Tucker (1981) have
shown that the calcite in most ancient limestones only contains 70 to 630 p.p.m. and that modern aragonite can contain as much as 10,000 p.p.m. Sr. The presence of large amounts of Sr in the low-Mg calcite is a strong indication that some aragonitic marine cementation did take place and was later neomorphosed to calcite. Although marine cementation did occur at Buckeye it was not extensive and only effected the stromatoporoid boundstones. According to Longman (1980), such cementation takes place in the marine stagnant zone where cementation only occurs within the skeletal micropores of the organisms. The cementation within skeletal micropores at Buckeye is likely due to similar processes to those described by Longman (1980). Other evidence supporting that marine cementation was minor and that sediment spent relatively little time in the active marine zone, includes lack of encrusting marine organisms, absence of marine sediments in cements, lack of micritization, and lack of borings on hard substrates (Longman, 1980). Low water circulation in the stagnant marine phreatic zone seems to explain why marine cementation is scarce at Buckeye. Longman (1980), also indicated that it is common to see marine sediments through which marine water circulated freely remain relatively uncemented.
Freshwater Cementation and Dissolution

Because fenestral porosity is only preserved when early cementation or infilling of evaporites takes place (Shinn, 1968), a second more extensive phase of cementation must have occurred at Buckeye to maintain open fenestrae because no evidence of evaporite formation has been recognized. The second cement present is a low Mg calcite cement similar to that known to precipitate in the fresh water phreatic zone. Evidence which supports a fresh water phreatic origin for this cement includes presence of moldic and vuggy porosity, neomorphism of unstable grains, blocky shaped calcite crystals, isopachous bladed calcite crystals, and presence of syntaxial overgrowths on crinoids fragments (Longman, 1980).

Cementation in the freshwater phreatic zone at Buckeye was sporadic, occurred simultaneously with dissolution, and developed during at least 2 different cementation phases. Cross-cutting relationships and grain contacts indicate that the first cementation phase precipitated syntaxial overgrowths on crinoids in the reef flank and sand apron grainstones (Figure 26), caused the development of bladed and prismatic calcite crystals (Figure 27), and neomorphosed aragonite into stable calcite. The second freshwater cementation pulse, formed
Figure 26. Syntaxial overgrowth on crinoid fossil.

Figure 27. Bladed freshwater calcite cement lining brachiopod shell fragment.

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the dominant cement type found in the Buckeye rocks, a blocky nearly equant calcite (Figure 28).

Because several different processes occur in the fresh water phreatic zone, according to the burial depth, Longman (1980), divided the freshwater phreatic zone into 5 separate divisions. In the first zone both calcite and aragonite dissolution occurs. The effects of this are present in several facies at Buckeye. The fenestral/pelletal packstone facies shows areas where dissolution has occurred and removed aragonitic skeletal grains and parts of the calcite matrix. Also the effects of dissolution are present in the nodular micritic open marine and skeletal grainstone facies where vuggy porosity has been formed. Although this process did occur at Buckeye its effects on the oil producing facies were relatively minor. The stromatoporoid boundstone, fenestral/pelletal packstone, and skeletal grainstone facies exhibit skeletal micropores, burrows, and grain contacts that show no evidence of secondary enlargement consequently porosity in these units must be considered to be at least partly primary.

The second division of the freshwater phreatic zone proposed by Longman (1980), is a zone of aragonite dissolution. Here only aragonite is dissolved creating moldic porosity. This can be seen in the skeletal grainstone and the fenestral/pelletal packstone facies
where molluscs and other shells have been removed by solution leaving the calcitic grains unaffected. This type of dissolution is not prevalent in the facies at Buckeye and only adds a small percent to the overall reservoir porosity.

The third division in the freshwater phreatic zone is a zone where aragonite is dissolved and calcite is simultaneously precipitated. Most of the neomorphism in the aragonitic skeletons of the stormatoporoids could have occurred within this interval. Although all stromatoporoids are now calcite there is growing
geochemical evidence and evidence involving similarities with modern faunal types that indicate stromatoporoids were once aragonite (Stearn, 1972, 1975; Bathurst, 1975).

Calcite cementation with no dissolution, the fourth process acting on rocks in the freshwater phreatic zone, can be seen to a limited degree in most of the rocks deposited at Buckeye. All facies contain pore spaces filled with equant block-like calcite crystals that usually coarsen towards the center. This process, although effecting all facies, was not extensive at Buckeye because of the large amounts of primary porosity preserved.

The fifth interval in the freshwater phreatic zone is an area where little active circulation occurs. This stagnant zone undergoes minor amounts of cementation and dissolution. Numerous examples can be identified in the facies at Buckeye, where scarcely any dissolution textures or cements are present. The patch reef facies, nodular open marine facies, and skeletal grainstone facies along with parts of the fenestral/pelletal packstone facies probably remained in this zone for extended periods of time.

Although diagenetic processes are very complex and are effected by many variables, climate plays a major role in what diagenetic processes operate. An arid climate, where only limited rainfall occurs, in
association with short periods of exposure, could cause the formation of a larger freshwater stagnant zone to develop at Buckeye, than is seen in other geologic settings. Combinations of low water circulation, limited time in the freshwater meteoric environment, and short durations of exposure (Moore, 1979), all probably played a major role in the development of the unusual set of diagenetic events which preserved the primary intraparticle and fenestral porosities found in the rocks of Buckeye. Matthews (1968), in research done on freshwater cementation in Barbados, found that if only small amounts of water are present, not much recrystallization will occur at or near surface temperatures and pressures. Longman (1980), also found that "if subaerial exposure occurs in arid climates, cementation in freshwater environments may be limited and primary porosity may be preserved (p. 461)."

Pressure Solution

The next diagenetic event that occurred at Buckeye, after initial compaction, cementation, and dissolution was the development of pressure solution features and associated fractures. Styolitization, which is a common product of chemical compaction, is abundant in all the facies at Buckeye. It appears in three major forms and truncates all cementation and porosity types indicating
that it is a late-stage diagenetic event (Figure 29). Pressure solution results when stress is applied to a rock (Sorby, 1908), and can occur during shallow or deep burial history of a rock. Styolites at Buckeye appear in three major forms: sutured, solution seams, and microstyolites. Sutured styolites and microstyolites swarms are the most common. Sutured styolites form at boundaries between units having structural resistance to stress and little, or no platy insoluble material (Wanless, 1979). This form is most common in the patch reef and fenestral/pelletal packstone facies. Microstyolitic bundles or swarms form in limestone that contain significant amounts of fine platy material (Wanless, 1979). These bundles are mostly found in the open marine facies which contain abundant fine material (Figure 30).

The styolites present at Buckeye have had several major influences on the field and its properties. First, styolitization has reduced the volume of limestone that originally was deposited and has destroyed some of the primary and secondary porosity present within the Buckeye rocks. Second, the styolites have increased permeabilities and caused minor secondary porosity to develop. The styolites, which commonly have a large horizontal extent, can act as pathways for the migration of fluids including hydrocarbons. Styolites connect
Figure 29. Sutured styolite formed from pressure solution.

Figure 30. Microstyolettes formed from pressure solution.
porous facies that otherwise would have no communication or have poor communication at best. Styolitization has helped integrate the porous zones in the South Buckeye field which based on distribution of facies might have become a series of isolated oil pools. The third influence that styolitization has exerted in the Buckeye oil field, is the creation of a source of calcium carbonate and other ions for late cementation. Styolitization provides a ready source of calcium carbonate which can be precipitated locally, although not common at Buckeye, or be transported and precipitated in other areas (DeBoer, 1977). Lastly, styolitization at Buckeye is associated with many small microscopic fractures. The fractures commonly are open and begin at the styolite seam. These fractures are a late stage diagenetic event which increase both permeability and porosity within the field (Figure 31).

Fluid Migration

The next major diagenetic process which occurred at Buckeye oil field is hydrocarbon migration. Hydrocarbons are found in almost all sutured styolites, in some microstyolites, and in most pore spaces. Facies which contain the greatest porosity have the most hydrocarbons, such as the fenestral/pelletal packstone and patch reef facies, although all facies contain some oil. The
position of hydrocarbons in pores and fractures indicate that migration took place soon after or simultaneously with stylolitization.

Dolomite Formation

The next major diagenetic process which occurred at Buckeye was the development of dolomite. Although the abundance of dolomite is relatively low, usually less than 10% and does not add anything to the porosity, it can be locally significant. The dolomite crystals that occur at Buckeye are usually large, dirty, saddle-shaped, and associated with stylolitization (Figure 32). The
majority of the dolomite rhombs present are found within styolite seams or in open pores. Because of their size, shape, and occurrence, the dolomite has been interpreted as being a deep burial dolomite and a late stage diagenetic event. Baroque dolomite is the term that has been used for this type of dolomite of this type (Folk, 1977). Dolomitization along styolites is fairly common in the geologic record and has been described by many authors including Wanless (1979) and Mattes and Mountjoy (1980).
Fracturing and Late Cementation

The last diagenetic events to effect the rocks deposited at Buckeye were microscopic fracturing and cementation. Late cementation can be seen in several places where calcite, and infrequently sulphate, has filled voids. Calcite cements usually fill fractures associated with styolitization. Sulphate cementation has only been identified in one large void filling fracture in the southeastern end of the Buckeye field. Although late cementation did take place at Buckeye, it was not extensive and reduced porosity only slightly. Also, dolomite rhomb edges have been corroded in a few areas by calcite indicating that at least some of the late stage diagenetic fluids were undersaturated with respect to Mg ions. Calcium carbonate and sulphate probably came from deep burial fluids and probably migrated through the pervasive styolitization within the area. The smectite to illite conversion of clays, (Smosna, 1984), might also have released significant amounts of Mg, Ca, Fe, and other ions into the system.

Microscopic fracturing is the last process to effect the rocks deposited at Buckeye. The fractures are commonly open indicating that they are a very late stage diagenetic event and about the same size and orientation as the fractures associated with styolitization. These
fractures probably formed as a result of loading and unloading of sediments and rock. Overburden would load sediments and cause lithostatic pressures creating stresses in the rocks. Subsequent removal of sediment by erosion would release this stress and create fractures from this unloading. It has been estimated by Cercone (1984), using thermal maturation studies, that as much as 3280 feet of Carboniferous strata has been removed by erosion from the geologic column.
BUCKEYE OIL FIELD

Field Characteristics

The Buckeye field is located in one of the major anticlinal trends present throughout the state. The surface of the field is relatively flat and slopes gently southeastward (Addison, 1940). Approximately 200 feet of structural relief exists from on the field to off the field (Figure 33). Isopachs show an increased thickness of carbonate rocks where shallow water deposition occurred (Figure 34). Because carbonate sedimentation rates are much greater in shallow, higher energy environments, increased thicknesses should be observed in these areas. This can be recognized in the north field where the Dundee is more than 400 feet thick and in the south field where thicknesses average around 350 feet. Thicknesses drop off to 200 off the field where only deeper water carbonates were deposited at a much slower rate.

Facies Modeling

Buckeye oil field is a combined stratigraphic and structural trap which has produced over 25 million barrels of oil. The field is actually 2 separate pools of oil (Addison 1940), which produce from different
Figure 33. Structure contour map on top of Dundee, Buckeye oil field. From Addison, 1940.
Figure 34. Isopach map of Buckeye and surrounding townships.
facies. The north field production comes from an fenestral and pellet dominated zone and the south field produces from a combination of patch reefs and grainstones. Stromatoporoid boundstone, nodular micritic wackestone/mudstone, skeletal grainstone/wackestone, and fenestral/pelletal packstone facies all have been recognized from Buckeye (Figure 35).

Facies modeling within the South Buckeye field shows a patch reef and fringing grainstone distribution which is characteristic of patch reef complexes (Figure 36). Grainstones, which commonly fringe the reefs and flank beds, which normally develop around the reefs, are both limited because of the small vertical extent of the patch reefs. In the off-reef areas slightly deeper water deposition occurred and open marine wackestones and mudstones were deposited. These open marine deposits are also present filling in areas between the reefs. Deposition above wave base occurred in shallow areas where a fenestral/pelletal packstone facies was deposited. Development of the various facies complexes at Buckeye could have resulted from a combination of several major processes. A decrease in the subsidence rate along with a lowering of sea level and the build up of carbonate through time, all could have played a major role in the development of the facies observed at Buckeye. It is most likely that a small sea level
Figure 35. Generalized facies diagram of Dundee Limestone near the end of shallow water deposition, Buckeye oil field.
Figure 36. Suggested lithofacies map of Dundee Limestone, Buckeye oil field; based upon initial production and core data.
fluctuation made conditions favorable for reef growth in North Buckeye, either because it was on a slight topographic high or because it was in a zone where conditions were favorable for submarine lithification. Once reef growth was established, reefs built up to wave base at North Buckeye. Another subsequent lowering of sea level then moved the reefs at North Buckeye close enough to the water surface to where they were occasionally exposed. This exposure brought reef growth to an end and initiated shallow water conditions which resulted in the burrowing organisms colonizing the muds with the subsequent creation of fenestrae. The South Buckeye area, which also moved up closer to the water surface, now became a site favorable for the development of patch reefs. The two fields, fenestral and patch reef intervals, developed contemporaneously as evidenced by coral and stromatoporoid skeletal debris found washed into the shallow water fenestral packstones. A saddle developed between the two fields where the water depth was too deep for the burrowing organisms to live and to shallow for the reef organisms to colonize. An increase in the subsidence rate or a major sea level rise then caused deeper water, open marine deposition, to cover Buckeye. The overall facies pattern at Buckeye is a shoaling or shallowing upward sequence where first nodular open marine, then patch reef, and finally
fenestral/pelletal packstone deposition occurred. The whole sequence was then terminated by a return of deeper water deposition.

Reservoir Quality

Cross sections which correlate pay zones, from cable tool drilling in the Buckeye oil field, give a good indication of overall field homogeneity (Figure 37). Correlations performed by Addison (1940), show that the North field produces from one uniform zone. Development of this fenestral packstone created a homogeneous field which has good porosity and high permeability throughout because of the connective character of the fenestrae. The south field, on the other hand, has a more discontinuous, widely distributed, pay zone. Horizontal discontinuity exists between patch reefs. Reef flank deposits provide some connection, but are not uniform in thickness. Vertical separation in the pay zone homogeneity, indicates that reef growth and fringing grainstone development took place at various times throughout the deposition of the Dundee in South Buckeye, although most of the major reef growth and reservoir development took place at or near the same time as fenestral/pelletal packstone development in North Buckeye. Average depth to the pay zones is approximately 70 feet down from the Dundee/Bell Shale contact.
Figure 37. Correlation of pay zones in Buckeye oil field.
From Addison, 1940.
North/South and east/west lithofacies cross-sections (Figure 38), show that the porous zones of the reef and debris/flank grainstones across South Buckeye correspond well with the pay zone correlations of Addison (1940). The cross sections across South Buckeye (Figure 39), show a disjointed distribution of patch reefs, fringing grainstones, and open shelf facies (Figure 40). Because porosity is mostly facies controlled within the South Buckeye field and the producing facies are discontinuous, breaks should have developed where oil could not have migrated through tight nodular micritic open shelf zones. However, since dry holes are scarce within the field, secondary permeability enhancers must exist. Styolitization and fracturing are responsible for much of the enhanced fluid migration. Correlating between facies types and initial production of oil wells (Figure 41), have shown patterns of facies distributions throughout the field (Figure 36). The highest production values, greater than 500 B.O.P.D., correlate with the largest thicknesses of reef. Thinner reef sections, between 10 and 24 feet, are found fringing the highest production reef centers. This indicates that production, for the most part, is very dependent upon the facies present in that area. Central reef cores have the highest porosity and permeability values and thus the greatest production figures. As one moves away from the
Figure 38. Lithologic cross-section reference map South Buckeye oil field.
Figure 39. East/west lithologic cross-section map South Buckeye oil field.
Figure 40. North/south lithologic cross-section map South Buckeye oil field.
Figure 41. Initial production map South Buckeye oil field.
reef cores thinner sections of reef are encountered and production falls off accordingly. Grainstones, depending upon their thickness and extent, have variable productions but almost always lower than the reef masses. The open shelf facies has the lowest porosity and permeability and thus is the poorest producer among all the facies. Late stage diagenetic events, styolitization and fracturing, have increased the permeability of this facies so it usually produces minor amounts of oil.
REGIONAL IMPLICATIONS

Buckeye oil field is the sixth largest producing oil field in the state of Michigan based on 1982 statistics. Numerous other Devonian fields produce oil and 7 of the top 10 fields within the state, produce from the Middle Devonian Dundee Formation. Examinations of cores from some of these fields, Mt. Pleasant, Reed City, and Porter, indicate similar facies deposition to Buckeye (Figure 41). The producing facies from these fields is dominantly in a shallow water fenestral zone. Diagenesis in these areas is also similar to Buckeye suggesting that the processes that effected Buckeye were widespread. One variation on this is in the western part of the basin and in heavily fractured areas, where dolomitization has enhanced primary porosities.

Implications from these observations, indicate that although diagenetic and depositional conditions at Buckeye are geologically rare, they are characteristic of much of the diagenesis and deposition that occurred in the Middle Devonian of the central and eastern parts of the Michigan Basin.

Future oil exploration within the Dundee Formation should be based upon facies and diagenetic models established at Buckeye. Prospective areas would include central and eastern parts of the basin where the
shallowing of water at the shelf edge could cause favorable conditions for patch reef and fenestral packstone development. Since porosity is largely facies controlled, facies interpretation will be a valuable tool in locating and predicting future oil reservoirs. Subsurface analysis involving facies, isopach, and structure mapping along with seismic modeling, should provide many clues in the search for new oil and gas deposits within the Dundee Formation.
FUTURE RESEARCH

More future research is needed before we completely understand all the conditions and processes which acted on the Devonian sea floor when the Dundee Formation was deposited. Although information gained from Buckeye gives us a good insight into the conditions that existed in that field and others like it, a good regional study is still needed so as to we can understand the entire picture. Questions brought to light from the research performed at Buckeye, that need further investigation, include: (a) the importance or lack of importance of regional trends in the Dundee oil fields, (b) the role that structures play in the development of Dundee oil fields, (c) the recognition of shelf edges if any exist in the Dundee, and (d) the regional variation of diagenetic processes which acted upon Buckeye and other Dundee oil fields.
CONCLUSIONS

The Buckeye oil fields Dundee production comes from an fenestral/pelletal packstone facies in the north field and from stromatoporoid patch reefs and fringing grainstones, in the southern field.

Porosity within the patch reef facies is mainly primary intraparticle porosity and porosity within the North Buckeye field is a primary fenestral porosity which has undergone secondary solutional enhancement in some places.

The regional and most widely developed facies of the Dundee Formation, is the Rogers City Member, a dark gray, non-porous, skeletal, wackestone/mudstone which represents deposition in a normal open marine environment.

Styolitization and fracturing greatly enhanced permeability by connecting adjoining facies and improving fluid and hydrocarbon migration within the Buckeye field.

Deposition at Buckeye oil field represents a shoaling upward sequence where porosity is facies controlled and facies are partly structurally controlled.

Deposition of the Dundee, in the Buckeye oil field, is similar in both diagenesis and facies development to other Dundee oil fields located in the central and eastern areas of the Michigan Basin.
BIBLIOGRAPHY


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