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STRATIGRAPHIC AND SEDIMENTOLOGIC ANALYSIS OF THE MIDDLE DEVONIAN FILER SANDSTONE

by

John Charles Rodwan

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
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The Filer Sandstone, a multistory assemblage of lenticular sand bodies, is a member of the Middle Devonian Amherstburg Formation of the Detroit River Group in the subsurface of the western and central portion of the Michigan Basin. It is distinguished from the reworked eolian and nearshore marine sand facies of the underlying Sylvania Sandstone by recognition of its barrier island facies relationships and stratigraphic position within enclosing carbonates unique to the Amherstburg Formation. Lithologically, the Filer ranges from a fine-grained, carbonate-cemented, supermature quartzarenite at its upper shoreface facies, to a texturally-inverted sandy carbonate at its lagoonal facies. Facies distribution was controlled by sea floor topography. Source area for the sand is believed to be Cambrian and Ordovician sandstones of the Wisconsin Highland region to the northwest. From there, wind and streams distributed the sand to oscillating strandlines with attendant barrier islands in the Amherstburg Sea.
ACKNOWLEDGEMENTS

For offering their guidance and suggestions I express thanks to Drs. William B. Harrison, W. Thomas Straw and John D. Grace. Also, I am indebted to the following persons for providing materials or lending their services to expedite this investigation: Bill Bolio of Wiser Oil; Darwin Buthala of Western Michigan University; Joyce Budai of the University of Michigan; Peter Clemens of Western Michigan University; Denise Rodwan of Information Transfer Systems; and, Dianne Roycraft of the Michigan Department of Natural Resources.

John Charles Rodwan
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INTRODUCTION

General Statement

The Middle Devonian Amherstburg Formation, within the subsurface of the western and central portion of the Michigan Basin, contains a discontinuous sandy lithofacies termed the Filer Sandstone. Typically, the Filer is an assemblage of thin lenses of carbonate cemented, supermature detrital sandstones that are enclosed by and locally interbedded with limestone and dolomite (Figure 1). Disagreement concerning the Filer's depositional history and its stratigraphic distinction from the underlying, more extensive Sylvania Sandstone has prevailed since its discovery in well cuttings in 1928. Due to its intermittent distribution, its lack of exposures and its lack of known economic quantities of hydrocarbons, it has not been the subject of thorough inquiry.

Purpose and Scope

The intention of this investigation is to broadly describe the stratigraphy, petrology and environment of deposition of the Filer Sandstone in order to permit a more complete understanding of the Michigan Basin's geologic history during the Middle Devonian. Its main
LATE SILURIAN - MID DEVONIAN COLUMNAR SECTION
of the MICHIGAN BASIN

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Figure 1. Columnar Section of Late Silurian Through Middle Devonian Strata of the Michigan Basin. Modified from Gardner, 1974.
thrust is to provide geologic evidence supporting the contention that the Filer is a distinct and mappable sand unit, separate in stratigraphic position and depositional facies from the earlier deposited Sylvania Sandstone, and to describe the paleogeographic setting responsible for its deposition. Previous investigations, at best, only superficially address the Filer.

Although this report primarily focuses on the Filer Sandstone, frequent discussion of other Detroit River Group units occurs. This method of treatment is necessary to allow the Filer's relationship with enclosing rocks be adequately expressed.

Previous Work

The first detailed geological account of Middle Devonian Sandstones of the Michigan Basin was published in the Michigan Geological and Biological Survey authored by Sherzer and Grabau in 1910. They were unaware of the Filer's presence due to its absence in surface exposures and the absence of subsurface exploration; however, they forwarded an important precursory analysis of the Sylvania Sandstone (then considered a unit of the now obsolete Monroe Group).

Although the Filer's type section was recorded by well drillers in 1928, it was not described in the
geologic literature until Enyert's 1949 unpublished doctoral dissertation of the Middle Devonian Sandstones of the Michigan Basin. This monograph long stood as the most comprehensive account of the Filer Sandstone.

The second notable contribution on the Filer is Landes (1951). It is a broad account of the stratigraphy and geologic history of the Detroit River Group which has been widely read by persons interested in the Devonian of the Michigan Basin.

Briggs (1959) followed with a paper representing his efforts in interpreting the lithofacies of the Middle Devonian in light of modern physical-chemical and oceanographic data. The basis for his interpretations of the sedimentologic history are the lateral distribution of lithostratigraphic units, which are aptly displayed in a series of maps.

Ehman (1964), under the direction of Landes and Briggs, also conducted a stratigraphic analysis of the Detroit River Group. Although he failed to directly address the Filer, he was a forerunner in deciphering the kaliedoscopic set of Middle Devonian depositional environments.

In 1974, Gardner published a landmark paper describing the Basin's Middle Devonian stratigraphy and depositional environments. His investigation represents
a comprehensive attempt at constructing the basin's Middle Devonian depositional history from facies patterns present in the rock record, particularly the Richfield Member of the Lucas Formation.

Lilienthal (1978) promoted further understanding of the subsurface rock record within the Basin by constructing a series of cross sections based on wireline logs and by compiling concise descriptions of the respective rock units encountered.

In 1985 a core workshop on the Michigan Basin's Devonian strata was held at Western Michigan University. In attendance were geologists interested in or knowledgeable on the Middle Devonian. Numerous ideas and interpretations of the Filer's occurrence and depositional history were discussed at this meeting.

Methodology

An extensive review of literature focused on the Michigan Basin subsurface revealed that the stratigraphic and facies relationships of Detroit River Group rocks has been subject to widely varying interpretations. Similarly, it was found that the Filer has received only rudimentary description and was sometimes miscorrelated or ignored. During the initial phases of this investigation it became clear that a concept of
"layer-cake" stratigraphy fails when addressing Detroit River Group units and a concept of highly variable facies transitions within relatively small vertical and areal extents must be adopted.

Following the literature review, drilling reports of wells within the Filer's suspected range and a random review of drilling reports outside the Filer's suspected range were examined. Comparisons were made among the reports of wells that penetrate Middle Devonian strata (Appendix A). Those reports with representative accounts of Filer or Sylvania Sandstone (or simply "sand") were selected to serve as control points (Figure 2).

Wireline logs from corresponding control wells were procured (when they existed) and 47 were chosen for correlation and cross-sectional definition of their respective sandstones. The logs were analyzed to determine the diagnostic signature the sandstones impart to them and subject formation contacts were picked and correlated. In this manner, the geometry of the sandstone bodies was defined and their vertical relationship to enclosing units became evident.

Armed with this gross morphological data, a review of the Michigan Basin's subsurface sample depositories was made to identify sources of Middle Devonian sandstone samples, both core and cuttings. The primary sources of
Figure 2. Map of the Southern Peninsula of Michigan Showing Study Area and Location of Wells Used for Study.
samples included Western Michigan University's Core Research Laboratory and the University of Michigan's Subsurface Laboratory. Of the approximately 2500 cubic miles of subsurface the Filer Sandstone occupies, only about 10 cubic feet of sample were available for examination.

Once samples were acquired, they were first reconciled with their corresponding drilling reports and wireline logs. They were next described as pertaining to their lithologic and petrologic parameters. Sedimentary structures and contacts were also noted. Sample analyses were made at four scales: (1) cores at specimen scale; (2) cores and disaggregated grains with low magnification binocular microscope; (3) thin section at 35X-250X magnification; (4) scanning electron microscope at 48X through 20,000X magnification. The thin sections were prepared from selected intervals of four cores. Grains that underwent scanning electron microscope (SEM) analysis were disaggregated from "chips" (from corresponding thin sections) using hydrochloric acid and coated with a thin veneer of gold. Thin section and SEM analysis forms the basis of the petrographic discussion.

Depositional conditions responsible for the Filer Sandstone were largely inferred by comparing facies relationships, petrography, texture, sedimentary
structures and external sand-body morphology, to well-documented accounts of Holocene sand environments.
The Michigan Basin is a roughly circular, relatively shallow, intracratonic structure bordered by the Canadian Shield to the north, the Wisconsin Arch to the west, the Kankakee Arch to the south and the Findlay Arch to the east. Its depositional center appears to be slightly northwest of Saginaw Bay. However, significant variations in the depocenter occurred during the Cambrian and Ordovician Periods. The Middle Devonian, a pre-Acadian Orogeny period, is tectonically characterized as a time of relatively continuous subsidence that is aptly reflected by its constituent sediments (Gardner, 1974).

Numerous authors have contributed to our knowledge of the Basin's structural evolution. Popular theories on its formation include: the Basin as an intervening region of structural subsidence partially enclosed by Precambrian derived arches (Pirtle, 1932); differential subsidence of major fault blocks (Lockett, 1947); flexure of an elastic lithosphere under a confined load (Haxby, Turcotte and Bird, 1976); and, wrenching (Prouty, 1983). According to Sleep and Sloss (1980), surficial loading is inadequate to account for the magnitude of subsidence that has occurred. Multiple
early Paleozoic heating events would be necessary if thermal contraction of the lithosphere is to be invoked. Deep drilling has not substantiated the presence of early Paleozoic heating events. Although no single theory is universally accepted, most investigators believe that the basement and lines of weakness within the basement played fundamental roles in the evolution of the Michigan Basin. Hinze and Merritt's (1969) Bouguer gravity and magnetic anomaly maps display parallelism to Gardner's (1974) isopach-lithofacies maps, which also is suggestive of a pre-existing basement control of sedimentation.

What is actually known of the Basin structure is primarily derived from subsurface data provided by drilling and geophysical exploration. From this data, especially core samples and wireline logs, we are able to observe the facies changes that correspond to the structural events in the Basin.
GENERAL STRATIGRAPHY OF THE DETROIT RIVER GROUP

In order to more fully understand the Filer Sandstone's occurrence and relationship to enclosing rocks, a general stratigraphic overview of the lower Detroit River Group is here expounded. At the beginning of the Devonian System, the Michigan Basin entered a period of major transgression with several episodic regressions. In the sequence terminology of Sloss (1963), the initial transgression corresponds with the beginning of the Kaskaskia Sequence and the stratigraphic hiatus following the Tippecanoe Sequence. Throughout the Michigan Basin, the basal contact of the sediments represented by the Kaskaskia Sequence marks the base of the Devonian. The Garden Island Formation, a greatly eroded sand-bearing carbonate unit, is the basal formation found in the Mackinac Straits region. Elsewhere in the Basin, the Bois Blanc, Amherstburg and Lucas Formations each contain a basal sand component.

The distinct, but interrelated, units of rock comprising the Detroit River Group cannot be simply characterized by a single core or a single columnar section. This is evidenced by the sequenced complexes of carbonate, evaporite and clastic sediments that were deposited in a facies mosaic of environments within the
intracratonic Michigan Basin. Primary factors resulting in the character of Detroit River rocks include: variations in sea level, subsidence rates, clastic input and rates of sedimentation.

The stratigraphic confusion that is endemic to the Detroit River Group is largely due to a lack of paleontologic control within the Group. Briggs (1959) recognizes that until fossil zones distinct from formations are established, many stratigraphic uncertainties will persist. For the present it is necessary to define its stratigraphy solely on lithologic parameters.

The formations of the Detroit River Group thin rapidly from the central basin area to the exposure area in southeast Michigan and northwest Ohio (Ehman, 1964). This is attributed to a transgressing sea on the northwest flank of the Cincinnati Arch and erosion and uplift on adjoining arches.

Garden Island and Bois Blanc Formations

Scattered across portions of the northern reaches of the Michigan Basin and possibly portions of southwest Michigan (Ells, 1958) are thin patches of the Lower Devonian Garden Island Formation. Gardner (1974) concludes, by way of sample and log analyses, that the
Garden Island is a basal clastic phase of the transgressive Kaskaskia Sequence closely related to the cherty carbonates of the Bois Blanc and the Sylvania Sandstone of the Michigan Basin and the Springvale and Oriskany Sandstones of Ontario and New York, respectively. In the subsurface it is typified by a buff-colored, sand-bearing dolomite.

The Bois Blanc Formation is recognized as the most widely distributed basal Devonian Formation in the Lower Peninsula. In the subsurface it is generally recognized as a brown, buff or gray carbonate containing variable amounts of chert. The Formation was originally named by Ehlers in 1945 to describe the 360 feet of cherty carbonates that are partly exposed on Bois Blanc Island in the Straits of Mackinac region. Locally, the Bois Blanc overlies the Garden Island Formation. No occurrences of the Bois Blanc have been recorded in the southwestern or southernmost tier of Michigan counties, thus, is there presumed absent.

In the subsurface, the top of the cherty Bois Blanc carbonates are interbedded and gradational with the sands and sandy carbonates of the Sylvania, or the Amherstburg when the Sylvania is absent. Its clastic and conglomeritic base generally lies immediately above the sub-Kaskaskia unconformity, or locally, the Garden
Island. The Bois Blanc-Sylvania interval has recorded thicknesses exceeding 800 feet in the central basin area. Thicknesses decrease markedly to the north and the northwest. In the west and the south, the Formation is poorly defined due to its removal or partial removal by erosion. Ehlers, Strumm and Kesling (1951) report the possibility that a portion of the Bois Blanc in southeast Michigan may be a sandstone that is erroneously assigned as basal Sylvania.

Correlation of the Bois Blanc can be accomplished with accuracy throughout the central basin area by noting its slightly higher radioactivity than that present in the overlying Sylvania. When the Sylvania is absent, however, it is differentiated from the overlying Amherstburg by its lower radioactivity and higher porosity.

Sylvania Sandstone

Overlying the Bass Islands Group carbonates in northwest Ohio and the Bois Blanc or Garden Island Formations in the Michigan Basin are found the extensive blanket sand deposits comprising the Sylvania Sandstone. The Sylvania has received much more detailed inquiry than the Filer Sandstone; partly due to the existence of Sylvania exposures in northwest Ohio and extreme
southeast Michigan, and partly due to its greater extent. The Sylvania Sandstone was first differentiated in 1871, but was not named until 1888 (Orton) after exposures in Sylvania Township, Lucas County, Ohio. These exposures and the exposures in Wayne County, Michigan, lie on the northwest flank of the Cincinnati Arch and are the only surface representatives of Detroit River Group sandstones. Hatfield, Rorhbacher and Floyd (1968) describe the Sylvania as a very sparsely fossiliferous, conspicuously cross bedded, supermature orthoquartzite that is the most lithologically distinct unit of the Detroit River Group. Other contributions to understanding the stratigraphy and depositional history of the Sylvania are by Sherzer and Grabau (1910), Alty (1932), Carman (1936), Landes, Ehlers and Stanley (1945), Enyert (1949), Landes (1951), Ehlers, Strumm and Kesling (1951), and Summerson and Swann (1970).

The basal Devonian (basal Kaskaskia) sandstones corresponding to the Sylvania Sandstone are the Oriskany Sandstone in the Appalachian Basin and the Dutch Creek Sandstone in the Illinois Basin. These cratonic basin sandstones, with their attendant basal unconformities, permit stratigraphers to identify the break between the Tippiecanoe and the Kaskaskia Sequences. Over much of the balance of the craton, however, the basal formations
of the Kaskaskia are carbonate rocks resting on other carbonate rocks. The unconformity in these cases is locally difficult to determine from single outcrops or cores.

Generally, the Sylvania's upper contact is conformable, but is truncated at the Formation's southernmost extent. Northward from the outcrop area, the upper contact becomes gradational and locally interbedded with overlying carbonates, rendering it difficult to define precisely. As a result of the southward increase in stratigraphic hiatus associated with the basal unconformity, the Sylvania rests progressively on older rocks southward.

The Formation represents the sediments deposited during a minor regression within an overall transgressive period (Gardner, 1974). In comparison to the Filer Sandstone, the Sylvania is a relatively thick unit, exceeding 300 feet near the Basin's center and in Washtenaw County. At its northernmost extent, its upper contact is conformable with the Amherstburg Formation except in isolated areas where it is unconformable with the Lucas Formation due to the Amherstburg having been removed by erosion. Where the Sylvania-Amherstburg transition is finely gradational and lacks fossils, the actual horizon chosen as the contact is arbitrary.
Moreover, only where the transition is sharp can the Filer's boundaries be delineated with a significant degree of confidence.

Since the Sylvania represents deposition during a minor withdrawal of the sea in an overall transgressive period, it is a time-transgressive unit; ages vary from Late Silurian through Early Middle Devonian. The Formation represents the greatest accumulation of sand during the Devonian System within the Michigan Basin and its geographic distribution coincides remarkably with the mid-Michigan gravity-magnetic high (Hinze and Merritt, 1969). Gardner (1974) states that this correlation, and the facies relationship with the underlying Bois Blanc carbonates, suggests a persistent shoreline environment along a shelf hinge-belt at the time of deposition. This hinge-belt is found trending approximately northwest-southeast from Clare County, Michigan to Monroe County, Michigan.

Amherstburg Formation

Throughout the subsurface of the Southern Peninsula, except in the southeast and southwest corners where it has been removed by erosion, are found strata of the Amherstburg Formation (Figure 3). Absence of the Amherstburg in southwest Michigan is attributed to
Figure 3. Amherstburg Formation Isopach Map. Contour Interval 100 Feet.
erosion prior to the overlapping Lucas Formation. In the eastern and southern portions of Monroe County, erosion is so complete as to have exposed the underlying dolomite rocks of the Bass Island Formation.

The Amherstburg was named from the thick-bedded brown dolomite brought to the surface during the dredging of the Livingstone Channel of the Detroit River, west of Amherstburg, Ontario. It was first described in detail by Sherzer and Grabau (1910) who wrongly assigned it Upper Silurian in age. Exposures are located in the Cummins Quarry in the southeast 1/4 of Section 2, T8S, R6E near Monroe, Michigan; in several quarries near Sylvania, Ohio; and, in roadcuts near Amherstburg, Ontario. The thickest known sections are found in the subsurface of the Saginaw Bay area, where intervals in excess of 300 feet are common. The Amherstburg's area of maximum extent roughly corresponds to the maximum extent area of the Sylvania Sandstone.

Two distinct members occur within the Amherstburg, the Filer Sandstone Member being a composite of shallow-water marine and barrier island sand facies, and the Meldrum Member being a biostromal carbonate facies. Except for the Filer Sandstone Member, the Amherstburg Formation is predominantly carbonate in composition. Dolomite prevails in the Formation's southern and western
extent; limestone prevails in the north and south (Figure 4).

Figure 4. Lithofacies Map of the Amherstburg Formation.

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Meldrum Member

The most notable feature of the carbonate portion of the Amherstburg Formation is the Meldrum Member. This dark-colored limestone and dolomite is typically best developed in the central portion of the basin (Figure 5) and is characterized by well-preserved fossil remains of corals and stromatoporoids. It is common practice for persons discussing the Detroit River portion of the Devonian to informally refer to the entire carbonate section between the lowermost evaporites of the Lucas and the top of the Sylvania as "Black Lime". This practice misrepresents the Amherstburg since it potentially misassigns up to 125 feet to its thickness and homogenizes it by ignoring its distinct members. Gardner (1974) assigned the name "Meldrum" to this black colored carbonate unit with the intent of easing stratigraphic confusion and aiding in the correlation of Detroit River Group strata.

Multiple intervals of Meldrum are locally interbedded with drab-brown, largely unfossiliferous carbonate rocks that typify the remaining carbonate portion of the Amherstburg. Its top extends from 50 to 250 feet above the base of the Amherstburg in the eastern and northern portions of the Basin and 20 to 100 feet
Figure 5. Meldrum Member Isopach Map. Contour Interval 50 Feet.
above the base in the western and southern portions. The lower boundary in many places is indistinct due to a gradual lightening of color. In wells where the contact between the Amherstburg and enclosing units is gradational and difficult to determine, the Meldrum has proved to be a reliable marker bed in approximating position in the subsurface column. The Meldrum facies, classified as either a wackestone,packstone or boundstone in the terminology of Dunham (1962), is typically best developed in the uppermost portions of Amherstburg sections. Its dark color is thought to be imparted by the presence of finely disseminated, carbonaceous partings. The observed upward increase in dark coloration is indicative of a reducing environment during deposition.

Filer Sandstone Member

Occurring within the lower sections of the Amherstburg Formation in the west and central portions of the Lower Peninsula are found the multistory-multilateral lenticular packages that comprise the Filer Sandstone Member. In vertical sections, the Filer generally occurs 75 to 140 feet below the lowermost evaporites of the Lucas Formation and 15 to 40 feet above the top of the Sylvania Sandstone; but considerable variations occur,
depending on position respective to other depositional facies. The Filer is locally interbedded with the Meldrum Member and is frequently multistory, suggesting that the depositional rate was essentially the same as the subsidence rate.

The Filer is portrayed on the generalized isopach map (Figure 6) as an east-west trending multi-lobed unit across the west and central portion of the Lower Peninsula. On a regional scale, its intermittent nature is difficult to depict due to poor distribution of subsurface control points and paucity of core samples. Therefore, a regional isopach map of the Filer is, at best, only a guide to estimating areal extent and thickness. Since outcroppings of Filer are non-existent, samples are from either borehole cuttings or occasional core retrieved from wells drilled for brine, injection, or hydrocarbons.

The Filer's type-section is based on the cuttings from the Ruggles and Rademaker 24 well, Filer Township, Manistee County (Appendix A). This well was drilled for brine; its cuttings are mounted on a strip log that is available for inspection at the Subsurface Laboratory at the University of Michigan. The Filer is assigned member status due to its invariable occurrence as a sand unit enclosed by Amherstburg carbonates, whether they be the
Figure 6. Generalized Isopach Map of the Filer Sandstone. Contour Interval 10 Feet.
drab-brown, slightly fossiliferous limestone and dolomite that typifies the Amherstburg, or the black, highly fossiliferous limestone and dolomite of the Meldrum Member. It is generally in conformable contact with its enclosing units, with diastems locally common.

Due to the relative minor extent of the Filer compared to that of the Sylvania's, and due to the vertical proximity and lithologic similarity between the two sandstones, they have frequently been mislabeled (often considered a single Sylvania unit). Stratigraphically, a more tenable theory is rendered when they are considered distinct units separated by significant amounts of time and by differing depositional facies. Misassignments of the Filer particularly occur at its eastern fringe, furthest from its Wisconsin Highland source area, where it is locally multistory and only a few feet above the sandy carbonates of the Sylvania. Distinction between the two units is made possible from careful wireline log correlation and by recognizing the Filer's barrier island facies assemblage within typical Amherstburg Formation carbonates.

In the Pure-Zimmerman A-1 well core, Osceola County (Appendix A), the Filer's upper section is in gradational contact with the Meldrum Member; in this section, isolated sand grains are observed "floating" in Meldrum
carbonates. Similarly, in the Hunt-McGuire 1-22 well core, Oscoda County (Appendix A), the Filer occurs as several thin beds separated by typical Amherstburg carbonates. These features are suggestive of an intertonguing of facies near the edge of the depositional environment.

Amherstburg-Lucas Formation Transition Strata

Following accumulation of the sediments deposited by the open marine to shelf facies of the Amherstburg, the basin became increasingly restricted and open marine facies all but disappeared for the remainder of Detroit River Group time. The Lucas Formation is the uppermost Detroit River Group formation and represents its major regressive phase. Only its basal portion containing the Richfield Member and the strata transitional with the Amherstburg Formation are discussed in detail here.

What is traditionally labeled as the Freer Sandstone Member occurs within the light-colored and largely unfossiliferous dolomite of the Lucas-Amherstburg transition strata below the last anhydrite stringer of the Richfield Member and above the darker colored, fossil bearing carbonates of the Amherstburg Formation. This is an idealized sequence; in no instance has a single core been curated and studied in which the Sylvania, Filer and
alleged Freer Sandstones are each distinctly present. The "Freer" is too indistinct to map, therefore should not be granted member status. It is likely that the Freer is simply a localized upper phase of the Filer within transitional Lucas-Amherstburg carbonates.

The Richfield Member is an interbedded sequence of anhydrite and dolomicrite with localized sandstone pods and stringers. Its deposition was relatively continuous, but evidence in the form of rip-up clasts deposited during storm events suggests that short-lived subaerial exposures occurred.
GEOMETRY

Information necessary to define the Filer Sandstone's geometry is scant. Specifically, it often escapes detection on wireline logs due to its intermittent and calcareous nature. Also, due to a lack of significant hydrocarbon shows, thus far, it is rarely cored and control points necessary to define its distribution are widely spaced. Internal features such as cross bedding, flow structures and in situ preferred grain alignments are known from only three closely spaced cores in the central portion of the Filer's lateral extent. Only in the western portion of the Basin is the Filer faithfully recorded by well site personnel. Nevertheless, the Filer's general morphologic nature can be envisioned by the careful construction of three-dimensional graphic representations based on available cores, cuttings and wireline logs.

Only when a series of relatively thick and carbonate-free sand sections are encountered by subsurface instruments do characteristic discontinuous sheet bodies become evident (generally, less than five feet of sand is undetectable with conventional wireline logging techniques). Mapping the Filer is a particularly difficult task when its carbonate content is high. The
greatest overall known accumulations of Filer are found in Manistee and Benzie Counties where thicknesses exceeding 50 feet are common. Although the Filer isopach map (Figure 6) implies that the subject sandstone terminates at the Lake Michigan shoreline, it is nearly certain that it continues westward beneath the Lake for a considerable distance. Due to the prohibition of offshore drilling in the Great Lakes, its western boundary cannot be accurately defined.

Based on the fact that a particular well may penetrate a relatively thick sandstone interval or multiple thin intervals, whereby offset wells within the same interval and perhaps less than one-half mile away encounter only minor sand shows or erosion surfaces, the Filer is considered discontinuous. Many of the "lenses" are actually composites of multistory and multilateral series of sandstone bodies, for this report termed "packages". This sort of morphology is common to prograding barrier island complexes and meandering river channels (Shelton, 1973). Although barrier islands are generally linear features, a coalescing of barriers and shallow marine sands by accretion may have formed the amalgamation of slightly elongate to ovate, tapered, sheet-like sand bodies that characterize the Filer Sandstone. The rather rapid sea level fluctuations that
caused the migration of these sands largely masks any "typical" sand body geometry that might by associated with a particular sedimentary environment.

The sand bodies comprising the Filer are more continuous than the cross sections (Figures 7 and 8) suggest, being connected by relatively thin sandstone beds or by carbonate units rich in floating sand grains that are representative of lagoonal environments. However, when core samples are not available (generally the case) greater continuity is difficult to substantiate. Distribution or isopach maps of the Filer are based on a significant degree of interpolation since subsurface control is not sufficient to describe any but the largest packages.

It should be noted that isolated occurrences of sand and sandstone within the Filer's expected vertical regime have been recognized in several localized areas significantly distant from the zero thickness line as indicated on the isopach map (Figure 6). It is likely that these occurrences represent isolated lentils and are of minor extent. Likewise, floating sand grains are observed throughout carbonate portions of the Richfield Member and the balance of Amherstburg sections. An excellent example of significant detrital sand populations within a largely carbonate and evaporite unit
Figure 7. Stratigraphic Cross Section Based on Wireline Logs. Datum is Filer Sandstone Top in Feet Below Sea Level as Measured From Kelly Bushings.
Figure 8. Stratigraphic Cross Section Based on Lithologic Logs. Datum is Filer Sandstone Top as Measured in Feet Below Sea Level From Kelly Bushings.
is the Hunt-Bray 2-30 well core, Clare County (Appendix A). In this core, floating sand grains are ubiquitous to the Richfield carbonates (which are interbedded with anhydrite stringers). These sandy intervals must simply be considered sandy lithofacies of the Richfield Member because the dictates of the Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983) hold that members cannot occur within other members.
IDENTIFICATION IN THE SUBSURFACE

It is important to discern among the sandstone units contained within the subsurface Detroit River Group in order to properly interpret their sedimentary and stratigraphic relationships. Gamma ray and neutron logs are of primary importance in identifying Detroit River Group sandstones. An example of the response a well developed Filer Sandstone interval imparts onto a gamma ray log from the northwest portion of the basin is shown in the Shell-Henry well log from Grand Traverse County (Figure 9).

Beginning with the earliest deposited unit, the Sylvania Sandstone, identification is accomplished by noting the basal unconformity and the predominance of sand in samples directly above the Bois Blanc or the sandy carbonates of the Garden Island Formation, or by noting the lowered radioactivity response the "clean" sands impart to gamma ray-neutron logs. Correlation of the Sylvania Sandstone in the center of the Basin is accomplished with a significant degree of certainty, but becomes more speculative as the edges of the depositional facies are approached. Along the northern fringe of its range, interbedded sandstones and carbonates are the rule. This characteristic is largely responsible for the
Figure 9. Typical Gamma Ray Log Showing Response to Lower Detroit River Group Strata.
stratigraphic ambiguities that have existed between the Filer and the Sylvania Sandstones. Cores from portions of the Sylvania-Filer overlap region locally contain multiple intervals of sandstone within the Upper Sylvania through the carbonates of the Lower Richfield, with individual intervals generally less than five feet thick that were deposited by largely similar processes.

The top of the Amherstburg Formation is identified in the subsurface by noting its anhydrite-free, carbonate lithofacies as observed in cores or cuttings, or by noting the characteristic response it imparts to wireline logs. Gamma ray-neutron logs typically display a convex-to-the right deflection and often show a distinctive radioactive peak (possibly from an ash bed) near the Formation's top. Although not a precise practice, as has been previously discussed, the Amherstburg's top in the subsurface can be estimated as being the carbonates just below the last major anhydrite strata of the Lucas.

Where samples are available, the top of the Amherstburg should invariably be selected as the darker-colored, slightly to highly fossiliferous carbonate rocks below the last anhydrite bed of the Lucas. The actual contact between the Amherstburg and the Lucas is arbitrarily selected when the two units are
gradational and are of similar lithofacies.

The Meldrum Member is considered a valuable marker bed owing to its distinct lithology (APPENDIX B, Plates 1-4), widespread extent and its characteristic response as seen on gamma ray-neutron logs. It is best developed in uppermost Amherstburg sections, though may or may not appear in any particular well within its described range, depending on the depositional facies present during accumulation.

Dependable identification of the Filer Sandstone without the aid of samples is accomplished by either the recognition of the lowered radioactivity response observed on nuclear logs when a relatively thick and carbonate-free interval is encountered or by recognition of its subtle response as seen within its expected interval when a minor occurrence is encountered. It invariably occurs within Amherstburg carbonates. In certain instances, particularly in the eastern portion of its range, it is noted to intertongue with the Meldrum Member. To the west it generally occurs lower in Amherstburg sections than in the east.
LITHOLOGY

All detrital grain components contained within Middle Devonian sandstone bodies of the Michigan Basin are lithologically similar. Carman (1936) conducted the first detailed petrographic studies of the Sylvania, but unfortunately restricted his work to outcrops of Sylvania Sandstone in northwest Ohio and southeast Michigan. Enyert (1949) followed with additional Sylvania studies and recorded the first detailed descriptions of the Filer Sandstone and sand within the Lucas Formation. In general, these sandstones may be classified as quartzarenites (Potter, 1967), owing to their supermature petrography, sheet-like geometry, cratonogenic derivation and their distribution on a craton margin. Due to the paucity of heavy minerals, the near absence of unresistant minerals, the high degree of rounding and sorting, and the overwhelming percentage of quartz, it is concluded that the component sands have undergone multiple cycles of eolian transport. The sands are monotonously cemented by either a syngenetic, crystalline limestone or a fine to coarse-grained secondary dolomite. Approximately 60% of the cement is dolomite and 40% is limestone. In only one instance is an interval of siliceous cement prominent. Carbonate content varies
from 4% to 30% and may act as either a cement or a matrix. When sand grains are suspended within a calcareous matrix, a shallow carbonate precipitating environment that was subjected to periodic incursions of wind-blown or washover sand is inferred (near-bar lagoonal facies).

A large proportion of the Filer Sandstone is observed to contain greater than 5% clay (indigenous carbonate mud in this case), which, in Folk's (1974) classification scheme, would result in classification as texturally immature. Since the detrital grains themselves are generally mature to supermature, yet contain varying amounts of clay sized material, a textural inversion is invoked (APPENDIX B, Plates 5-8). This textural type indicative of a mixing of products of two energy regimes, with the sorted and rounded sand grains having been blown from barrier bars or dunes (high energy) and deposited in a carbonate mud, lagoonal substrata (low energy). In most cases, the grains are evenly disseminated throughout the matrix, although bioturbation occasionally results in irregular sand patches and stringers.

Common to Detroit River sand grains are frosted surfaces believed to result from multitudes of grain collisions while undergoing transport. Krynine (1948)
reports that only in a dunal environment can significant frosting and a high degree of rounding be achieved. Frosting is characteristic of modern desert sands and, to a lesser degree, beach sands, which have undergone a significant amount of transport (APPENDIX B, Plates 9-10). Since the sands are multigeneration, to a large degree the grains were probably already frosted (as well as sorted and rounded) upon introduction into the Filer sand distribution network. In many cases, close inspection of the grain surfaces reveals subsequent polishing of the frosted surfaces (especially in Sylvania grains), presumably the result of agitation in strandline environments. Whatever the case, the mere fact that grain frosting occurs is not sufficient evidence to conclude an eolian mode of transport.

Frosting aside, quartzose Detroit River sand grains commonly exhibit syntaxial silica overgrowths (APPENDIX B, Plates 11-14). Scanning electron microscopy aptly displays the overgrowths as multifaceted, often doubly terminated and complex silica veneers (APPENDIX B, Plates 15-18). In isolated instances the overgrowths display evidence of mechanical weathering, which is suggestive of an earlier generation of overgrowth having undergone the destructive influence of subsequent transport. The doubly-terminated crystals commonly have the long axis of
the long axis of the newly generated crystal of greater dimensions than the original grain. When mud content is low (such as in barrier bar or beach facies where significant winnowing has occurred) and enlargements abut, sutured contacts are commonly observed (APPENDIX B, Plates 19-22). Other than being optically continuous with their respective parent grain, the actual boundary between adjacent overgrowths is sometimes difficult to determine.

The majority of quartzose grains display straight to slightly undulose extinction and contain diminutive gas bubbles, bubble trains and inclusions, all of which are suggestive of an igneous origin (Pettijohn et al, 1972). The balance of the quartz grains, approximately 5%, display undulose to extremely undulose extinction (APPENDIX B, Plates 23-26) and a few grains are polycrystalline, all of which are suggestive of a metamorphic source.

The Sylvania Sandstone in the outcrop is a massive to cross bedded, white, highly-friable sandstone interbedded with varying amounts of dolomite. Actually, it may be considered either a sandstone, a dolomitic sandstone or a sandy dolomite depending on the percentage of carbonate material present, often which approaches 60%. Carman's (1936) grain size and sorting studies
indicate a high degree of uniformity of the Sylvania in the area of its outcroppings. He asserts that the sand at these locations represent the Formation's southern terminus and accumulation furthest from its source area. Accordingly, the grains are of a finer mean grain size and contain fewer heavy minerals than their counterpart sands to the north. Hatfield et al. (1968) report a modal, mean and median grain size each very near to 0.25mm with typically 90 to 98% of the grains between 0.1 and 0.5mm.

Carman (1936) reports some locales in southeast Michigan where the Sylvania is prominently cross-bedded, with varying dip directions of the laminae, as in dune sand. Cross-bedding has not been observed in the exposures of northwest Ohio. Hatfield et al. (1968) also describe a northwestward inclination of cross beds in the outcrop area which corresponds to the regional dip and regional thickening into the Basin. Also, the long dimensions of the grains here suggests preferred orientations in that direction. Gardner (1974) maintains that the grain size distribution and orientation appears to be a product of northwesterly flowing marine currents.

The lithology of the Filer Sandstone has previously been reported as similar, if not identical, to the Sylvania Sandstone. It is now known that although their
detrital populations are almost indistinguishable, their overall lithologies are quite different. Previous investigations were based largely on the descriptions of the sandstone as given in drilling reports and on the occasional examination of cuttings samples. Three relatively thin core intervals containing the Filer have been studied for this report. Their inspection reveals that they have not been previously subjected to thorough lithologic investigations, i.e., they were obtained largely intact, neither being slabbed nor segmented for insoluble residue analysis or thin section preparation. Since the Filer has frequently been mislabeled, it is possible that a relatively thick interval was cored but was assigned to the Sylvania Sandstone.

Broadly, the Filer can be considered a quartzarenite. A point count of non-quartz grains reveals that less than 1% of the grains are of a composition other than quartz. Minor amounts of microcline, orthoclase, epidote, garnet, hornblende, limonite, magnetite, pyrite, rutile, tourmaline and zircon have been observed in thin sections. The heavy minerals zircon, tourmaline, pyrite and limonite make up a very small fraction of the total non-quartz composition. The best samples of Filer known to exist include the following: the mounted cuttings from the
Ruggles and Rademaker 24 well; the five foot interval of Filer from the Pure-Zimmerman A-l core, Osceola County; and, the five foot Filer interval from the Pure-Mulder 1 core, Clare County (see Appendix A for well locations). The sand in these samples range from very fine to medium-grained, are rounded to very well rounded, sorted to very well sorted and approximately 60% dolomite cemented and 40% limestone cemented. Sorting, rounding and packing vary widely in relatively thin vertical distances. Although not prominent, a coarsening upward trend of grain size is evident within individual sand bodies. Bimodal sorts are commonly observed. The described textural variations oppose generalizations made by previous investigators who portray the Filer as invariably a well-rounded and well-sorted sandstone. Authigenic pore fillings, largely calcite, dolomite, anhydrite and celestite, were formed from precipitation of migrating pore fluids.
INTERNAL FEATURES

Since multiple thick intervals of Filer Sandstone were unavailable for examination, it is probable that a fair representation of sedimentary structures contained within the Filer was not observed. However, several thicker intervals of Sylvania and numerous sandy intervals within Amherstburg-Lucas transition strata were examined and their component sedimentary structures noted.

Drilled in 1945, the cores taken from the Pure-Freer 1 well, Clare County (Appendix A), contain the thickest known sandstone section, 47 feet, within Amherstburg-Lucas transition strata. The well was presumably cored due to a show of gas. It actually produced for a short period of time, generating a fair amount of speculation as to the possibility of other hydrocarbon shows in other similar intervals. Slabbing of the core for this report revealed numerous sedimentary structures and diagenetic features previously not known to occur in Middle Devonian sandstones outside of the Sylvania. As evident in the photomicrographs and photographs of core sections in APPENDIX B, Plates 27-30 cross bedding, bioturbation and dewatering structures are prominent. The cross bedding and bioturbation observed
are typical of nearshore deposition.

Of particular interest is the cross stratification and burrowing observed in the Pure-Freer 1 core. The cross beds are relatively thin and uniform, typically the sort formed in a nearshore setting by ripple phenomena. Although the detrital grains in this section display mature, multigeneration, quartzose sands typically associated with eolian deposition, the fact that nearshore deposition features are prominent, lends credence to a nearshore depositional facies model. Also evident in the Pure-Freer 1 core are numerous well-preserved burrows and dewatering (degassing?) structures. Many burrows clearly show as vertical, homogeneous structures passing through varicolored beds and laminations.

In portions of the Pure-Zimmerman A-1 core, the sand grains are loosely packed in a nearly black limestone and dolomite matrix representative of a reducing, carbonate environment. In one interval the grains are locally concentrated in crenulated laminations, probably algally derived, averaging 0.5 cm in thickness. It is likely that the grains in this section were wind transported from an adjacent bar or dune and deposited in a supratidal environment.

Indicative of an emergent or shoaling facies are
blocky, torn remnants of paleosols intermixed with the bedding or laminations. A striking example of paleosols are found in portions of the Hunt-Bray 2-23 core (Appendix A).
DEPOSITIONAL HISTORY OF DETROIT RIVER SANDS

Detroit River time can be divided into two general periods of major transgression and regression (Figure 10). The initial transgressive-regressive cycle resulted in the deposition of the carbonates and clastic sands of the Sylvania-Amherstburg interval. The second cycle resulted in the deposition of the carbonates and evaporites of the Lucas Formation.

It is well known that fine to medium-grained, well-sorted, well-rounded quartzose sand is a common constituent of many units of Early and Middle Paleozoic age in the central part of North America. According to Summerson and Swann (1970) these sands occur in varying concentrations in the Middle Devonian rocks that immediately overlie the erosion surface truncating the Silurian and Lower Devonian strata as shoreline and shallow marine deposits, marking subsequent advances and retreats of the Devonian sea. These authors, who studied the patterns of Devonian sand of the North American craton, assert that the vertical repetition of similar-appearing sandstones has led to misidentification and miscorrelation of stratigraphic units in this region.

The basal Kaskaskia surface represents the base of the Devonian throughout the Michigan Basin. Sand is
Figure 10. Figure Showing Oscillatory Nature of Seas of the Michigan Basin During the Early and Lower Middle Devonian. $T =$ Overall Transgressive Period. $R =$ Overall Regressive Period. Modified From Gardner, 1974.
present on this surface whether the lowest formation is the Garden Island, as in the Straits of Mackinac area, or the Sylvania, as in the widespread arc trending from the central basin area to northwest Ohio.

Sylvania Sandstone

Geologists have long disagreed about the depositional history of the Sylvania. As previously discussed, Sherzer and Grabau (1910) postulated that eolian processes were responsible for the Sylvania's deposition, basing their contentions primarily on the fact that a large percent of the Sylvania's grains are frosted as seen in modern sand dunes. Carman (1936) later refuted the notion that eolian forces were the sole depositional agent for the Sylvania. His study concluded that the Sylvania's deposition was the result of reworking of eolian sands by marine waters. His interpretations are more tenable; being based on the fact that facies gradations exist between the overlying Amherstburg and, where present, the underlying Bois Blanc. A combination of eolian and fluvial processes are believed to be responsible for supplying the large quantities of sand necessary; marine currents subsequently distributed the sand along a persistent strandline. This sequence occurred concurrently with the
Bois Blanc and Amherstburg deposition in the offshore portions of the sea. The initial deposition of the Sylvania is broadly correlated with the final stages of Bois Blanc deposition (Ehman, 1964).

Landes (1951) states arguments against the postulation that the Sylvania accumulated by current action, such as modern beach and barrier sands. For one, the size of the deposit exceeds that of any known models of similar deposition. Also, the sands are relatively isolated from their probable supply area and lack the silt and clay sized clastics that are invariably associated with current transported sands.

The Devonian sea at the advent of Detroit River Group deposition was largely restricted to the northeast corner of the Michigan Basin. The emergent land across the balance of the Basin underwent extensive erosion. Much of the exposed land received wind blown sands that were subsequently reworked within the northwest-southeast trending strandlines of the slowly retreating Bois Blanc Sea. At some point the retreating sea stabilized and proceeded to advance to the south and west. The resultant oscillating beach zone of this early Amherstburg Sea allowed accumulation of the bulk of Sylvania sand. Due to the lack of significant land vegetation during the Middle Devonian, eolian forces were
a trenchant geologic agent for the transportation and distribution of clastic material.

According to Briggs (1959), as the shoreline regressed it reworked and transported much of the sand into more rapidly sinking portions of the basin, which are represented by the thickest Sylvania sections. Subsequent transgressions left the sand behind in deeper offshore waters (where lime-mud occurred), burying the sand below the depositional interface.

The major source of the Sylvania sands, as is the source of all the Middle Devonian sands of the Michigan Basin, is the Wisconsin Highland region to the northwest (Figure 11). This is largely supported by the fact that heavy mineral analysis (Enyert, 1949) shows a high degree of similarity between the Sylvania sands and the older sandstones of the region to the northwest, particularly the Ordovician St. Peter and older sandstones. Also, as has been pointed out by several workers, the mean particle sizes decrease southward and the degree of sorting increases southward. In the outcrop area of northwest Ohio and southeast Michigan, the mean grain size is approximately one-third of that found in wells of the central basin area. Preferred grain alignments are noted in thin sections prepared from cores, however, since the cores are not oriented...
Figure 11. Regional Map of the Michigan Basin Area Showing Basal and Middle Devonian Sand Source Areas and Distribution. Modified From Summerson and Swann, 1970.
with respect to their geologic setting, this data is useless for paleocurrent and paleoslope determinations. Outcrop studies have suggested to Hatfield et al. (1968) the Findlay Arch a local detrital sand distribution center, which would render dual source areas for the Sylvania.

Filer Sandstone

Following deposition of the Sylvania, the shallow Amherstburg Sea with its gently sloping and undulating sea bottom transgressed (Figure 12). Successively, the Basin entered a period of increased subsidence and a major southward advance of the sea. The waters of this expanded sea became increasingly hospitable to the existence of shallow, warm water biota. Corals and stromatoporoids particularly thrived, forming extensive carbonate banks around the northern and southeastern rims of the Basin. Basinwide distribution of the corals indicate the widespread shallow nature of the sea at this time.

Numerous northeast trending, elongate patches of land with shallow intervening areas -- lagoon/barrier-island environments -- existed throughout significant nearshore portions of the Basin at this time (Figure 13). These areas were subject to blanketings of
Figure 12. Paleogeographic Map of the Amherstburg Sea Showing Major Depositional Environments. Modified From Briggs, 1959.
Figure 13. Hypothetical Paleogeographic Setting and Block Diagram Showing Depositional Facies Within a Northwest Portion of the Amherstbure Sea Strandline.
wind blown and marine reworked sand from southeast advancing dunes. Retreating sea levels allowed for gradual migration of subaqueous bars, resulting in disjointed multistory-multilateral sheets (Figure 14). The areas of emergence occurred at different places at different times since sea level was undergoing constant fluctuations. Thus, the Filer is a diachronous unit.

Since the sea was relatively shallow throughout the extent of the Basin, and vegetation was not present as a stabilizing medium, sand grains were incessantly driven off barrier islands and isolated plateaus and deposited in waters downwind. It is conceivable that individual grains could be driven many miles and deposited directly in the waters of the sea during storm events. These erratic grains are described in samples as "floating," owing to their support by a carbonate matrix. Lucas Formation anhydrite does not contain sand due to its displacive nature.

The deposition of the Amherstburg Formation closed with a complete withdrawal of the sea, allowing extensive emergences with sufficient relief for erosion to occur. Sand dunes and attendant sand sheets further migrated southeastward under the influence of the prevailing wind.

Published literature on Paleozoic sandstone bodies morphologically and lithologically similar to the Filer
Figure 14. Cross Section Through the Michigan Basin During Deposition of the Amherstburg Formation and its Constituent Members.
is scarce. However, there exists several well-documented treatises on Holocene barrier island environments analogous to the setting believed to be similar to the Filer's. Shelton (1973) describes the Galveston Island complex of Texas as a subaerial portion of a large sand barrier feature that initially was a small submerged bar that grew by beach and shoreface accretion (Figure 15), possibly similar to that of the Filer (Figure 16).

Preservation of barrier features during burial depends chiefly on the extent of erosion accompanying a subsequent transgression. It is believed that the bulk of eolian deposits and the uppermost part of a beach sand tend to be eroded by lateral accretion, leaving the preserved sand-bearing section composed largely of shoreface sediments. Potter (1967) reports that beds within tidal sand bodies are generally lenticular and commonly contain small channels and washouts. It is likely that portions of the Filer are representative of tidal environments, having been the shallow lagoonal deposits behind the main accumulations within the barrier bar. The tidal channels, coupled with the erosion factor, largely account for the Filer's intermittent nature.

This author believes the environment of deposition responsible for the morphology of the Filer is actually a
Figure 15. Cross Sectional Facies Model Through a Galveston Island Barrier Feature. Modified From Shelton, 1973.

Figure 16. Cross Section Through Hypothetical Facies Model Representative of the Filer Sandstone Depositional Environment. Adapted From Davies et al, 1971.
complex of closely related, gently sloping, shallow, nearshore marine sedimentary environments.

Sandy Lithofacies of Lucas Formation

Following a significant withdrawal of the Amherstburg Sea and a period of widespread emergence, the transgression of the Lucas Sea commenced. Once again the transgression was oscillatory, allowing wind driven and marine reworked sands to be carried onto the barrier bars adjacent to the strandline of the western portion of the basin.

The resulting barrier islands, sand laden lagoons and washover fans gave rise to the isolated sand bodies within the Lucas-Amherstburg transition strata. Sands found higher in section were either derived from the localized and waning remnants of barrier environments or were driven into place by storms.
SUMMARY AND CONCLUSIONS

It would be convenient if numerous cores of Detroit River Group Sandstones were available, with individual sand units clearly separated by carbonate strata of distinct lithofacies that are correlable across wide expanses of the Basin. However, as is now obvious, this is improbable because widely spaced drilling sites are responsible for the majority of the subsurface data, and facies, both laterally and vertically, change rapidly. Compounding these handicaps, the Sylvania-Amherstburg interval is rarely cored. Data for the Filer Sandstone are especially scant. Therefore, interpretation of wireline logs and the few existing samples must be relied on heavily. The conclusions of this report were necessarily assembled from fragmental information to form a composite model of sedimentation and of sedimentary environments.

By way of lithofacies analysis at both the macro- and micro-scale, it is concluded that the Filer Sandstone occurs in a stratigraphic position distinct from the Sylvania Sandstone. It can be shown that the two sandstones are separated by carbonate rocks of a texture and constitution unique to the Amherstburg Formation. Although the concept of a sequence of oscillating
Middle Devonian shorelines composed of multigeneration quartzose sands is not inaugural, the concept of barrier islands adjacent to those shorelines and the petrographic analysis of subject sands is, indeed, inaugural.

Although important discoveries of hydrocarbons have not been found within the Filer Sandstone, it should be noted that sand body geometry and interparticle porosity is suited to potentially serve as reservoirs, especially for those sands proximal to the overlying anhydrite beds of the Richfield Member (which would serve as impermeable caps). If Amherstburg carbonates would in any instance serve as source beds, economic quantities of hydrocarbons within Filer sands are quite possible. Permeability of the sands are subject to question.

The chief conclusions of this investigation are as follows:

(1) Geometrically, the Filer Sandstone is an assemblage of elongate sand bodies that have coalesced to form multistory-multilateral packages. Individual units appear lenticular, but are not readily definable due to the paucity of subsurface information on the Filer Sandstone interval. The thickest sections noted are between 50 and 70 feet. Laterally, the Filer appears as a multi-lobed unit trending east-west across the western and central portion of the Michigan Basin.
(2) The Filer Sandstone is a distinct and mappable sandstone member of the Amherstburg Formation vertically separated from the underlying, more extensive Sylvania Sandstone by carbonate rocks typical of the Amherstburg. In the eastern portion of the Basin, where the Filer Sandstone overlaps the Sylvania Sandstone, it is difficult to discern between the two units due to intervening carbonate strata that is transitional and locally sand-rich.

(3) Texturally, the Filer can broadly be defined as a fine-grained, well-sorted, well-rounded, carbonate cemented quartzarenite. However, dependent on the particular facies being analyzed and subsequent diagenetic activity, it can range from a supermature orthoquartzite to a texturally inverted sandy mudstone. Its detrital components are 99%+ quartz, with only minor amounts of heavy minerals and only rare grains of non-resistant minerals. Approximately 60% of the sand is dolomite cemented and 40% is limestone cemented. Dolomite generally appears secondary. Syntaxial silica overgrowths on quartz grains are common.

(4) An oscillating sea level, a gradually sloping nearshore bottom and an abundant supply of sand sized material resulted in the accretionary beach-lagoon-barrier island environment of the Filer
Sandstone. It was an overall regressive period, with the sea ultimately confined to the basin depocenter near the contemporary Saginaw Bay.

(5) The sands and sandstone contained within Amherstburg-Lucas Formation transition carbonates should be considered an upper phase of the Filer Sandstone, and not a separate "Freer" Sandstone Member of the Lucas Formation.
## APPENDIX A

Location of Wells Used in Study

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<tr>
<th>WELL NAME</th>
<th>PERMIT</th>
<th>SEC-TWP-RNG</th>
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<tr>
<td>1. Swanson Cons.-Metzger 1</td>
<td>4942</td>
<td>5-20N-4E</td>
</tr>
<tr>
<td>2. Rayburn-Horbart 2</td>
<td>8975</td>
<td>9-20N-4E</td>
</tr>
<tr>
<td>3. Wagner-Moskowitz 1</td>
<td>28907</td>
<td>13-20N-4E</td>
</tr>
<tr>
<td><strong>BAY CO.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Berlin-Brandt 1</td>
<td>19861</td>
<td>17-14N-3E</td>
</tr>
<tr>
<td>5. Busk-Buezek 1</td>
<td>17943</td>
<td>20-14N-3E</td>
</tr>
<tr>
<td>6. Gulf-Bateson 1</td>
<td>5331</td>
<td>2-14N-4E</td>
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<td>7. Gallaher, Bachelder-Bateson 19847</td>
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<td>8. MNR et al-Staudacher 1-2</td>
<td>31386</td>
<td>2-14N-4E</td>
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<td>9. Dow-Fee 2</td>
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<td>10. Gulf- Salina 1</td>
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<td>11. NRM Conrad 1-26</td>
<td>36028</td>
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<td><strong>BENZIE CO.</strong></td>
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<td>13. Shell-Dinger et al 1-36</td>
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<td>15. McClure-St. Inland 1-27</td>
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<td>16. Pure-Freer 1</td>
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<td>17. Pure-Mulder 1</td>
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<td>19. Hunt-Bray 2-30</td>
<td>32392</td>
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<td><strong>GLADWIN CO.</strong></td>
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<td>20. Sun-Davis 1</td>
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<td>21. AHC, Sun Basin-Hall 1</td>
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<td>35-18N-1W</td>
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<td>22. AHC, Sun Basin-Lett 1</td>
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<td>23. Shell-Weber 4-4</td>
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<td>24. Carter-Lemcool 1</td>
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<td>25. Miller-Menzel 6-9</td>
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<td>26. Shell-Henry 1-4</td>
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<td>27. Shell-Fraser 3-4</td>
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<td>28. Shell-Fraser 6-4</td>
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<td>31. Roosevelt-Gibson 1</td>
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<td>32. Pure-Datham 2</td>
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<td>41. Morton C-2</td>
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<td>43. Shell-Maple Grove 1-20</td>
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<td>44. Wolverine-Martella 1-20</td>
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<td>45. Shell-Asaila 1-27</td>
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<td>46. Shoemaker-Rogers 1</td>
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<td>58.</td>
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<td>Hunt-McGuire 1-22</td>
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<td>ROSCOMMON CO.</td>
<td>Sun, NM-USAB 1</td>
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<tr>
<td>WEXFORD CO.</td>
<td>NMEX-St. Springfield 1-31</td>
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APPENDIX B

PLATES

Plate Descriptions 1-4


4. Pure-Freer 1 (18-17N-6W), Clare County. Depth 5050 in Filer Sandstone Member. Fine to Medium-Grained, Well-Rounded, Carbonate Cemented, Massive to Irregularly Laminated Sandstone. Burrowing Structure in Mid-Section and Cross Bedding near Top. Barrier Island/Lagoon Transition Facies.
Plate Descriptions 5-8

5. Pure-Freer 1 (18-17N-6W), Clare County. Depth 5074 Feet in Filer Sandstone Member. Photomicrograph @ 35X (Crossed Nicols). Fine-Grained, Well-Sorted, Moderately Rounded, Carbonate Cemented Quartzarenite. Near-Barrier Island Facies.

6. Pure-Mulder 1 (18-17N-6W), Clare County. Depth 5086 Feet in Filer Sandstone Member. Photomicrograph @ 100X. Very-Fine to Medium-Grained (Poorly Sorted), Well-Rounded, Carbonate Supported Quartzarenite. Textural Inversion Typical of Lagoonal Facies.

7. Pure-Mulder 1 (18-17N-6W), Clare County. Depth 5081 Feet in Filer Sandstone Member. Photomicrograph @ 35X (Crossed Nicols). Fine to Medium-Grained, Poorly-Sorted, Well-Rounded, Dolomitic-Lime Cemented, Texturally Inverted Quartzarenite.

8. Pure-Freer 1 (18-17N-6W), Clare County. Depth 5043 Feet in Filer Sandstone Member. Photomicrograph @ 100X. Medium-Grained, Well-Rounded, Carbonate Cemented Quartzarenite. Pressure Solution Features Prominent.
Plate Descriptions 9 & 10

9. Pure-Mulder 1 (18-17N-6W), Clare County. Depth 5081 Feet in Filer Sandstone Member. SEM Photograph @ 800X. Silica Overgrowth Encircles Grain. Grain was Disaggregated From Dolomite Matrix Using Hydrochloric Acid. Note Dolomite Rhomb Ghosts.

10. Pure-Freer 1 (18-17N-6W), Clare County. Depth 5043 Feet In Filer Sandstone Member. SEM Photograph @ 304X (Left) and 3040X (Right). Complex Silica Overgrowths Pitted With Rhombic Voids.
Plate Descriptions 11-14

11. Pure Mulder 1 (18-17N-6W), Clare County. Depth 5081 Feet in Filer Sandstone Member. Photomicrograph @ 100X. Medium-Grained, Well-Rounded, Dolomite Cemented Quartzarenite. Solution-Dissolution Features Prominent. Note Quartz Overgrowths and Sutured Contacts.

12. Pure-Mulder 1 (18-17N-6W), Clare County. Depth 5081 Feet in Filer Sandstone Member. Photomicrograph @ 100X (Crossed Nicols). Medium-Grained, Moderately-Rounded, Dolomite Cemented Quartzarenite. Prominent Solution-Dissolution Features.

13. Pure-Freer 1 (18-17N-6W), Clare County. Depth 5043 Feet in Filer Sandstone Member. Photomicrograph @ 100X (Crossed Nicols). Medium-Grained, Well-Rounded, Silica Cemented Quartzarenite.

Plate Descriptions 15 & 16

15. Pure-Mulder 1 (18-17N-6W), Clare County. Depth 5080 Feet in Filer Sandstone Member. SEM Photograph @ 5040X. Surface Detail of Silica Overgrowths Showing Complex Terminations, Slight Diagenetic Alteration and Residual Carbonate.

16. Pure-Mulder 1 (18-17N-6W), Clare County. Depth 5080 Feet in Filer Sandstone Member. SEM Photograph @ 20,400X. Detail of Silica Overgrowths Showing Irregularities on Surface of a Rhombic Void. Note Silica Flakes That are Indicative of Multiple Overgrowth Generations.
Plate Descriptions 17 & 18

17. Pure-Freer 1 (18-17N-6W), Clare County. Depth 5043 Feet in Filer Sandstone Member. SEM Photograph @ 304X (Left) and 3040X (Right). Silica Overgrowths Displaying Well-Developed, Doubly-Terminated Quartz Crystals and Frosted Surface. Crystals Developed in a Pore Space of a Tight Aggregate of Sand Grains.

18. Pure-Freer 1 (18-17N-6W), Clare County. Depth 5043 Feet in Filer Sandstone Member. SEM Photograph @ 304X. A Group of Quartzose Sand Grains Displaying Silica Overgrowth Varieties. Grain at Center Right has Exceptionally Well-Developed Crystalline Overgrowth That Doubles its Long Axis Length.
Plate Descriptions 19-22

19. Pure-Zimmerman A-1 (12-17N-7W), Osceola County. Depth 5072 Feet in Filer Sandstone Member. Photomicrograph @ 250X. Grain Etching and Overgrowths Formed From Intense Solution-Dissolution Activity. Note Inclusions and Strain Markings Within Grain.


21. Pure-Zimmerman A-1 (12-17N-7W), Osceola County. Depth 5073 Feet in Filer Sandstone Member. Photomicrograph @ 100X. Fine to Medium-Grained, Moderately Rounded, Carbonate Cemented, Stylolitic Quartzarenite.

Plate Descriptions 23-26

23. Pure-Mulder 1 (18-17N-6W), Clare County. Depth 5080 feet in Filer Sandstone Member. Photomicrograph @ 35X. Large Oil-Stained Lithoclast Within Fine to Medium Grained, Moderately- Rounded to Well-Rounded, Carbonate Cemented Quartzarenite.

24. Pure-Mulder 1 (18-17N-6W), Clare County. Depth 5084 feet in Filer Sandstone Member. Photomicrograph @ 100X. Highly Altered, Partially Replaced Crinoid Columnal Within Medium-Grained, Well-Rounded, Carbonate Cemented Quartzarenite. A Rare Example of Intact Fossil Remains Within Filer Strata.

25. Pure-Zimmerman A-1 (12-17N-7W), Osceola County. Depth 5073 feet in Filer Sandstone Member. Photomicrograph @ 100X (Crossed Nicols). Medium-Grained, Well-Rounded (Slightly Elongate), Quartz Grain Showing Slightly Undulose Extinction.

Plate Descriptions 27-30

27. Pure-Freer 1 (18-17N-6W), Clare County. Depth 5048 Feet in Filer Sandstone Member. Fine-Grained, Well-Sorted, Moderately-Rounded, Carbonate Cemented Sandstone. Bottom Two-Thirds is Intensely Bioturbated Sandstone. Upper Third is Finely Laminated Sandstone.

28. Pure-Freer (18-17N-6W), Clare County. Depth 5052 Feet in Filer Sandstone Member. Medium-Grained, Well-Rounded, Carbonate Cemented (Friable), Cross Bedded Sandstone. Upper Shoreface or Barrier Island Facies.

29. Pure-Freer 1 (18-17N-6W), Clare County. Depth 5085 in Filer Sandstone Member. Fine-Grained, Well-Sorted, Moderately Rounded, Dolomitic-Lime Cemented Sandstone. Prominent Dewatering (Degassing?) Structure in Mid-Section. Disconformable Contact Near Top.

30. Pure-Freer 1 (18-17N-6W), Clare County. Depth 5086 in Filer Sandstone Member. Fine to Medium-Grained, Moderately-Rounded, Dolomite Cemented, Bioturbated sandstone. Upper Shoreface Facies.
BIBLIOGRAPHY


