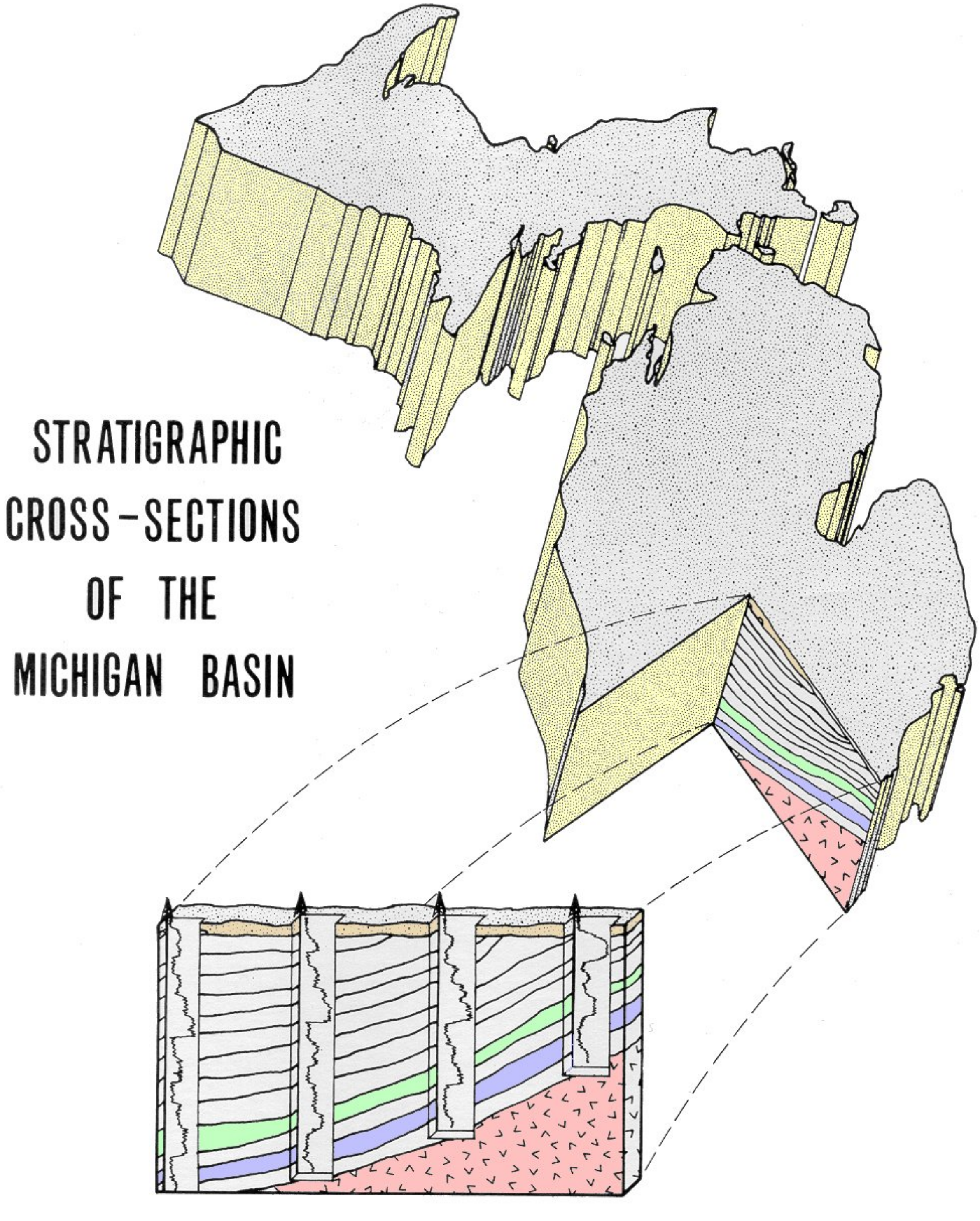
Report of Investigation 19



Michigan Department of Environmental Quality
Geological and Land Management Division

Preface

In July 1975 a new unit, the Geology and Minerals Research Unit, was created in the Michigan Geological Survey Division. The purpose of the unit is to investigate the geology and the resource potential of the State and provide a data base for more detailed geological endeavors.

Pertinent to these objectives, unit personnel determined that geophysical log cross-sections or correlation sections would be useful in delineating the formations in the subsurface of the Southern Peninsula in greater detail. The 15 cross-sections presented in this report cover the entire stratigraphic sequence present in the subsurface, from the Jurassic through the Precambrian. They depict correlations, based principally on gamma ray logs, of the recognizable groups, formations, and members in the basin, as well as other correlatable units or beds. The information thus provided by the sections will be very helpful to governmental agencies, industry, university people and private citizens for an understanding of the geology of the subsurface of Michigan. It will also provide a data base for more detailed geologic study and essential information for more effective decisions in land use planning.

The writer expresses gratitude to Garland D. Ells, Michigan Geological Survey, James H. Fisher, Michigan State University, and Glenn C. Sleight, McClure Oil Company, for their critical review and useful suggestions in correlating the many geologic formations found in the Michigan Basin. I am also grateful to Beverly L. Champion for editing the text and Gregory A. Wilson and Darrel Hodge for preparation of the plates. A special thanks goes to Robert C. Reed, who reviewed the text and provided many helpful suggestions in the preparation of this report. The writer also thanks Lois A. Padgett for rough-draft typing and Lois J. DeClaire for final-typing of the manuscript.

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Stratigraphic Cross-Sections of the Michigan Basin

Abstract

The strata of the Michigan Basin, encompassing a span of geologic time from the Cenozoic Era into the Precambrian, have been correlated in a series of cross-sections, using gamma ray logs from approximately 100 wells drilled in Michigan. Fifteen cross-sections have been constructed. All of the sections emanate in radiating fashion from the deepest well drilled in the State, the McClure Oil Company - Sparks, Eckelbarger, Whightsil No. 1-8 in Gratiot County, which attained a total depth of 17,466 feet. Each of the fifteen cross-sections is composed of six or seven separate sections, showing the entire stratigraphic sequence present in the wells in that particular cross-section. In conjunction with the gamma ray logs depicted in the sections, other geophysical logs are shown in order to demonstrate porosity, density, conductivity and lithology of the strata in various parts of the basin. The terminology applied to the rock units is essentially that which is used in Michigan's subsurface investigations.

Some of the special characteristics of each formation are discussed in the text. Among these are the lithology, some depositional history and the resource potential of the formation.

During the process of researching the rock strata of Michigan from the geophysical logs, several distinctive horizons were noted in some of the formations, which were present over a wide enough geographic area to aid in correlating the log curves. Such horizons were especially apparent in the Traverse Group, the Detroit River Group, the Cincinnatian Series and the Black River Group. These horizons are useful in defining changes in the radioactivity of the rock and, hence, fades changes.

Porosity zones are abundant in several formations of Devonian age, particularly the Traverse Limestone, the Dundee Limestone and the Lucas Formation. These zones can be utilized for defining potential hydrocarbon reservoirs, lost circulation zones, water zones and potential liquid waste disposal reservoirs.

One of the principal intents of this investigation is to provide a more complete picture of the subsurface geology of the Southern Peninsula of Michigan for industry personnel, government agencies, educators and the general public. These cross-sections can be used as reference material or guides from which more explicit and detailed research on the geology of Michigan can be done. They can also serve as a data base for future development planning or land use policy development in Michigan.

Introduction

The present decade has been witness to the development of an intensified national concern for the wise and conservative use of our nonrenewable resources. It is also imperative that wise land-use decisions be made in any area where mineral or energy resource potential is present. To help achieve these goals, many kinds of data are needed. One type of data base deals with geologic information pertaining to the rock formations of Michigan's Southern Peninsula. Many new wells have been drilled in this region during the past decade. Because these new wells add to the geologic knowledge of Michigan, they are important in the search for oil and gas resources, for salt and brines, and other uses. To better delineate the stratigraphy of the rock formations in the subsurface of the Southern Peninsula and thus enhance the geologic data base, a new series of cross-sections based on geophysical logs is presented. Fisher et al. (1969) constructed two cross-sections of the Michigan Basin using geophysical logs, and they were helpful in the preparation of this report.

A stratigraphic cross-section or correlation section is one of the geologist's tools for defining and depicting the subsurface geology of a specific area. A series of such sections, properly constructed, will show the entire stratigraphic sequence as well as particular salient aspects of the formations in various portions of the area. The cross-sections can also be used as a base from which further studies can proceed. The discussion and sections of the subsurface of the Southern Peninsula are intended to show various features which may be useful in future studies.

In order to show the geology in sufficient detail, 15 separate cross-sections crisscrossing the Southern Peninsula were constructed (see Plate l). Approximately 100 wells are shown in these cross-sections, and they are listed in Appendix I. The focal point from which the cross-sections emanate in radiating fashion is located in Section 8, T10N, R2W, North Star Township, Gratiot County. This key well, the deepest well drilled in Michigan, is the McClure Oil Company - Sparks, Eckelbarger, Whightsil No. 1-8. This oil and gas test penetrated a portion of remnant Mesozoic Jurassic rock and the entire sequence of Paleozoic rocks in the basin. The well, therefore, was an excellent point from which to anchor the cross-sections. These sections are composed of radiation and electric logs. Gamma ray logs are the tools most useful in correlating formations and units in this area and they were used extensively in this study. In conjunction with the gamma ray logs, other logs from various parts of the basin are portrayed to demonstrate the porosity, density, conductivity, and lithology of the strata in a number of different localities.

The purpose of this investigation is to give industry, government and university personnel, and the private citizenry a more complete picture of the subsurface geology of the Southern Peninsula. These cross-sections can be used as a data base for many purposes: exploring for oil and gas; delineating porosity or lost circulation zones; determining brine disposal or other waste disposal possibilities; providing more information for casing points; showing more fully on a regional basis how to choose formation tops more consistently; and planning future developments in the State. This report is not intended for correlating the surface formations with their subsurface counterparts; but it may be useful as a base for future studies. Formation and group names in this report are those normally used in Michigan's subsurface investigations.

Along with the cross-sections constructed for this investigation are discussions of the characteristics of individual formations. The lithologies of the formations are not the same everywhere in the basin because of facies changes, and some of these variations are analyzed. Other points covered in the discussion are difficulties involved in determining some formation limits, and controversies encompassing correlations of some formations.

Some of the controversial correlations reviewed in the text involve the Michigan Formation and Marshall Sandstone, Ellsworth Shale and Antrim Shale, and the Dundee Limestone and Lucas Formation.

Geologic Setting

The Michigan Basin is a relatively shallow intracratonic structure which includes all of the Southern Peninsula, part of the Northern Peninsula and parts of Wisconsin, Illinois, Indiana, Ohio, and Ontario. It is bounded on the north by the Canadian Shield; on the east and southeast by the Algonquin and Findlay arches; on the southwest by the Kankakee arch; and on the west and northwest by the Wisconsin arch and Wisconsin Dome. The center of the basin is generally presumed to be at or near the region surrounding Saginaw Bay (see Newcombe, 1933).

The Michigan Basin is composed predominantly of downwarped Paleozoic and younger rocks which are manifested in concentric bands of outcrops and subcrops beneath Pleistocene glacial drift (see Dorr and Eschman, 1971). The exterior portion, consisting of the oldest rocks, is expressed in outcrops of Cambrian sandstones along the shore of Lake Superior. The "bands" of rocks are successively younger toward the interior of the basin. Jurassic age "red beds", the youngest consolidated sediments, are encountered in the center. The Michigan Basin is believed to have originated in Precambrian time with a continuation of downwarping throughout Paleozoic time. On the basis of previous studies, major periods of downwarping appear to have occurred during Silurian-Salina time and Devonian-Detroit River time.

Much of the Michigan Basin is covered by a veneer of glacial drift. In some areas in the Southern Peninsula the rocks are exposed at the surface, while in other areas over a thousand feet of drift cover the bedrock.

The strata which are present in Michigan range from Jurassic age to Pennsylvanian, Mississippian, Devonian, Silurian, Ordovician, and Cambrian (see Chart l). All of these systems are not present over the entire area; some have been removed by pre-Pleistocene erosion.

Rocks of Jurassic age are uppermost in the basin and are located only in the central and west central portions of the Southern Peninsula (see Figure l). The next lower sequence of strata encountered is Pennsylvanian in age and is found in the central and south central portion of the State. The thickness of Pennsylvanian rocks ranges from 0 to 765 feet and the System is first encountered at depths from 0 to 600 feet. The Mississippian System underlies the Pennsylvanian. It ranges from 0 to 1700 feet thick and the top of the System occurs at depths from 0 to 1100 feet. Rocks of Devonian age, below the Mississippian, underlie the entire Southern Peninsula of Michigan except for the extreme southeastern corner. Devonian rocks range from 0 to 3600 feet in thickness and are first found at depths of 0 to 2600 feet. Silurian rocks which underlie the Devonian, subcrop and outcrop in the extreme southeastern corner of Michigan, as well as in the eastern portion of the Northern Peninsula. The top of these strata can be found at depths from 0 to 5300 feet and may be as thick as 4200 feet. The Ordovician System is the next rock sequence encountered. These rocks are found beneath the entire Southern Peninsula but do not outcrop in Lower Michigan. They do outcrop, however, in several localities in the Northern Peninsula. They are first encountered at depths from 1250 to 9000 feet in the Southern Peninsula and may be as thick as 2500 feet. The oldest Paleozoic rocks encountered are Cambrian in age. These strata are sparsely drilled in the State and therefore knowledge of the subsurface Cambrian rocks is very limited. Wells which have penetrated the strata, however, show that the top of the Cambrian ranges in depth from 2600 to 11,700 feet and that the rocks attain a thickness of 2500 feet or more.

Stratigraphic Cross-Sections

Fifteen major cross-sections were constructed which traverse the Southern Peninsula of Michigan in various directions from a common center (see Plate 1). Each of these sections is broken down into smaller entities in order to show the response of gamma ray curves and other log curves in more detail. In the southern part of the State each cross-section is divided into five or six separate parts which include, in descending order: l) a section covering, where applicable, the Pleistocene and Jurassic, Pennsylvanian and Mississipian; 2) one showing the Lower Mississippian and

Upper and Middle Devonian; 3) a section of the Middle and Lower Devonian and Upper Silurian; 4) a section of Middle and Lower Silurian; 5) one covering the Upper and Middle Ordovician; and 6) where available, a section of the Lower Ordovician and Cambrian.

In the northern part of the Southern Peninsula the strata are separated into sections somewhat differently. The stratigraphic sequence is thicker due to increased subsidence of the basin and more deposition of evaporites and other strata. More sections were necessary to depict the entire sequence. The strata included in these sections are as follows: 1) where applicable, the Pleistocene and Jurassic, Pennsylvanian and Mississippian; 2) Lower Mississippian and Upper and Middle Devonian; 3) the Middle Devonian; k) the Upper and Middle Silurian; 5) the Middle and Lower Silurian; 6) the Upper and Middle Ordovician; and 7) the Lower Ordovician and Cambrian, where enough wells were drilled which penetrated these rocks.

Datums selected were the Sunbury Shale, Antrim Shale, Bell Shale, C Unit, Trenton Group, and Glenwood Shale. The Antrim Shale was used in the southern portion of the State in constructing a part of the Devonian section. In the northern portion, however, because of the thickness of the evaporites, it became more practical to use the Bell Shale as a datum.

Each section contains the maximum number of formation correlations deemed possible. The formations are generally separated according to electric and radiation log characteristics; however, samples from several wells were studied in order to tie the electric log picks as closely as possible to lithologic differences. Some formations contain individual beds which can be correlated for considerable distances and these are also shown.

Stratigraphy and Correlation

The sedimentary rock sequence in the Southern Peninsula of Michigan ranges from Jurassic "red beds," confined to the central portion of the basin, to Cambrian sandstones above the Precambrian basement. Paleozoic rocks, from youngest to oldest, are represented by the Pennsylvanian, Mississippian, Devonian, Silurian, Ordovician, and Cambrian systems. Beneath these are strata of Precambrian age, the oldest rocks in Michigan. They are composed of various granites, quartzites, and other types of igneous, metamorphic and sedimentary rocks. All of the above systems contain formations which have had or will have potential for mineral resource or hydrocarbon production. These potentials as well as other pertinent matters, such as lithology, porosity, correlation problems, and other related subjects of interest, will be discussed in the following descriptions of the formations.

Jurassic System

The chart "Stratigraphic Succession in Michigan" (Chart 1) shows Jurassic sediments of the Mesozoic Era as the youngest consolidated sediments encountered in the Michigan Basin. The beds are predominantly poorly consolidated sands and shales with gypsum beds appearing throughout the sequence. The rocks have been described as Kimmeridgian in age and are, for the most part, red.

These Jurassic strata are found in a relatively small area in the central to west central portion of Michigan (Figure 1). They have been dissected and eroded extensively by glacial processes of the Pleistocene Epoch; as a consequence, Jurassic sediments are not present in all of the general area, but may be as much as 400 feet thick where present. The beds are considered to be continental elastics. They intertongue abruptly with other types of rock in the sequence and show the irregular bedding characteristics typical of continental deposition. It is difficult to correlate these beds on the basis of electric logs, although they have been identified by Shaffer (1969) on the basis of palynology.

An attempt has been made to correlate sediments previously identified as Jurassic in age in cross-section A-D, Plate 23 on the basis of gamma ray log characteristics as well as some lithologic descriptions of the units. Few radiation log correlations of Jurassic sediments have been conducted in the past. Those presented here are possible correlations, and also show the stratigraphic position of the Kimmeridgian in these drill holes. Further study of gamma ray log interpretations in the red bed sequence is essential to facilitate accurate correlations of these sediments.

Pennsylvanian System

Rocks of Pennsylvanian age are limited in areal extent generally to the central portion of the Southern Peninsula (see Figure 1). The Pennsylvanian System in Michigan is composed essentially of two formations, the Grand River and the Saginaw. The uppermost Grand River Formation is predominantly sandstone and is basically indistinguishable from the Saginaw Formation. In past studies the two formations have not been separated in the subsurface on the basis of geophysical logs, and they are not differentiated in this investigation.

It is general practice to group all Pennsylvanian strata found in the Michigan Basin into the Saginaw Formation. A maximum thickness of about 765 feet of Pennsylvanian rocks is found in the northwestern portion of the area of deposition. The Saginaw is generally composed of interbedded sandstones, shales, limestone, and coal. The sandstone beds vary considerably in thickness and thin or pinch out in relatively short distances. At the base of the Saginaw is a unit called the Parma. The medium to coarse grained Parma sandstone is generally less than 100 feet thick but may be as much as 150 feet in some areas. The unit appears to be lenticular in shape and cannot easily be distinguished as a separate entity in the subsurface.

In early Pennsylvanian time the area of deposition was a shallow basin with a series of rivers flowing into it from the east. Previous studies of the Saginaw Formation indicate that several cycles of deposition occurred, and many local unconformities developed. During the total time of deposition of Pennsylvanian sediments, several minor inundations of the sea occurred from the northwest and west. Cyclothems were deposited during Saginaw time and were separated by other beds such as the Verne Limestone, a marine deposit. Deposition of cyclothems is indicative of an unstable coastal environment in which marine submergence and emergence occur. Beds, of coal are associated with the cyclothems. Thus the sedimentary conditions ranged from marsh fluvial-deltaic on the east to shallow brackish marine on the northwest and west (Cohee, 1951). Pennsylvanian rocks were then covered by Jurassic red beds.

In the Saginaw Formation, coal beds have been found which range from a few inches to 7 feet in thickness. Most of the mined coal, however, was approximately 30 inches thick (Kalliokoski, 1976). The coal beds generally are quite thin and pinch out within a distance of a few hundred feet. Because the sedimentary conditions fluctuated rapidly, none of the coal seams appear to be continuous over any great area. More than 46 million tons of coal have been produced in Michigan since 1835 (Cohee et al., 1950); but no coal is being produced at the present time.

Only one field in the State has yielded oil or gas from the Saginaw Formation, and that was the Elba field in southeastern Gratiot County. In the Elba field, a few wells in Parma sandstone produced natural gas. The amount of gas present was small and all of the wells have since been abandoned. Future prospects do not appear to be favorable for any significant production of oil or gas from any of the Saginaw strata.

All of the cross-sections dealing with the uppermost strata of Michigan show at least some portion of the Saginaw Formation. Very little work has been done previously on correlation of Pennsylvanian strata based on gamma ray log information and very little correlation has been attempted in this report. The Pennsylvanian is generally identified only on an individual well basis using radiation logs. Some lithologic studies have been done but none have been integrated with radiation logs and the gamma ray response.

The Pennsylvanian is characterized by sequences of high- and low-radioactive strata that vary in intensity and thickness from place to place. These variations are caused mainly by changes in lithology from sandstone to argillaceous material. The individual beds in the Pennsylvanian can probably be delineated after further detailed study.

The interval of geologic time between the end of the Pennsylvanian period of deposition and Jurassic "red beds" deposition, as well as the time between Jurassic deposition and the beginning of the Pleistocene Epoch, were significant periods of erosion of strata in the Michigan Basin. An unconformity is present also at the base of the Pennsylvanian, and this is noted on the cross-sections.

Mississippi System

Thousands of wells drilled in the Michigan Basin have penetrated rocks of the Mississippian System. The sequence is thickest in the central part of the State. The strata range from zero thickness around the edges of the Southern Peninsula to 1700 feet in the center of the basin. Mississippian strata outcrop in several widespread areas; in other areas these rocks may first be encountered 1100 feet below the surface. Mississippian formations include, in descending order, Bayport Limestone, Michigan Formation, Marshall Sandstone, Coldwater Shale, Sunbury Shale, Berea Sandstone, and Bedford Shale.

Bayport Limestone

The Bayport Limestone, named by Lane in 1899, is the stratigraphically youngest Mississippian formation encountered in the Michigan Basin. It varies from 10 to more than 100 feet thick and consists of light to dark gray fossiliferous limestone and dolomite interbedded with quartz siltstone and sandstone. The formation may also contain chert concretions in certain zones. Some individual beds are lenticular and are not extensive laterally.

The variability in the thickness of the Bayport is due in part to an erosional unconformity between it and the overlying Pennsylvanian rocks. In some areas the formation has been completely eroded away and the Pennsylvanian lies on the Michigan Formation. Hence, the Bayport can vary from 0 to slightly over 100 feet thick, but it is generally less than 100 feet.

The Bayport appears to have accumulated in a shallow sea into which silt and sand were being carried from both the northeast and west. The abrupt lateral alternation and intertonguing of limestone, dolomite, and sandstone indicate rapidly shifting environments of deposition in which waves and currents had a strong effect on the type of sediments accumulating. The Bayport contains intraformational conglomerates and breccias, a fact which may imply the existence of strong wave action during part of the time of deposition.

The Bayport appears to have some resource potential. Presently, some Bayport limestone quarrying operations exist and they will probably continue in the future. Galena has been reported in the formation in Huron County. This reported occurrence may warrant further investigation.

Future possibilities for oil and gas extraction do not appear to be promising.

Correlation of the Bayport from place to place is quite difficult. This is due mainly to variations in lithology, and the fact that little detailed correlation work has been done using electric logs. However, an attempt has been made in this report to correlate the Bayport in the central basin area of deposition.

As shown in cross-sections A-B through A-H, Plates 9, 16, 23, 29, 3,», 38 and 44, the thickness of the Bayport can vary from well to well. This is most likely due to erosion which took place during and after Bayport deposition. The formation is characterized by fairly low radioactivity when compared to some of the overlying Saginaw Formation and underlying Michigan Formation. This is due to the typical gamma ray response generally found in limestones and sandstones, which compose the bulk of the beds. The Bayport is difficult to correlate because of lack of information on its exact position in the stratigraphic sequence on gamma ray logs, and the scarcity of studies defining the formation accurately in individual wells. The position of the Bayport in this study was defined from well records submitted by various companies, and an attempt was then made to correlate the lithologic description with the gamma ray log.

Michigan Formation

The Michigan Formation underlies the Bayport in the Michigan Basin. This unit, named by Winchell in 1861, is exposed in Kent, Huron, and losco counties. It is composed of beds of anhydrite and gypsum, gray to dark gray and greenish-gray shale, limestone, dolomite, and sandstone. The formation is economically important in that a portion is quarried for gypsum, and gas has been produced out of a sand known as the "Michigan Stray". Presently, many Michigan Stray gas field reservoirs are being used for gas storage.

The Michigan Formation is limited to the central part of the basin. The perimeter of the formation is an erosional edge. The area of Michigan Formation deposition appears to have had a complex history of erosion which began with pre-Bayport uplift and continued throughout Pennsylvanian time. Many channels were cut into and through the Michigan Formation which were subsequently filled with younger sediments.

Two units in the Michigan Formation are readily correctable throughout much of the area of preservation. These zones are known as the "Triple Gyp" and "Brown Lime". The "Triple Gyp" (see Plate 2) is a unit consisting of three anhydrite or gypsum beds and beds of shale. It is about 30 to 40 feet thick and can be traced over much of the central basin area. This zone is a potential source of gypsum, since it is presently being mined in Kent County in western Michigan and Iosco County in eastern Michigan. In the future other mining operations may be stimulated by increased demand for gypsum. Another correlatable zone is the "Brown Lime" (see Plate 2). This unit is a 10- to 20-foot thick brown dolomite which can be traced over much of the lower part of Michigan. The top of the "Brown Lime" is used for structure contouring in areas where gas production is obtained from the sandstone body known as the "Stray Sandstone". This sandstone is found about 100 to 150 feet below the "Brown Lime" in some fields in the central part of the Southern Peninsula.

At the base of the Michigan is the unit known as the "Stray Sandstone". Several theories have been proposed regarding the depositional history of the "Stray" and its relationship to the Michigan Formation and Marshall Sandstone. The sandstone appears to be variable in thickness and areal distribution; for example, it can be anywhere from 0 to 100 feet thick in the central basin area. It is irregular in the subsurface, and has been compared to the shoestring sands of Kansas and Oklahoma. Many geologists have included the "Stray" in the Michigan Formation in the subsurface; but they have also correlated it with the Napoleon member of the Marshall in southern Michigan outcrop areas.

Prior to extensive drilling in the Southern Peninsula, the contact between the Michigan and Marshall was placed at the first appearance of sandstone beneath the Michigan evaporites. This practice prevailed until further drilling in the central part of the basin revealed sandstone above the lowermost anhydrite. This sandstone, termed the "Michigan Stray", contained large quantities of gas (see Rawlins and Schellhardt, 1936). The boundary between the Michigan and Marshall was then placed at the first carbonate encountered below the "Stray". As drilling progressed in the basin it became clear that a close relationship existed between the "Stray" and Marshall in the southwestern area of distribution.

Some geologists believed that the "Stray" was younger than the Marshall and represented redeposited Marshall. Still others were of the opinion that the upper part of the Marshall was time equivalent to the "Stray". One recent study by Moser (1963) indicates that the Marshall in the southwestern part of the State is time equivalent to the Michigan. In the central and northeastern portions of the basin the Marshall is postulated to be older than the Michigan and separated from the "Stray" by other units. In this report the "Stray" is shown as a separate entity whenever possible.

Correlation of the Michigan Formation throughout the basin is complicated by the erosion surface separating it from the overlying Pennsylvanian rocks. Cross-sections A-B, A-C, and A-E, Plates 9, 16 and 29, show some of the problems involving preglacial erosion surfaces. The top of the formation has been chosen on the basis of lithology as well as gamma ray radiation characteristics.

The Michigan "Stray" varies in thickness from 0 to 100 feet or more (see Plates 23 and 38). The "Stray", where it is well developed, is generally located about 100 feet below the "Brown Lime"; or it may be as close as 50 feet or less (see Plate 38) below the "Brown Lime" marker. The base of the Michigan is generally picked at the last large radioactive response before the clean Marshall is encountered (see Plate 23). Correlation is especially difficult in the southwestern portion of Michigan and the correlations presented are tentative at best. The high radioactivity normally found at the base of the Michigan "Stray" decreases in this area, making correlation difficult.

Marshall Sandstone

The next lower Paleozoic formation to be encountered is the Marshall Sandstone. It is composed predominantly of sandstone and silt-stone, with some zones exhibiting red coloration. The Marshall, named by Alexander Winchell in 1861, is exposed in Jackson, Hills-dale, and Calhoun counties in southern Michigan, Ottawa County in southwestern Michigan, and Huron, Tuscola, and possibly Sanilac counties in eastern Michigan.

According to several investigators, i.e. Monnett (1948), Cohee (1951), and Moser (1963), Marshall time was introduced by crustal movements in the basin and in the adjacent land areas. The crustal movements resulted in uplift of granitic rocks in the Wisconsin Highland area. These rocks became an important source of sediments for the Michigan Basin for the first time during the Mississippian Period. The first sediments from this area appear to be fine grained red and buff sands which were deposited on the Coldwater.

In the eastern part of the State, according to Monnett (1948), no sudden change in type of deposits occurred in early Marshall time because the sediments were from the same source and manifested the same lithologic character as the nearshore facies of the Coldwater. A gradual rise of the land surface on the east is postulated, which resulted in a westward migration of the shoreline. Throughout Marshall time the depositional basin was shrinking due to elevation of surrounding land areas.

Near the middle of Marshall time, the part of the Laurentian upland which had been the eastern source of Coldwater and lower Marshall sediments began to rise. During this time medium grained and some fine-grained sands were brought into the Marshall sea from the east and west. These sands were deposited over the sea floor, with the thickest accumulations in low areas and the thinnest on topographically high areas.

According to Monnett (1948), Marshall deposition did not end simultaneously in all areas. The first deposits of the Michigan Formation accumulated in the more placid portion of the sea while Marshall sands were being deposited in less quiet water. By this time an extremely arid environment existed over both the depositional area and the adjacent land. Streams carried sand into the depositional area from the Wisconsin Highland intermittently during the initial stages of deposition of the Michigan Formation.

Investigators in the past had thought that the red portions of the Marshall could be used as stratigraphic markers. However, enough data is now available from Moser (1963) and other researchers to indicate that red coloring in Marshall deposits is of little value as a stratigraphic marker from a regional point of view. It has also been shown that red coloration is not limited to lower Marshall strata. Although red sediments are more characteristic of lower beds, they are also present in the uppermost part of the formation in western Michigan. The base of red sediments does not necessarily signify the base of the Marshall. Therefore, it does not seem practical to separate the lower Marshall Sandstone from the upper Marshall (Napoleon Sandstone) on a regional basis because of the red color.

The Marshall Sandstone has not yielded significant quantities of oil or gas, although some production has accrued. Prospects for a significant increase in oil and gas potential do not appear to be promising and the Marshall, therefore, is not considered a good exploration or drilling target. Brine is produced from Marshall deposits in Gratiot County and rough dimensional stone is quarried from the Napoleon member in Jackson County.

The top of the Marshall in this study is picked at the base of the last high radioactive "kick" in the Michigan, just before a cleaner Marshall sand is encountered. This is true whether or not the "Stray" is present. An examination of Plates 9, 16 and 23 reveals that this gamma ray curve can be used for correlation purposes with some degree of accuracy in most areas.

A study of the sections discloses that the thickness of the Marshall may vary because of the presence of the Michigan "Stray". Examination of the cross-sections also shows that the lower portion of the Marshall is slightly more radioactive than the upper portion (see Plate 2). This variation in radioactivity, as reflected in the curves, is a useful tool for correlating the Marshall.

Coldwater Shale

The next Mississippian formation encountered immediately below the Marshall Sandstone is the Coldwater Shale. It consists predominantly of gray and bluish-gray shale, is micaceous in some areas, and contains lesser amounts of limestone, dolomite, siltstone and sandstone. Wherever it is present, it overlays the Sunbury Shale and Ellsworth Shale. It was named by Lane in 1893 from exposures in the Coldwater River near the town of Cold-water in Branch County. It is also exposed at other places in Branch County and Hillsdale County, and along the shore of Lake Huron in

Huron and Sanilac counties. A red argillaceous limestone or dolomite unit at the base of the formation, known as the Coldwater "red rock", is persistent over much of the basin and varies from 10 to 20 feet in thickness.

On the western side of the Southern Peninsula the Coldwater Shale contains an argillaceous dolomite zone known as the "Coldwater Lime" or "Speckled Dolomite" (Hale, 1940 (see Plate 3,0 • This facies can be correlated through much of western Michigan. Eastward, it grades into shale. In the eastern part of the State several sandstone beds appear in the Coldwater, particularly in the upper portion. The uppermost sandstone beds make it especially difficult to define the contact between the Marshall and Coldwater. One of the sandstone beds in the lower part of the Coldwater, the "Weir sand", actually yields some shows of gas. A few gas wells have been completed in the "Weir sand". An occasional show of oil is found in the limestones of the Coldwater shale on the west side of the State.

A noticeable feature of the Coldwater is the prominent thinning of sediments from the center of the State to the western margin (see Plates 34 and 38). While the formation is approximately 1,000 to 1,100 feet thick in the central and eastern parts of the State, it thins to about 500 to 600 feet in western Michigan. It also thins in a southward direction from central Michigan, but the thinning is much less than toward the west.

The westward thinning of the Coldwater seems to reflect either an overlapping of the sediments on higher structure or thinning away from an eastern source. The lithology of the formation indicates westward convergence as opposed to any loss of lower beds, which would be expected in an overlap situation; so the first possibility seems unlikely.

It appears that the Coldwater Formation thickens geometrically to the east where coarse elastics prevail in the formation. It is significant to note that the percentage of sand is highest in those areas where the Cold-water reaches maximum thickness. This could be interpreted to mean that in addition to being in closer proximity to the inferred source, the coarse clastic sediment distribution is related to the subsidence of the Coldwater depocenter. The higher quartz sand content suggests that the eastern part of the basin was a nearshore environment and the water was very likely shallow. The percentage of elastics decreases westward; i.e., clastic content is close to 100 percent in eastern and central Michigan and decreases to 60 to 70 percent in western Michigan (Chung, 1973)-

The correlation of the Coldwater throughout the basin is fairly simple and straightforward. The Sunbury Shale, where it exists in Michigan, serves as an excellent base. The upper portion of the Coldwater is sometimes difficult to correlate in part of eastern Michigan because of the transitional nature of the contact with the Marshall. The top of the Coldwater was chosen at the first high-radioactive response below the Marshall Sandstone beds, as shown on Plates 23 and 76.

Several units are present in the Coldwater which can be correlated in more detail. The Coldwater "red rock" at the base of the formation is a persistent unit which can be traced over much of the basin. This unit generally has a lesser radioactive response than the sediments above or the Sunbury Shale beneath. It thickens on the western side of the State, as seen on Plates 29 and 34.

Some sandstone and limestone beds in the formation could be correlated if more meticulous studies were performed. The accomplishment of petrographic studies and more detailed correlations could help to unravel the depositional history of the Coldwater.

Sunbury Shale

The Sunbury Shale, generally underlying the Coldwater in the Michigan Basin, extends over a large part of the Southern Peninsula. The Sunbury was first identified in 1900 by R. C. Lane in samples from a well drilled on the campus of the University of Michigan in Ann Arbor. Because it is a readily recognizable unit which extends over a wide area, it is a good correlatable marker bed over much of the basin. No outcrops of Sunbury Shale have been found anywhere in the State.

The Sunbury Shale underlies Coldwater rocks except where it pinches out or grades into the Ellsworth Shale on the western side of the State. It is quite similar to the Devonian Antrim Shale lithologically and ranges in thickness from zero in the western portion (see cross-section A-G, Plate 38) to about 120 to 140 feet on the eastern side (see cross-section A-N, Plate 76). In the eastern part of the State it overlies the Berea sandstone, but in most of the western portion it overlies the Ellsworth Shale.

Berea Sandstone

The Berea Sandstone, underlying the Sun-bury, was identified by Rominger in 1876 in a well drilled in the Courthouse Square at Ann Arbor. The formation is confined to the eastern side of the State and appears to be a deltaic-type deposit. It grades into the upper Ellsworth on the western side of the Southern Peninsula; but a small amount of the Berea unit may be present in the Ellsworth in some of the western counties. The sandy unit has, in the past, been called the "Berea" or "Berea Horizon" (Hale, 1941). The zone, where present on the western side, becomes a dolomite with a small amount of sand rather than being a completely sandy horizon. The Berea overlies the Bedford everywhere on the eastern side of Michigan and the contact appears to be gradational.

The Berea Sandstone is generally separated into three lithologic units (Cohee and Underwood, 1940). The lower unit is light gray, fine grained, dolomitic, silty and shaly, micaceous, pyritic sandstone, cemented with silica. The middle unit is friable, fine grained sandstone composed of angular quartz grains. Thin beds of shale and tightly cemented sandstone are interbedded with the friable sandstone in places. The upper unit is lithologically similar to the lower unit but is less shaly and pyritic. These units, although identifiable lithologically, cannot be separated on the gamma ray logs, so they are not delineated on the cross-sections.

Natural gas and oil have been produced from the Berea Sandstone in several areas in eastern Michigan. The most important fields which have produced oil are the Saginaw and Birch Run fields in Saginaw County, the Otisville field in northeastern Genesee County, and the New Lothrop field in Shiawassee and Genesee counties. Some of the more important gas-producing fields are Clayton, Deep River, and North Adams fields in Arenac County and Logan field in Ogemaw County. Other fields in the eastern part of the State have produced from the Berea, and wells outside of these fields have had shows of oil and gas.

The producing zone, located in the upper part of the sandstone, is from 13 to 16 feet thick and is generally of low permeability. Initial production from the oil wells ranged from 5 to 185 barrels per day and from the gas wells 1 million to 16 million cubic feet of gas per day.

The "Berea" dolomite on the western side of the State has also yielded hydrocarbons. Some of the fields are found in Muskegon and Oceana counties; most of them produce oil.

The Berea Sandstone in eastern Michigan is easily correlated, with some possible minor difficulties in recognizing the basal portion because of the transitional contact with the Bedford. The upper contact is easily distinguished from the Sunbury Shale. The Berea generally includes all those portions of sandstone and shale or dolomite above the more consistent Bedford Shale, as shown in cross-sections A-M, A-N, and A-0, Plates 71, 77 and 85.

Approaching the central portion of the basin, the Berea starts losing its identifying characteristics and is not generally distinguished from the Bedford below. The Berea gradually changes to a dolomitic and shaly entity and eventually grades into the upper Elsworth on the western side of the Southern Peninsula. In the central portion of the basin where the Berea and Bedford are not easily distinguished as separate entities, the unit is generally called the Berea-Bedford (see Plates 10 and 17).

Bedford Shale

The Bedford Shale, identified by Rominger in 1876, is predominantly gray. As stated previously, the Berea and Bedford contact is gradational in some areas where the upper part of the Bedford may be silty and sandy. It is confined to the eastern part of the State. Several of the cross-sections show that both the Berea Sandstone and the Bedford Shale grade into or interfinger with the Ellsworth Shale and upper part of the Antrim Shale on the western side of the State.

In this report the Bedford is generally confined to that portion which is composed predominantly of gray shale. It may contain some sandstone or siltstone beds, especially at the transitional contact with the Berea, but it is usually distinguished without much difficulty. The Bedford shows greater radioactivity than the Berea above, as seen on Plates 71 and 77; and it is much less radioactive than the underlying Antrim. These criteria can be used to bracket the Bedford for purposes of correlation.

As a result of stratigraphic, paleontologic, and palynologic studies of these formations by Dewitt (1970), the Mississippian-Devonian boundary in northern Ohio is placed in the basal 2 to 10 feet of the Bedford Shale. Whether the basal part of the Bedford Shale in the Michigan Basin is of Devonian or Mississippian age is a moot point at present according to Dewitt (1970). In the western portion of the State where the Berea and Bedford are absent, the top of the Devonian is placed near the top of the Ellsworth, based on correlation from the eastern part of the basin. For convenience, general practice is to place the Mississippian-Devonian contact at the top of the Antrim in eastern Michigan, and at the top of the Ellsworth in western Michigan.

Devonian System

Rocks of the Devonian System are found beneath Mississippian strata. Thick sections of Upper and Middle Devonian rocks are present in the Michigan Basin, but Lower Devonian strata are essentially absent. The only rocks of Lower Devonian age which may be present, those of the highly eroded Garden Island Formation, are not readily identified in the subsurface.

Devonian formations and groups identified in the subsurface of the Southern Peninsula are, in descending order, the Ellsworth Shale confined to the west side of the basin; Antrim Shale; Traverse Formation; Traverse Limestone; Bell Shale; Dundee Limestone; Detroit River Group; and Bois Blanc Formation. The Detroit River Group is composed of the Lucas Formation, the Amherstburg Formation, and Sylvania Sandstone.

From an economic standpoint, rocks of the Devonian System are of prime importance to the people of Michigan. A major proportion of the petroleum produced through the years has come from rocks of Devonian age. Potential for future production of hydrocarbons is excellent. Many of the currently active fields are expected to continue supplying oil and gas, and prospects for new discoveries remain good. The significance of Devonian rocks from an economic standpoint will be reviewed in more detail in sections dealing with the individual formations.

Ellsworth Shale

The Ellsworth Shale is the uppermost Devonian formation encountered in Michigan. It is found, for the most part, on the western side of the State in the same stratigraphic position as the Berea, Bedford and the upper portion of the Antrim on the east side. It was first described by Newcombe in 1932 in cuttings from a well drilled for oil at Muskegon. Ellsworth Shale is exposed at a few localities in Antrim and Charlevoix counties.

The Ellsworth is predominantly green shale in both the surface and subsurface; but some gray and greenish-gray shales occur near the contact of the Ellsworth and Antrim in the subsurface. Ellsworth beds are quite silty in places in western Michigan, particularly in the southwestern portion where a considerable amount of siltstone is interbedded with the greenish-gray shale. Where it is present on the western side of the State, the Ellsworth can range in thickness from 250 feet to as much as 700 feet.

According to Bishop (1940), the depositional environment of the Antrim, which underlies the Ellsworth, was characterized by a gradual increase in both temperature and humidity. Vegetation thrived in this climate and became available eventually for deposition in the Antrim seas. Incorporation of the vegetation in the sediments gave the Antrim its characteristic black or brown color. Later, a period of increased aridity, during which the greenish-gray Ellsworth Shales were laid down, culminated in a withdrawal of the sea. Weathering and erosion followed, giving rise to widespread oxidation of the exposed Ellsworth formation. With the beginning of Coldwater time, southwestern Michigan was downtilted toward the northeast, and the minor basin in which the Ellsworth was deposited lost its identity. From the northeast the Coldwater sea then transgressed upon the exposed Ellsworth, incorporating oxidized debris in the basal member of the Coldwater formation. These, then, were Bishop's ideas concerning the depositional history of the Ellsworth and the contiguous formations.

The correlation of the Ellsworth Shale in western Michigan and its transitional contact, facies relationship, or interfingering with the Berea, Bedford, and Antrim is shown on several of the cross-sections. If a line is drawn from western Charlevoix County to western Branch County, it will mark the area of transition from Berea, Bedford, and the upper part of the Antrim on the east to Ellsworth on the west. This transition area (shown on cross-sections A-D through A-I, Plates 24, 30, 35, 39, 45 and 51) is where the Berea, Bedford, and upper part of the Antrim lose their specific radioactive characteristics and change to the typical green shale radioactivity of the Ellsworth. Probably, more of a facies or interbedding change between the units exist than is shown on the cross-sections; but for the purposes of this report, the change is shown as being rather abrupt.

In some areas of northwestern Michigan the basal portion of the Ellsworth shows increased radioactivity (see Plate 24, the Henry No. 1-4), and this portion has, in some cases, been included in the Antrim. In this report, however, the higher radioactive area is included in the Ellsworth because recent Michigan Geological Survey studies have indicated that it correlates with some of the lower Ellsworth beds (Ells, 1979).

Antrim Shale

The Antrim Shale was named by Lane in 1901 from exposures found in the northwestern corner of Antrim County. Exposures can also be seen in Charlevoix, Cheboygan, and Alpena counties. It has a range of thickness from 120 feet where it is not cut by Pleistocene erosion to 600 feet in portions of northern Michigan. The Antrim is predominantly dark gray to black and brown, hard, thin-bedded, brittle, carbonaceous shale interbedded with gray shale in the lower part. Near the base of the Antrim, dark brown bituminous limestone concretions occur. They are from two to five feet in diameter and consist of a variety of calcite called anthraconite. Pyrite and marcasite grains are associated with the anthraconite. These concretions are unique in that they are found only in the Antrim Shale in Michigan, and in Antrim equivalents elsewhere.

According to Asseez (1967), the Antrim sea in Michigan was widespread and must have received a great quantity of organic matter which resulted in deposition of the characteristic black to brown shale. He also believes that the Antrim was deposited in an euxinic environment, whereas the Ellsworth Shale accumulated in a more open sea on the western side of Michigan in alternating oxidizing and reducing environments. The lighter colored green shale of the Ellsworth was caused by green varieties of clay minerals, chiefly glauconite, as well as the abundance of ferrous ions and the scarcity of organic matter. For a more complete discussion of the Antrim, refer to Ells (1979).

The Antrim Shale may contain important hydrocarbon resources for use in the future. This formation is currently being studied in more detail by several groups in order to determine its hydrocarbon potential. Some wells in Otsego County have produced Antrim gas for a number of years, and there may be potential for more Antrim gas in other areas of the State.

The Antrim unit has a complex geologic history and is somewhat complicated to correlate. As reported in the discussion of the Ellsworth, the upper part of the Antrim on the eastern side of the State interfingers with, or exhibits a facies relationship with, the Ellsworth in western Michigan. Therefore, delineating the true top of the Antrim can be difficult in some of central and northern Michigan, as shown on cross-sections A-D, A-E, and A-F, Plates 24, 30 and 35. These sections show an abrupt change from a large Antrim section on the east to a much thinner unit on the west. A detailed study of the Antrim has been done by Ells (1979), and should be referred to for a more complete understanding of this interval.

Another problem involving the Antrim is the transitional nature of lower beds with the underlying Traverse Group in certain areas of the State. In southern Michigan the contact is, for the most part, easily recognized because the transition zone is small and a fairly clean break occurs between the highly radioactive Antrim and the Traverse Group. In northern Michigan, however, this transition zone is much more extensive and presents a more complicated picture. As can be seen on cross-section A-C, Plate 17, the upper part of the Traverse Group contains some highly radioactive beds which, in some previous studies, have been included in the Antrim. In this report the base of the Antrim has been chosen at the last extremely radioactive zone discernable before the general transition to less radioactive shales.

Traverse Group

The Traverse Group in the subsurface of the Michigan Basin is generally divided into three units. These units, in descending order, are the Traverse Formation, Traverse Limestone, and Bell Shale at the base of the Group. It is difficult to correlate these subsurface units with the many surface formations of the Traverse. A study of the Traverse Group directed toward correlating the surface and subsurface expressions would be most helpful. Traverse rocks are found at the surface in Alpena, Presque Isle, Cheboygan, Emmet, and Charlevoix counties in the northern part of the Southern Peninsula but do not crop out in southern Michigan. The Traverse Group is variable in thickness, with a maximum of about 875 feet near Saginaw Bay and a general thickness ranging from 800 feet in the north to less than 100 feet in southwestern Michigan. The lithology is diverse in the subsurface, with many facies changes throughout the sequence (see Cohee, 1947).

The Traverse Formation, the uppermost unit of the group, is considered by many to be a transition zone between Antrim Shale and Traverse Limestone. The unit in the central and western part of the State is composed of gray shale in the upper portion and gradually grades to more calcareous shale and argillaceous limestone near the base. The Traverse Formation in eastern Michigan is not the same lithologically and is not easily correlatable with the central and western facies. It is, therefore, common practice in subsurface stratigraphic interpretations in the eastern part of the State to combine the Traverse Formation and the Traverse Limestone.

The middle unit of the Traverse Group is the Traverse Limestone. Variation of facies is more prevalent in this unit than in the others. In eastern Michigan, the so-called Traverse Limestone is predominantly shale with the highest percentage of shale content being located in the "thumb" area of southeastern Michigan. Progressing westward the shales become more calcareous and the limestones purer in central Michigan. In the western part of the State the full section of the Traverse Limestone is predominantly pure limestone with some beds of dolomite and argillaceous dolomitic limestones. In southwestern Michigan some lithographic limestone beds are present in the lower part of the unit and chert is also abundant in some of the pure limestones. Reefs have been found in Alpena County quarries and probably exist in the subsurface in other parts of the State. Observed reef buildups occur with reef heights of 30 feet and exhibiting dips of 30° to 40° on the flanks.

The Bell Shale is the lowermost formation of the Traverse Group and is consistently shale where present. It is about 80 feet thick in the outcrop area in Presque Isle and Alpena counties and more than 100 feet thick near Saginaw Bay in eastern Michigan and in Manistee County in western Michigan. It is generally 60 to 70 feet thick in the central basin area, but thins toward the south where it eventually pinches out.

The Traverse Limestone has been a prolific producer of oil and gas in the Michigan Basin since the late 1920's. A number of fields in the Southern Peninsula have yielded oil and gas from Traverse Limestone, with the Walker field in Kent and Ottawa counties being the most prolific to date. Over 17,150,000 barrels of oil had been produced in the Walker field by the end of 1977, and about 99 percent was from Traverse Limestone.

Most of the Traverse fields are located in the southwestern quadrant of the State, where the Traverse is predominantly carbonate. Some of these fields may be producing from small bioherms in the Traverse, while in others production is a result of porosity pinchouts. Still other fields may be located on structural traps caused by folding, or salt collapse of the A-l, A-2, or B evaporites in the Sa1ina which has resulted in formation of traps in the Traverse (see Mesolella and Weaver, 1975). Porosity in Traverse Limestone reservoirs can be as much as 9 percent and ranges from vugular to intercrystalline. Permeability is as high as 100 millidarcies. Though the Traverse rocks have been drilled intensively in some parts of the basin, well density figures show large areas of poorly explored but potentially productive territory yet to be drilled.

The Traverse Group has been correlated in more detail than many of the other subsurface formations. It has been separated into Traverse Formation, Traverse Limestone, and Bell Shale, which are the correlatable units.

The upper portion of the Traverse Formation has been considered to be transitional between the Antrim Shale and Traverse Limestone. The Traverse Formation is not well developed in the eastern and southeastern portion of the State, so it is not usually described as a separate entity in these areas. As seen on Plates 3, 10, 17, 24, 35, 39, 45, 51, and 57, the Traverse Formation becomes more discernible in a western and northern direction. The upper radioactive portion of the Traverse Formation, which is that part above correlation line TF-1 (see Plate 10), can be delineated in much of western and northern Michigan. This correlation line is useful in determining the base of the Antrim Shale and the top of the Traverse Limestone. Within the Traverse Limestone, six recognizable horizons, TL-1 through TL-6, are delineated and traced on many of the gamma ray log sections. These correlative horizons provide a basis for following facies changes in the subsurface. In addition to the correlative horizons, several porosity zones in the Traverse Limestone are delineated in certain areas of the State, and these are correlated on many of the sections.

From the top of the Traverse Limestone to the top of horizon TL-3, the section generally contains more carbonate than the section from TL-3 to the Bell Shale throughout northeastern Michigan. An example of this is shown on Plates 3 and 10, where the lower portion contains an appreciable amount of shale and the upper portion is composed of limestone, calcareous shale and shale. In western and northwestern Michigan the Traverse Limestone is predominantly calcareous above horizon TL-4, whereas below this marker, clay content increases slightly (see Plate 24). In southern Michigan the Traverse Limestone thins a great deal and the markers are very useful in correlations in that part of the basin.

A series of porosity zones is present in the upper portion of the Traverse Limestone. As seen on cross-sections A-B through A-J (Plates 10, 17, 24, 30, 35, 39, 45, 51 and 57) many of these porosity zones can be traced from well to well over large areas. The porosity zones furnish valuable information because they point out where possible lost circulation zones or hydrocarbon-bearing zones may occur. Many of the zones have been found to contain water; but abundant economic deposits of hydrocarbons have also been found in the Traverse Limestone.

The Bell Shale is the basal formation of the Traverse Group. As shown on the cross-sections, the Bell can be traced over a large part of the basin with some degree of accuracy. Cross-sections A-G and A-l (Plates 39 and 51) in particular show that the Bell pinches out in the southern portion of the basin, and the contact between the Traverse Group and the underlying Dundee Limestone becomes more tentative.

Dundee Limestone

The next Devonian formation which is readily recognizable in the subsurface is the Dundee Limestone. The Dundee in this report combines both the Rogers City Limestone and Dundee Limestone, as they are not generally distinguished in the subsurface on the basis of radioactivity logs. The differentiation into two formations by previous workers (see Cohee and Underwood, 1945; Knapp, 1947) was based largely on faunal succession and minor differences in lithology between the units. Minor differences in the color as well as the lithology of part of the rock poorly distinguish the two units in certain areas, but overall the Rogers City and Dundee are not readily separable.

The term Dundee was first used by Lane in 1895. Dundee rocks underlie most of the Southern Peninsula, and are directly beneath the glacial drift in Wayne and Monroe counties in southeastern Michigan. They are exposed at the surface in Sibley quarry in Wayne County and along Mason Creek in Monroe County. The greatest thickness of Dundee rock, including the Rogers City Limestone, occurs in the area near Saginaw Bay where it may be as much as 475 feet thick. In most of western Michigan, Dundee strata are less than 100 feet thick with much of the area containing less than 40 feet. The formation is absent in the extreme southwestern portion of the State.

The Dundee Limestone is predominantly buff to brownish-gray, fine to coarsely crystalline limestone. Exceptions to this occur in the extreme western and southwestern areas where the formation is entirely dolomite. In much of the central basin it is composed of both limestone and dolomite with some anhydrite beds. Dolomite is generally found at the base of the formation. According to Gardner (1974), the Dundee appears to be a biostromal shelf carbonate with dark fine grained offshore facies deposited in a sea transgressing from east to west. A sabkha-lagoonal facies on the west records the retreat of evaporite deposition from the Michigan Basin.

To date, the Dundee has been the most prolific oil producer in the State. Several porous zones in the formation produce oil and gas. Lost circulation and water zones may also occur where porosity is present. Studies have shown that these porous zones are lenticular and vary considerably in thickness and permeability. The porosity may be either indigenous or secondary and occurs in both limestones and dolomites of the Dundee.

One important porosity zone in the Dundee that can be traced over a large area is the "Reed City". This zone has produced large quantities of oil and gas. It has been variously interpreted as part of the Dundee Limestone or part of the Detroit River Group. Study still continues concerning the "Reed City" and its age relationship with the Dundee and Detroit River.

The "Reed City" can be correlated over a large portion of the basin. A report by Landes (1951) places the zone in the uppermost part of the Lucas Formation at the top of the Detroit River Group. Where the "Reed City" is productive of oil and gas, it yields non-sulfurous, sweet crude from vugular and inter-crystalline porosity in dolomite beneath an anhydrite bed.

In this report, the "Reed City" porosity zone is placed in the Dundee, and therefore the formation may be of greater expanse than the generally accepted norm, especially in portions of southern Michigan. However, in tracing the Dundee from the northern part of the basin, where it is well developed in the subsurface, to the southern two to three tiers of counties, the correlations seem to point to a thicker section in southern Michigan.

In southeastern Michigan, however, correlation of the base of the Dundee becomes especially difficult (see cross-sections A-K through A-0, Plates 62, 66, 71, 78 and 86). In the reports of several researchers, including Gardner (1974) and Majedi (1969), the base of the Dundee in this area has been placed at different horizons. It has been variously chosen at: 1) gamma ray log marker DR-1 (Gardner, 197,0; 2) below this particular marker and the good porosity zone (Majedi, 1969); 3) above the marker and within the good porosity (Gardner, 1974; Majedi, 1969); and 4) above the marker and above the good porosity (Gardner, 197,0 •

The writer has attempted to distinguish the base of the Dundee in southeastern Michigan after correlating it in a representative section in northern Michigan. Inspection of the several cross-sections from the southeastern area reveals that the base of the Dundee may be in a porous-looking interval according to neutron readings in some areas (see Plate 66, the Messmore No. 1) and below this zone in others (see Plate 71, the Noonan No. 1-14). The writer believes, however, that the base is above the high-radioactive marker bed, DR-1, in most cases.

Previous mention has been made of several good porosity zones in the Dundee which can be traced over much of the basin. These porosity zones, as shown on several of the cross-sections, are critical because of their water content and the possibilities for lost circulation. They have also been significant as prolific oil producers, and the potential for the discovery of more oil still exists. As seen on cross-sections A-B through A-J, Plates 11, 18, 25, 30, 35, 39, 45, 51 and 57, porosity zones can be followed readily on the neutron logs. And pinchouts in porosity are significant in the search for hydrocarbons.

Detroit River Group

The Detroit River Group, which underlies the Dundee, is composed of three formations in the subsurface: the Lucas Formation, the Amherstburg Formation and the Sylvania Sandstone (see Chart l). The Anderdon Formation, known from surface exposures, is not ordinarily identified in the subsurface, but is included in the uppermost beds of the Lucas Formation. The rocks of the Detroit River Group are present over virtually all of the subsurface of the Southern Peninsula and are variously composed of dolomite, anhydrite, salt, dark brown to black limestone and sandstone. It is difficult to determine the contact between the Dundee and Lucas Formation in some places; but stratigraphers generally place the contact at an anhydrite bed which occurs within a few feet of the top of the Lucas Formation, where such an anhydrite is recognizable (see Plate 25). Where the anhydrite bed is not present, other lithologic differences become the basis for selecting the contact, e.g., dolomite versus limestone, color differences, and crystallinity.

Lucas Formation

The uppermost rocks of the Detroit River Group constitute the Lucas Formation. In the central part of the basin the formation consists of beds of dolomite, anhydrite, salt, limestone, and sandstone. Some of the carbonate rocks are argillaceous, but shale is conspicuously absent. The Lucas varies in thickness from as little as 20 feet in Berrien County in the southwestern corner of the State to over 1,000 feet in the central portion, where much of the section is composed of evaporites.

The evaporites of the Lucas Formation are principally anhydrite and salt. The anhydrite is much more widespread than the salt, which is usually confined to the upper half of the evaporite sequence in the central part of the basin. According to Gardner (1974) all of the salt appears to lie within the 500-foot thickness line of the Lucas, and most of the salt having an aggregate thickness exceeding 400 feet is confined to the deepest part of the basin in Missaukee and Roscommon counties, where the formation is more than 1,000 feet thick.

Anhydrite in the Lucas Formation generally increases in abundance basinward. Gardner (1974) has shown that in the center of the basin anhydrite occurs above and interstratified with salt; but the greatest volume is found in the lower half of the evaporite sequence, below the salt beds. Although salt is not present away from the central portion of the basin, anhydrite is still fairly abundant toward the rim; but the amount gradually decreases at the flanks of the basin.

Several oil and gas producing zones are present in the Lucas Formation. These are, in ascending order: the Richfield zone, the "sour zone", and the "Reed City" zone, if the Reed City is placed in the Detroit River Group rather than in the Dundee. The Richfield generally includes all of the section that produces sweet crude below the massive anhydrite, which underlies the lowest Detroit River salt beds, and above the fossiliferous black coralline limestone of the Amherstburg (Hautau, 1952). Where the Richfield is best developed, it appears to span an interval of about 200 feet. The section is comprised of several dolomite beds, ranging from a few inches to 10 feet in thickness, separated by anhydrite and some limestone lenses. Six of the beds have shown oil saturation and four are considered important reservoirs. Oil and gas accumulations in Richfield pools are generally related to anticlinal structures, and most of those that have been found so far are associated with the larger central basin anticlines. Richfield porosities range up to 30 percent, and the average porosity for total pay sections in individual pools is between 14 and 17 percent. Permeabilities range from 5 to 60 millidarcies and average 4 to 6.5 for overall pay sections in individual pools.

The "sour zone" produces a high-sulfur oil and gas from thin, low-permeability, porous dolomite and limestone strata found between thin salt and anhydrite beds through an interval of about 100 - 150 feet. In the central part of the basin where salt beds are thickest, the "sour zone" lies between a thick salt bed and an underlying anhydrite sequence. "Sour zone" production is generally associated with anticlinal structures in the central basin area.

The Lucas Formation has been significant in production of salt and brine. Salt in the Lucas has been exploited by the brine well method in Manistee County since 1881 and in Mason County since 1886. These salt-producing areas are close to the western edge of deposition of the salts. The salt beds are thin, but are close to the surface and adjacent to water transportation. Natural brines, which are of great importance to Michigan's chemical industry, are present in the carbonates of the Lucas (see Sorensen and Segall, 1970- Important brine constituents such as iodine, bromine, and chlorides of potassium, calcium, magnesium, and sodium are extracted and processed to make various chemical compounds.

Accurate correlations of several beds and zones in the Lucas Formation are fairly easily achieved. But selection of a consistent break between the base of the Dundee and top of the Lucas is not always possible. When radioactivity logs are used for correlation, the contact between the Dundee and Detroit River Group is generally traced from wells where anhydrite can be identified to wells in which anhydrite is not present, and then other significant features must be used to delineate the units.

In the north central portion of the Southern Peninsula the top of the Lucas (called the top of the Detroit River by most geologists) is always placed above the first Detroit River salt (see Plate 4). Toward the edges of the basin where salt is not present, selecting the top becomes more difficult, especially in southeastern Michigan.

In the Lucas Formation, several beds and porosity zones have been correlated. Correlatable horizon DR-1 (see Plate 57) is a bentonite bed which had been previously identified in the Kawkawlin, Michigan area (see Ba1trusaitis, 1970). This bed can be recognized over parts of the basin and is helpful in identifying the upper portion of the Lucas and correlating the lower beds. The bentonite shows a distinctively high radioactive reading, and consequently is readily detected.

Another bed or group of beds which is identifiable over much of the basin is referred to as DR-2 (see Plate 18). These beds, which are three argillaceous dolomites separated by anhydrites where they are best developed, have been recognized as consistent and correlatable units by geologists studying the stratigraphy of the basin. They are significant, especially in central and northern Michigan, because they directly overly a zone known as the "massive anhydrite" which, in turn, overlies the Richfield (see Plate 18, the Yake No. l).

The Richfield is the lowest portion of the Lucas, as shown on Plates 4, 11, 18 and 25. Several porosity zones located in the Richfield can be correlated over the central and northern Michigan area. These porosity zones may contain valuable hydrocarbons. In southern Michigan, the Richfield is not as well developed as in northern Michigan, and cannot be correlated with as much accuracy. The porosity is not as well developed, nor is the formation as productive of oil.

Another oil zone, not correlated in these cross-sections but identified on several of the sections, is the "sour zone" (see Plates 18 and 78). This zone is not as easily recognized nor correlated in the basin. Therefore, it has only been labeled on specific gamma ray logs.

The correlation of individual salt beds in the Lucas was not attempted. These salt beds are abundant in the northern and central portions of the basin and are important economically. A more detailed study of the Lucas would be helpful in identifying individual salt beds as well as the carbonate beds which contain economically important quantities of brine.

Amherstburg Formation

Immediately below the Lucas Formation are rocks of the Amherstburg. The formation was originally defined by Sherzer and Grabau (1909) and includes the beds lying between the Lucas and the Sylvania Sandstone where present. In some areas where the Sylvania is not present, the Amherstburg is underlain by the cherty Bois Blanc Formation. In southwestern Michigan, the Bois Blanc is absent and Detroit River rocks lie directly on the Bass Islands as well as other strata of Silurian age. The Amherstburg is present everywhere beneath the surface in the Southern Peninsula except in the southeastern and southwestern corners of the State, where it has been removed by erosion. It is composed predominantly of limestone with subordinate dolomite in some areas of the northern and eastern parts of the Southern Peninsula. But it is all dolomite in the western and southern areas of occurrence. A sandstone lentil, found on the west side of the State and known as the Filer Sandstone, is probably a part of the Amherstburg. But there is some debate as to whether the Filer is in the Amherstburg or is actually a part of the Sylvania.

One of the distinguishing characteristics of the Amherstburg Formation is its relatively dark color. It is essentially brown to black fossiliferous carbonate which is more often limestone than dolomite. It can usually be distinguished from the overlying light-colored, anhydrite-rich, mostly nonfossiliferous dolomites of the Lucas. The dark color of the Amherstburg has caused many geologists to refer to this formation as the "Black Lime". In many subsurface sections, however, the dark color becomes lighter downward and the base of the formation is sometimes difficult to ascertain.

Through the years, several theories have been postulated concerning the depositional environment of the Amherstburg. One theory by Gardner (1974) holds that the increasingly dark color upwards suggests a reducing environment which was still able to support diverse and abundant fauna. The waters may initially have been sufficiently aerated to permit sustenance of life; but the sea floor became steadily more stagnant due to weakening currents, until the corals were buried in the carbonaceous lime muds. The faunas flourished during the early transgressive phase of the Amherstburg. Then, with cessation of transgression, intermittent stagnation occurred, as evidenced by the dark coloration and excellent preservation of fossils in the black limestone facies. Water depths probably remained within the zone of photosynthesis; but decreased circulation of the water led to several periods when life could not exist.

Correlation of the Amherstburg over much of the basin is possible because in many areas the formation exhibits slightly higher radioactivity than most of the surrounding rocks. Many of the cross-sections show three correlation lines associated with the Amherstburg (see Plate k). The upper line depicts the top of the Amherstburg as it is defined in this report. The black limestone typically identified as Amherstburg was chosen to be the top of the formation, and was found in several wells at this point. The middle line denotes a correlatable marker, which has, in the past, been designated as the top of the Amherstburg. It is another usable correlation point; but if this is chosen as the top of the formation, the upper black limestone as well as the "Filer Sandstone", a part of the Amherstburg, would not be included in the formation. Finally, the lower line defines the base of the Amherstburg, which can be recognized readily when underlying Sylvania Sandstone is present. However, where the Sylvania is not present, or when an attempt is made to correlate in southeastern Michigan, problems develop in choosing the proper gamma ray response in order to delineate the base of the formation.

If the gamma ray curve response supposed to represent the Amherstburg in northern, western, and central Michigan is correlated carefully into southeastern Michigan, 50 feet or more of sand seems to be present above the Amherstburg, as shown in cross-section A-L (Plates 66 and 67, the Messmore No. 1, Lopez No. 1, and Jorgensen No. 1). The Sylvania in many areas of the State contains carbonate beds and it may be that the Amherstburg is one of them, or an abundance of sand is found above the Amherstburg in southeastern Michigan.

In western Michigan, the Filer Sandstone exists in the upper portion of the Amherstburg. This sandstone is identified as associated with the Amherstburg, and the log curves of several wells (see Plate 25) indicate this. The Filer is generally confined to the western portion of Michigan. It appears from correlations, as interpreted in this report, that the Filer is above the Sylvania in the Amherstburg, and is not directly associated with nor in contact with the Sylvania (see also Landes, 1951).

Sylvania Sandstone

The Sylvania Sandstone is the basal formation of the Detroit River Group. It was named by Edward Orton in 1888 from outcrops in Sylvania Township, Lucas County, Ohio. It is composed predominantly of well rounded and sorted, fine to medium grained sandstone with lesser amounts of silt, chert and carbonate. The Sylvania Sandstone is not found everywhere in the Michigan Basin; it is located in portions of northwestern, central, and southeastern Michigan (see Landes, 1949 and 1950. The sand body is 50 to 75 miles wide, and over 300 feet thick in the center of the basin. In several areas Sylvania Sandstone is an important brine producer.

The depositional history of the Sylvania has been a subject of disagreement among earth scientists. Some geologists assert that because of the facies gradation between the Sylvania sands, the Amherstburg carbonates, and the cherty Bois Blanc, a marine depositional environment is a logical supposition. Others believe that both eolian and fluvial processes supplied sand to the seaway where it was redistributed by marine currents and deposited along coastal areas concurrently with offshore carbonates of the Bois Blanc and Amherstburg. Sherzer and Grabau (1909) postulated an eolian origin for the Sylvania while Carman (1936) suggested a reworking of eolian sands by marine waters.

Correlation of the Sylvania Sandstone in the central portion of the basin is shown in cross-section A-M, Plate 72. The low radioactivity reading of the sand relative to the carbonates occurring above and below it allows for bracketing of the Sylvania with some degree of accuracy. On the edges of the depositional area, however, correlations become more speculative due to a decrease in sand deposition and also a decrease in the variability of the radioactive response between the Sylvania and the surrounding strata.

Plate 26 shows that the Sylvania slowly loses its characteristic low radioactivity in northwestern Michigan as more and more carbonate is introduced into the formation. Sample analysis by the writer confirms that the Sylvania is present in the area as depicted on Plate 26.

Some sand is found in the southwestern portion of the Southern Peninsula which may also be the Sylvania (see Plate 52). Since the classification is still questionable, the Sylvania shown on the plates is qualified with a question mark.

Bois Blanc Formation

The Bois Blanc is the basal formation of the Devonian System generally recognized in the Southern Peninsula. The name was introduced by Ehlers (1945) to apply to 360 feet of strata on Bois Blanc Island in the Straits of Mackinac region. In the subsurface, the cherty Bois Blanc carbonates are interbedded and gradational with Sylvania sandstones, or the Amherstburg where the Sylvania is not present. Studies of wells drilled in the central basin area in Ogemaw County have revealed that the Bois Blanc may be over 800 feet thick (see Plate 4, the State-Foster No. 1). The thickness decreases from the central basin area to the north and northwest, where it may be about 300 feet thick in Leelanau County, and to the southeast where it disappears in Monroe County. The Bois Blanc Formation is absent in the southwestern and southern counties.

No discussion of the Bois Blanc Formation would be complete without mention of the Mackinac Breccia. Masses of indurated breccia are left standing as scenic chimney rocks, pillars and arches in the Straits region. The breccia contains rocks of Bois Blanc age as well as blocks and fragments from the Detroit River Group, and the Bass Islands and Salina groups of Silurian age. The Mackinac Breccia is the most prominent rock in the Straits area in the northern part of the Southern Peninsula and the southern tip of Mackinac County in the Northern Peninsula.

According to Landes (1945) the Mackinac Breccia formed by leaching of Salina salt and subsequent collapse of the overlying rocks. Leaching occurred during emergences of the land in the Straits area after the salt had been deposited. Percolating underground water was the most probable cause of leaching great quantities of salt from the Salina deposits. A number of caves and caverns were produced where the salt was above the groundwater table. These underground caves initiated a condition of instability which led to the collapse of the cavern roofs. The overlying rock fell and slid downward and eventually came to rest in jumbled fashion. Thus rocks of different formations and varying ages were brecciated and tumbled together. Some parts of the breccia were later indurated. The age of brecciation was at least post-Bois Blanc and is probably post-Detroit River and pre-Dundee.

The Bois Blanc can be correlated accurately over much of the central basin area. As shown on Plates 11, 26 and 67, the Bois Blanc, because of its slightly higher radioactivity, can be distinguished from the overlying Sylvania. In northern Michigan, where Sylvania Sandstone is not present, the Bois Blanc can generally be differentiated from the overlying Amherstburg by its lower radioactivity and higher porosity (see Plates k and 18).

In western and southern Michigan, however, the Bois Blanc Formation has been removed by erosion and is not well defined. In western Michigan, the formation previously has been correlated or identified with a very low-radioactive zone just above the Bass Islands. The current data shows that the Bois Blanc may include some of the carbonates with higher radioactive readings which occur above this low-radioactive zone (see Plates 26 and 31). Correlations extending from the central basin area where a full section of Bois Blanc is present to the western part of the state appear to verify this conclusion. In the southern part of the State, correlation of the Bois Blanc is complicated by changes in lithology, thinning of strata above and below the formation, and erosional unconformities. As shown on Plates 40, 46 and 52, the Amherst-burg, Sylvania, Bois Blanc and Bass Islands thin in a south and southwesterly direction and some of their radioactive characteristics change. The Bois Blanc eventually disappears in southern Michigan due to erosion, as seen on Plates 46, 52 and 58. In following the lithologic characteristics of the Bois Blanc into southern Michigan, chert can be found in some of the cuttings at a depth where the Bois Blanc should be located according to radioactive characteristics on gamma ray logs. This adds more credence to correlation of the Bois Blanc into southern Michigan.

Silurian System

Silurian age rocks lie beneath Devonian strata in the Michigan Basin, separated from them by an unconformity in many areas. In descending order the Silurian rocks are divided into the Bass Islands Group, Salina Group, Niagara Group, Cabot Head Shale, and Manitoulin Dolomite. The Salina Group is further subdivided into informal units, the G Unit, F Evaporite, E Unit, D Evaporite, C Unit, B Evaporite, A-2 Carbonate, A-2 Evaporite, A-l Carbonate, and A-l Evaporite. The Silurian strata contain vast amounts of salt, and hundreds of pinnacle reefs. These strata are important economically because of the limestone, dolomite, salt, and oil and gas which are obtained or produced from them.

Bass Islands Group

The Bass Islands Group was named for several islands near the western end of Lake Erie, where rocks of the group outcrop. In southern Michigan (Monroe County), Bass Islands rocks are divided in outcrop into Raisin River Dolomite and Put-in-Bay Dolomite, but these formations are seldom separated in the subsurface. In the Straits of Mackinac region, northern Michigan, Bass Islands rocks in outcrop are called St. Ignace Dolomite.

In the northern part of the Southern Peninsula, the Bass Islands rocks are about 325 to 350 feet thick, while in the center they attain a thickness of approximately 575 feet. In Presque Isle County the top of the Bass Islands is about 500 feet below sea level while in Alpena County it drops to about 900 feet and in Midland County it is more than 4200 feet below sea level.

Bass Islands rocks in the subsurface are typically dense, buff dolomites which are sparsely oolitic in the upper portion. Lower in the section gray argillaceous dolomite is intermingled with buff dolomite, and in the interior part of the basin several thin anhydrites and salt beds are present. The contact between the Salina and Bass Islands rocks is generally considered to be transitional and conformable. However, an unconformity exists between the Silurian and Devonian in many parts of the basin and especially over large portions of southwestern Michigan. In this region the Devonian formations lie upon successively older and stratigraphically lower units of the Salina Group. In the extreme southwestern corner of Michigan the Salina has been completely removed and Devonian rocks lie directly upon the Niagaran. The extent of the erosional truncation in this region appears to be related to the thick Niagaran reef complex on the Indiana-Ohio platform and the Kankakee Arch. In this region the truncation is greatest where Niagaran rocks are thickest. Where the Niagaran reef complex is thinnest, the truncation is less pronounced and a thicker section of Salina-Bass Islands rocks is preserved.

Correlation of Bass Islands strata is fairly routine where a full section of the formation is developed. In southern Michigan, however, thinning due to depositional phenomena and Bass Islands erosion make correlation less secure. As shown on Plate 58, the Bass Islands in the southern area becomes thinner, but still contains some beds which are slightly more radioactive, and can be correlated. But in southwestern and extreme southern Michigan (see Plates 46, 52 and 58), these beds are not present and correlation becomes speculative at best.

Salina Group

Subsurface units of the Salina Group occur below the Bass Islands dolomite in Michigan. Salina Group rocks were separated by Landes (1945b) as Units A upward through H, with Unit H being equivalent to the Bass Islands. The A Units were later modified by Evans (1950). Subsequent exploration in Michigan has brought about a more detailed subdivision of the strata. Most of the subdivisions are based on gamma ray log curves which can be traced over a great portion of the basin. The name "H Unit", as applied by Landes to the Bass Islands rocks, has been dropped and Bass Islands is now in standard usage. The G Unit, as originally described, has undergone a revision of definition and is now designated in a different manner. The point where the unit was previously located on logs from wells on the margins of the basin was shown to grade basinward into the F Evaporite. Present practice is to call the top of the G Unit in the center of the basin at the point which geologists previously called the "H Shale". For a more detailed discussion of the Salina Group see Ailing and Briggs (1961).

The G Unit is the uppermost formation of the Salina Group. In the center of the Southern Peninsula it consists generally of gray dolomitic shale and can be readily distinguished from the light-colored Bass Islands rocks above. As the G Unit is traced to the basin margins, it thins and becomes less argillaceous, and in the extreme southern portion of the Southern Peninsula it cannot be distinguished from Bass Islands rocks by using gamma ray logs.

The G Unit in the center of the basin is characterized by high radioactivity as shown on Plate 5. When this unit is traced into southern Michigan (see Plate 58), it thins markedly and eventually becomes unrecognizable at the southern margins. In the past many geologists arbitrarily picked the top of the Salina in southern Michigan at the massive radioactive zone which occurs beneath the point where the present G Unit is chosen (see Plate 58, Crawford No. 1, at a depth of approximately 2680 feet). However, the G Unit, although thin, can be recognized in many areas at the edges of the basin and should be defined as shown in the sections. The G Unit, along with many of the Salina formations, has been removed by pre-Devonian erosion in southwestern Michigan (see Plates 46 and 53). This unconformity has been discussed by Ells (1958, 1962, and 1967a) and is an important feature in delineating the geological history of this portion of the basin. The use of gamma ray logs facilitates more accurate correlation for this area, thus verifying the existence of the unconformity.

The next lower formation of the Salina Group is the F Evaporite. A succession of pure and impure salt beds, thin anhydrites and anhydritic shale beds, shaly dolomites and dolomites comprise the F Evaporite. The shales are generally gray, greenish gray and reddish gray, while the dolomites are gray, buff, and brown. The F Evaporite thins from 970 feet in Ogemaw County to zero thickness in portions of southwestern Michigan, having been completely removed by erosion. The thinning is due mainly to a decrease in salt deposition in a south-westward direction and eventual pinchout of the salt; but thinning of the shale and dolomite beds also occurs.

The F Evaporite has been subdivided into six convenient units: F salt 1 upward to F salt 6 which are based on gamma ray-neutron log curves (Ells, 1962 and 1967) (see Plate 5). They may not be recognized in all localities through sample studies, although they are usually distinguishable upon meticulous examination of good samples. The six units are evident on gamma ray logs and are very useful in stratigraphic correlation of Salina beds.

As seen on Plates 58 and 63, the evaporites are lost in southern Michigan and the shales and carbonates remain; and these entities are correlated in this area. The evaporites are also lost in the extreme northern part of the Southern Peninsula. As seen on Plates 12, 19 and 26, the evaporites extend northward a greater distance over the Niagara barrier reef than they do in southern Michigan. This observation is an important feature in delineating overall evaporite deposition in the Michigan Basin.

The F Evaporite sequence is underlain by the E Unit, a series of gray, greenish-gray, and red shales interbedded with thin dolomites. The unit ranges from 90 to 120 feet thick, but has been removed by erosion in much of southwestern Michigan. On the western side of the basin a porous dolomite occurs near the base. This porous zone grades eastward and basinward into shales. The porous dolomite, called the "E Unit" or "Kintigh Zone" (see Plate 52), has produced some oil. The E Unit when compared with the overlying F Evaporite remains fairly constant in thickness because of its general lack of evaporites.

The D Evaporite, encountered beneath the E Unit, is a sa1t bed which averages about 40 feet in thickness. The unit is split by a thin dolomite bed which causes a consistent deflection on gamma ray logs. When all of the evaporite units in the basin are examined, the D Evaporite appears to have the smallest areal extent in Michigan, and appears to be limited to the basin interior. The D Evaporite gamma ray log curves can be followed with a great degree of accuracy over the depositional area, making the unit one of the most easily recognized Salina units in Michigan.

The C Unit, below the D Evaporite, is one of the most widespread of the Salina units. It can be traced throughout most of the Southern Peninsula and may be traced as far east as New York (Ultieg, 1963). It is a gray shaly dolomite averaging about 60 feet in thickness but in some wells or localized areas it may be over 120 feet thick. No salt beds are found in this unit; but a thin bed of nodular anhydrite or dolomite is present which persists over a large part of the basin.

The C Unit is important to this study because of its widespread occurrence in the Michigan Basin. It is used as the datum for correlating all of the Silurian strata in this report. As shown on the plates pertaining to the Salina Group, the radioactive characteristics of the C Unit are constant except for a small area in southern Michigan where the unit becomes abnormally thick (see Plate 52) and a part of extreme northern Michigan where it thins markedly (see Plates 19 and 27).

The B Evaporite underlies the C Unit and is composed predominantly of salt in the lower part and a series of salt, shale, and dolomite beds in the upper half. It is over 475 feet thick in the central portion of the basin and less than 50 feet thick in the southern Niagaran reef complex. Toward the southern margin of the basin the B Evaporite thins because of pinching out of the lower salt. Salt beds that lie between thin dolomite layers grade to anhydrite and eventually pinch out. In the southern portion of the basin where the B Evaporite is thin and anhydrite is not present, the unit is not easily distinguishable from the underlying A-2 Carbonate on gamma ray logs; but an attempt is made to delineate the unit in these regions. According to radioactive characteristics, the B Evaporite is composed almost entirely of shale and dolomite in extreme southern Michigan (see Plates 53 and 59, the Clark No. 1 and Laser No. 1 wells).

The A-2 Carbonate lies sequentially beneath the B Evaporite. It is composed of dark to light colored limestones and dolomites. Where it overlies the reef complex on the margin of the basin, the A-2 Carbonate is usually dolomite. In the central part of the basin some poorly developed anhydrite beds occur within the A-2 Carbonate. The basal part of the formation contains some carbonaceous partings in the limestone or dolomite which are similar to the "poker chip" shales of the A-l Carbonate, a stratigraphically lower unit. In much of the central basin area, the A-2 Carbonate maintains an average thickness of 150 feet but thins to less than 100 feet in the southern and northern parts of the Southern Peninsula. Near some of the pinnacle reef development in southern and northern Michigan the formation becomes anomalously thick, attaining as much as 275 feet of beds. In southwestern Michigan it has been removed by erosion.

Oil and gas have been produced from the A-2 Carbonate. In some counties in southwestern Michigan the upper part of the formation consists of porous dolomite while the lower portion is shaly limestone. Gas has been produced from the porous dolomite where conditions for entrapment are favorable. It is very likely that the A-2 Carbonate will produce more gas and oil in the future.

Correlation of the A-2 Carbonate is fairly simple and straightforward over much of the basin because it is generally bracketed by two evaporite units, the B Evaporite above and the underlying A-2 Evaporite. However, in areas where these evaporites are not present, especially in southern Michigan, the correlations are somewhat more speculative.

The thickness of the A-2 Carbonate and selection of the base over the southern reef bank is debatable among some geologists. These correlation sections delineate the A-2 Carbonate radioactive characteristics and follow them as far and as accurately as possible from the center of the basin into southern Michigan. As depicted on Plates 59 and 6k, the unit loses many of its characteristics when traced from the center of the basin southward, and correlation becomes difficult. However, the unit appears to show somewhat higher radioactivity than some of the surrounding strata, and this is helpful for identification.

In northern Michigan also the A-2 Carbonate is difficult to correlate in some areas because of the loss of overlying and underlying evaporites. This is especially true of the base of the formation (see Plate 13). However, it does maintain some of the radioactive characteristics, and can be separated from underlying units with a greater degree of assurance than in the southern portion of Michigan. The formation is characterized by a slightly more radioactive base in some portions of northern Michigan, as shown on Plate 27.

The A-2 Evaporite, which underlies the A-2 Carbonate in much of the basin, is predominantly pure salt in the center of the State. In this area it is more than 475 feet thick, grading laterally into anhydrite near the margins of the basin and eventually pinching out. Where the A2 Evaporite is all salt, it is common practice to call it the A-2 salt; where it is all anhydrite, the term A-2 anhydrite is applied.

In areas where pinnacle reefs are encountered, the A-2 Evaporite may thin drastically over the pinnacle and is generally anhydrite. Near the depositional edge of the A-2 Evaporite, either solution or migration of the salt has occurred. Either of these events could serve as a mechanism for developing structure in overlying beds which in turn could result in the entrapment of oil and/or gas. Some pools in southwestern Michigan are related to this phenomenon (Ells, 1967).

The correlation of the A-2 Evaporite is relatively straightforward where the unit exists. It can be delineated accurately where a full section is present, and can be followed to areas where it pinches out in northern and southern Michigan, as shown on Plates 20 and 53, respectively.

The A-l Carbonate, the next unit encountered, is similar to the A-2 Carbonate in that it is essentially a dark colored limestone or dolomite, or both. The basal portion in some places contains thinly laminated dolomite separated by carbonaceous partings, possibly suggestive of cyclic deposition in deep or quiet water. These laminated intervals are similar to beds found in the A-2 Carbonate, which are also termed "poker chip". In some southern portions of the basin where pinnacle reefs are existent, thin anhydrite beds may also be present within the A-l Carbonate. These two, and sometimes three, beds of anhydrite are termed "rabbit ears" by well-site geologists (see Plate 53, Midlam No. l), and they are sometimes indicative of reefing in the vicinity. The anhydrite beds have in some cases been confused with the underlying anhydrite equivalent of the A-l Evaporite.

The thickness of the A-l Carbonate is generally least in the basin interior and greatest around the inner margin of the basin where pinnacle reefs occur. Over a large part of central Michigan this unit ranges between 50 and 75 feet thick, whereas in some portions of the pinnacle reef belt it achieves a thickness of 100 to 125 feet. The thickness may be biologically controlled by masses of algal material near pinnacle reef development. The unit is sometimes absent over tall reefs and may be missing over the reef bank complex. Where the A-l Evaporite is not present below the A-l Carbonate, it may be difficult to separate the A-l Carbonate from Niagaran rocks. But in some cases the A-l Carbonate can still be recognized on gamma ray log curves where the formation occurs over pinnacle reefs and associated with the reef bank, as illustrated on Plates 53 and 64, the Midlam No. 1 and the Grau No. 1.

Oil and gas are produced from the A-l Carbonate in Michigan. The formation produces not only in association with Niagaran pinnacle reefs, but also in other areas where favorable entrapment conditions exist. The A-l Carbonate is generally a dolomite in those areas where production is obtained.

The A-l Carbonate is easily correctable in central Michigan, as are most of the other Salina Units. Difficulties arise, however, in distinguishing the formation in northern and southern Michigan. As shown on Plates 13 and 20, the A-2 Evaporite is not present in northern Michigan, and the A-2 Carbonate and A-l Carbonate are in contact. The premise for separation of the two is the slightly higher radioactivity shown at the bottom of the A-2 Carbonate. The base of the A-l Carbonate is also difficult to define in this area. Plates 13, 20 and 27 show that the radioactive variations between the A-l Carbonate and underlying Niagara are very subtle. The writer believes that the base is at or near the area selected in the correlation sections.

In some areas of southern Michigan, A-l Carbonate correlation is also speculative. Judging by the radioactive characteristics of the unit, the writer believes that although the base of the A-l Carbonate is open to speculation, it is near the zone selected on Plates 53 and 59. It does not extend into extreme southern Michigan.

The A-l Evaporite is the lowermost formation of the Salina Group. In the center of the basin it is predominantly salt, but toward the margins it grades into anhydrite. It achieves a thickness of 475 feet in the central portion of the basin, but gradually pinches out near the reef complex. It is generally absent over the crests of pinnacle reefs, but may be present on the reef flanks as anhydrite.

The upper and lower limits of the A-l Evaporite can be outlined reasonably well over most of the basin. Where the formation changes from salt to anhydrite on the basin margins it can be delineated by its lesser gamma ray radioactivity and the characteristic anhydrite response on neutron logs. These characteristics can be used to follow the formation into northern and southern Michigan areas where it eventually pinches out (see Plates 27 and 59, respectively).

Sylvinite beds occur within the A-l Evaporite in the central part of the basin (see plates 6, 13 and 20). The sylvinite, according to Matthews and Egelson (1974), is a mixture of sylvite (KCl) and halite ($NaCl$), and underlies some 13,000 square miles of Michigan. This potash facies occurs as a lens within a lenses of halite and the potash increases in thickness and purity basinward. It may also be found at the base of the A-l Carbonate as shown on Plate 6, Garland No. 1. The sylvinite portion may be distributed through as much as 140 feet of aggregate thickness of A-l Evaporite, with individual beds being much thinner. Potassium values when measured as l<20 are as high as 40 to 45 percent in some individual beds.

It is of interest to note that evidence of apparent faulting in the A-l Evaporite and Niagaran sections of rock has been found in a well drilled in Sanilac County (see Plate 80). The well is the Humble Oil and Refining Company's Hoppinthal No. 1, located in the C NE, NE, of Section 16, T19N, RI5E, Fremont Township, Sanilac County. A description of the zone, submitted in 1964 by the company along with the well logs, follows:

The No. 1 Hoppinthal encountered a basically normal section except in the lower Silurian where 701 of A-l salt and Niagaran dolomite were repeated. After drilling a normal A-l salt and 38' of underlying Niagaran, a reverse fault was crossed, and the well encountered 32' of additional A-l salt before topping the Niagaran for a second time at 4736 feet.

Niagara Group

Beneath the lowermost A-l beds of the Salina are rocks of the Niagara Group of Middle Silurian age. The Niagara consists of carbonate beds in the upper portion and carbonates, argillaceous carbonates, shales and chert in the lower portion. The lower portion, generally referred to as the Clinton, is thought to be equivalent to the Manistique and Burnt Bluff Groups which are exposed in the Northern Peninsula (see Chart l). The upper portion of the Niagara Group is not designated by a formal formation name in the subsurface, but it is generally correlated with the Engadine, exposed in the eastern portion of the Northern Peninsula.

Pinnacle reef buildups in Michigan may sometimes be present in the upper portion of the Niagara Group. This segment is generally separated into three lithologic units in the subsurface according to oil field terminology. In descending order they are: the "Brown Niagaran", the "Gray Niagaran", and the "White Niagaran". Subdivision into these units is based mainly on color, texture, and stratigraphic position. According to many geologists, most of the pinnacle reef buildup occurred during the time when Brown Niagaran beds were deposited.

The upper Niagara rocks which are nonreef but are near the barrier and pinnacle reefs consist of tan to gray, dense, argillaceous, micritic fossiliferous carbonates. Toward the interior of the basin, the nonreef Niagara is still a dense, argillaceous, fossiliferous carbonate, but it thins markedly and also displays a mottled reddish-brown coloration due to the presence of hematite. Thinning in the basin interior may be attributed to a lack of organic buildups away from the reef belt.

According to Mesolella et al. (197,0, the Michigan Basin was characterized by open circulation and normal marine salinity during Niagara deposition. A barrier reef complex built principally by stromatoporoids flourished around the rim, and a belt of coral pinnacle reefs existed immediately basinward of the barrier-reef complex. In the basin interior the processes of organic reef building were negligible and carbonate sedimentation rates were lower than along the margins. The barrier and pinnacle reef complexes around the basin margins produced hundreds of feet of carbonate rock.

The Niagara carbonate sedimentation rate gradient may also explain the distribution of hematite staining in the Niagara rocks (Mesolella, 197,0. Mesolella reports a suggestion by A. G. Fischer that small amounts of limonite were precipitated throughout the basin in conjunction with Niagara carbonate deposition. Where the sedimentation rates were high along the margins, the limonite was buried and underwent reduction to form such iron minerals as pyrite. In the basin interior, however, low sedimentation rates resulted in slow burial of organic material and destruction of the material by bacterial action. Therefore, organic material generally was absent from these sediments and limonite was preserved and dehydrated to form hematite.

In Michigan, the lowermost portion of the Niagara group of Middle Silurian age is generally referred to as the Clinton. These rocks can readily be identified on gamma ray logs in most of the southern part of the State, but in the northern Southern Peninsula they are difficult to distinguish from overlying strata. Although proper usage of the term "Clinton" has been a subject for debate, the term has been applied for many years by geologists working in the State.

In southern Michigan, the Clinton is generally identified by its argillaceous nature as well as its higher gamma ray radioactivity (see Plate 73). It is composed of gray to green shales, tan to brown, finely crystalline dolomite and argillaceous dolomites.

In northern Michigan the Clinton is no longer argillaceous, but becomes a massive carbonate containing some chert beds. It is not as radioactive as in southern Michigan (see Plate 6). An interesting and important feature of the formation is the difference in thickness from the southern to the northern part of the Southern Peninsula. In the south, these strata are generally 50 feet or less. In the northern portion of the basin, however, these rocks may be over 400 feet thick. The change in thickness and lithology is gradual. More information concerning the Niagaran in northern Michigan is found in Shelden (1963).

The Niagara rocks have yielded large quantities of oil and gas. Most of the hydrocarbon accumulations are confined to the pinnacle reefs in the upper portion of the Niagara Group. These pinnacle reefs have been discovered throughout much of lower Michigan just basinward from the barrier reef complex. The reefs may be up to several hundred feet high and may cover as much as 1000 acres or as little as kO to 60 acres. The reservoir rocks, having intercrysta11ine and vugular porosity, are dolomitized remains of reef-building organisms. Porosity and permeability values vary considerably within a single reef and between individual reefs, but the porosity averages about eight percent and permeability about 27 millidarcies.

The top of the Niagara in the center of Michigan's Southern Peninsula can be correlated easily because of the overlying A-l Evaporite. Around the edges of the basin, however, the formation is less identifiable. The top of the Niagara in southern Michigan is chosen at the base of the last radioactive bed in the A-l Carbonate, as shown on Plates 47 and 64. When many more logs are inspected than the number shown on the cross-sections, this correlation point can be traced over much of southern Michigan.

Distinguishing the top of the Niagara Group is sometimes difficult in many areas of northern Michigan. The technique used in this study was tracing characteristics of the A-l and A-2 Carbonates above, and some of the strata beneath the top of the Niagara. Approaching the basin edge, the overlying units become thinner and some changes in facies (i.e., rocks become slightly more argillaceous), and thus some changes in log characteristics (higher radioactivity), occur (see Plate 13, White and Burns No. l). This method proved most helpful in selecting the top of the Niagara in northern Michigan.

As shown on Plates 47, 53, 59, 64 and 68, the Clinton is defined by higher radioactivity than the overlying strata in southern Michigan. This signifies that the rock is more argillaceous and these higher radioactive curves can be followed over much of southern Michigan. Tracing these higher radioactive beds into northern Michigan, however, a decrease in radioactivity is noticeable along with a marked thickening of the strata.

Cabot Head Shale

The Cabot Head Shale occurs stratigraphically below the Niagara Group. In the subsurface of southeastern Michigan the Cabot Head consists of red, greenish-gray and gray shales. As the formation is traced westward across the State, it becomes progressively less argillaceous and is thinner in the southern portion of the Southern Peninsula. In the northern part of the basin it contains some anhydrite, and is generally thicker and more argillaceous than in western Michigan. Rather slow sedimentation probably characterized the period during which the shale was deposited.

The Cabot Head Shale can be correlated in the subsurface over the entire Southern Peninsula. The formation was initially defined in southeastern Michigan and compared with a well in Ontario in which the Cabot Head was delineated. It was then correlated in a westerly and northerly direction from this point. As shown on Plates 68, 64, 59, 53 and 47, the Cabot Head exhibits a less radioactive and thus less argillaceous character in a westerly direction. It is also thinner in this direction, but the radioactive characteristics still remain similar so that correlation is possible.

In a northerly and northwesterly direction the Cabot Head is characterized by an interbedding of shales and carbonates, as shown on Plates 6, 13 and 20. It also thins, but not to the degree that occurs in southern Michigan. In northern Michigan, recognition of the limits of the formation is complicated by the proximity of other argillaceous beds and a lack of deep control in that area.

Manitoulin Dolomite

The base of the Silurian System is represented in Michigan by the Manitoulin Dolomite. It is typically a thin- to thick-bedded, gray-to buff-weathering dolomite. On a fresh surface it is sometimes light blue-gray. In southeastern Michigan the formation is predominantly dolomite; but in northern Michigan some shale beds become prominent in the unit. Like the Cabot Head, the Manitoulin thins in a westerly direction, and in some areas it cannot be differentiated from the Cabot Head.

For these cross-sections, the Manitoulin, like the Cabot Head, was first compared with the formation in Ontario for definition and then carried into southeastern Michigan. As the Manitoulin is correlated from the area of St. Clair County to the west and southwest, the formation thins, as shown on Plates 73, 68, 64, 59, 53 and 47. In a northerly direction it changes character, exhibiting greater radioactive tendencies and thus more argillaceous content (see Plates 6, 13 and 20). However, it does not thin toward the northern part of the State as much as in southern Michigan and is, therefore, easier to identify in northern Michigan.

Ordovician System

The Ordovician System is the next older rock sequence in the Michigan Basin. Ordovician rocks are found in the subsurface throughout the Southern Peninsula and in the southeastern portion of the Northern Peninsula. They outcrop in an arcuate belt in the Northern Peninsula.

The uppermost group of the system in the subsurface is the Richmond. As shown in "Stratigraphic Succession in Michigan" (Chart 1), the Queenston Shale and Utica Shale are sometimes separated from the Group. General practice, however, is to call all of the Richmond Group the Cincinnatian (a time-stratigraphic term) in the subsurface; this study follows that practice.

In descending order, the next strata are the Trenton and Black River groups. They are not subdivided into individual formations in the subsurface, but are generally distinguished as separate entities throughout the Southern Peninsula. The basal member of the Black River Group, the Glenwood, is identified in this report and correlated throughout the basin.

The St. Peter Sandstone has formation status and underlies the Black River. The St. Peter is not found in the entire basin, however, having been removed by erosion in some localities, and it is not delineated in this report.

The oldest group of Ordovician strata is the Prairie du Chien. It is divided in the subsurface into three formations which, in descending order, are the Shakopee Dolomite, the New Richmond Sandstone, and the Oneota Dolomite. In many areas these formations cannot be distinguished, and in several parts of the basin they are absent due either to erosion or nondeposition. They are not, therefore, delineated on the correlation sections.

Cincinnatian Series

The first sequence of Ordovician sediments in the subsurface is the Cincinnatian Series. Red sediments at the top of the Series are sometimes identified as Queenston Shale. The Cincinnatian is composed of shales, argillaceous limestones or dolomites, and relatively pure limestones. Individual beds undergo facies changes in various parts of the depositional area and these facies can, in many cases, be traced by using gamma ray logs. An erosional unconformity at the contact between Silurian and Ordovician sediments exists in some areas of the basin. Separation of the Silurian and Ordovician systems is difficult in some localities because of the unconformity.

An unpublished thesis study by Nurmi (1972) showed that the Cincinnatian could be divided into units. He divided the Upper Ordovician, including the Utica shale, into six separate units. The Utica was designated "unit one" and the remaining five units comprised the Cincinnatian. Nurmi 's study revealed that many of the units could be correlated over large portions of the basin; and the current investigation tends to corroborate this fact. Nurmi also showed that the uppermost unit he defined was missing in several portions of the basin. CS-Unit 5 of this report, the uppermost unit of the Cincinnatian, can be easily recognized in the central portion of the basin. Where the unit is present in the central and southern portions of the basin it contains some red shale. Progressing in a northward direction, however, carbonate stringers appear and increase in number. In some areas near the margins of the basin some of the upper strata have been eroded, and the carbonate beds which occur below the unit are scarcely distinguishable from the Silurian Manitoulin Dolomite above.

Other units delineated by Nurmi (1972) and those shown as correlatable units in this study are composed, in many areas, of inter-bedded shales and carbonates. The lithology of these units is quite variable due to facies changes which occur throughout the basin.

These various facies can be correlated if careful sample studies are made, but gamma ray logs show the correlation of these facies in a more precise manner. Cohee (1948) and Nurmi (1972) have described the depositional history of the Cincinnatian. Such information is valuable and necessary for an understanding of the lithologic changes which occur throughout the basin.

As shown on the sections, the upper part of the Cincinnatian has been separated into 5 correlatable units, CS-Unit 1 through CS-Unit 5. These are not exactly the same units as those shown by Nurmi (1972) in his unpublished Master's thesis. Plate 7 shows that the Cincinnatian, where it is well developed, is a series of shales or highly argillaceous materials denoted by high radioactivity, and limestones and/or dolomites denoted by low radioactivity. Many of these units can be followed accurately through the central basin area, but at the outer edges some of the units are less distinct.

Plates 7, 14 and 21 in the northern part of the basin show that the upper unit, CS-Unit 5, is thicker in this area and possesses slightly different radioactive characteristics than it has in the center of the basin. As this unit is followed to the center of the basin and southward (Plate 60), a noticeable thinning, caused by an apparent unconformity, occurs.

In the southwestern portion of Michigan, as shown on Plates 46 and 54, the Cincinnatian thins significantly and the character of the radioactive response changes. In this southwestern direction, erosion has stripped away some of the upper strata. As the units are followed into southeastern Michigan it is also evident that an unconformity is present at the top of the Cincinnatian, and some of the upper strata have been removed (see Plate 65).

Plate 7, the Sparks, Eckelbarger, Whight-sil No. 1-8 well, shows an argillaceous unit (CS-Unit 1) which is quite difficult to distinguish from the underlying Utica Shale. As this unit is traced to other parts of the basin it thins and contains much more calcareous material (see Plates 14, 28, 48 and 60).

Radioactive characteristics of the middle units (CS-Units 2, 3 and 4) of the Cincinnatian remain more constant than those of the upper and lower units. As shown on the sections, the thicknesses of the middle units also remain fairly constant throughout the basin, with only minor changes on the periphery. These changes in thickness can be noted on Plates 21, 48, 54 and 65.

Utica Shale

The next Ordovician formation, beneath the upper units of the Cineinnatian, is the Utica Shale. It is uniformly gray to dark gray shale with minor amounts of green shale in the upper portion and some black shale just above the Trenton. In southeast Michigan some limestone stringers occur in the middle of the uni t.

The Utica is variable in thickness, ranging from 200 feet in western Michigan to as much as 400 feet in southeastern Michigan. There also appear to be areas in the basin where the unit is anomalously thin or thick. These occurrences apparently are related to subsurface structures such as the Howel1 anticline in Livingston County, where the Utica is anomalously thin.

As shown in the cross-sections, the Utica retains its high radioactive response throughout Michigan. It is easily correlatable because of the sharp break with the underlying Trenton, which shows low radioactivity, and the overlying upper portion of the Cincinnatian, which is less radioactive than the Utica (Plates 5k and 60). Because of the distinctive, sharp contact between basal Utica and the top of the Trenton Group as shown by the log curves, the base of the Utica Shale was used as a datum for correlating both underlying and overlying strata.

Trenton Group

Trenton rocks of Middle Ordovician age underlie the Utica Shale throughout the Southern Peninsula. The Trenton generally is undivided in the subsurface; but it is separated into two formations in the Northern Peninsula, where it outcrops (see Chart 1). In the Southern Peninsula it ranges from about 200 to near 475 feet in thickness. Structure contours on the top of the Trenton Group show about 11,000 feet of relief from the outcrop area in the Northern Peninsula to the center of the basin near Clare and Gladwin counties.

In the subsurface the Trenton is composed predominantly of light-brown to brown and gray fossiliferous, finely crystalline to medium crystalline limestone (see Cohee, 1945b). In the northern portion of the Southern Peninsula the Trenton becomes increasingly argillaceous. It is also generally more argillaceous near the base. Dolomite may occur in the section, but it is usually confined to areas along major anticlinal axes and faults or fractures where secondary dolomitization has taken place.

The Trenton Group, as well as the underlying Black River Group, strata are important oil and gas zones in Michigan. The largest field discovered to date in the basin is the Albion-Scipio field, which extends for 35 miles in a northwest-southeast direction across parts of Hillsdale, Jackson and Calhoun counties. This trend is comprised of several narrow, linear oil fields located on or along a probable deep-seated fault or fracture zone. Along the fractures, the Trenton and Black River rock has been dolomitized, and it is from these dolomitized fractures that oil is localized (see Ells, 1962). Production from the field is in excess of 100 million barrels of oil and nearly 175,000,000 Mcf of gas (Ells, 1978). Both the Trenton and Black River rocks have great potential for additional production in the future.

The correlation of the Trenton Group throughout Michigan is well established. The top of the Group is easily distinguished by the sharp break on the log curves from the highly radioactive Utica Shale above to the upper limestone of the Trenton. The base of the Group is generally selected beneath the last argillaceous or slightly higher radioactive portion of the Trenton (see Plates 33 and 60).

In the northern part of the basin, the Trenton is somewhat more difficult to bracket because it becomes thinner and is more highly radioactive. The upper portion especially shows significantly higher radioactivity (see Plates 14 and 21). The correlatable bed labeled TG-1 can be followed over a large portion of the basin and is an aid in correlating the Trenton Group.

Black River Group

The Black River is the lowermost group of Middle Ordovician strata in the Southern Peninsula. The lithology of the Black River is similar to that of the Trenton, predominantly a brown to gray limestone. Like the Trenton Group, it also appears to be more argillaceous in the northern part of the Southern Peninsula. A distinctive bed found near the top of the Black River in parts of southern Michigan is called the "Black River Shale". It is a thin shale bed that induces a characteristic curve on gamma ray logs (see Plate 5,0). It is widely used as a marker for mapping purposes.

The thickness of the Black River Group in Michigan varies from about 150 to 500 feet. It is generally thickest in the central and southern portions of the basin and thins in a northerly direction. Near the Albion-Scipio trend area the thickness is fairly constant, ranging from 239 to 247 feet.

At the base of the Black River Group is a member referred to as the Glenwood Shale. This unit, according to DeWitt (1960), is composed of dolomitic sandstone, sandy and silty dolomite, and dolomitic shale in the western part of the basin. The sandy and silty beds in the Glenwood thin to the east, and most of the formation is greenish-gray pyritic shale in central Michigan.

The Glenwood Shale appears to be a transitional bed between the St. Peter Sandstone and the Black River limestone.

Practical correlations of the Black River Group have been established by gamma ray logs throughout the basin. The "Black River Shale" marker bed near the top of the group (see Plate 48) can be used in some cases to locate the top of the Group successfully. The shale marker can be followed over a large portion of Michigan, but in the northern area it cannot be traced. The top of the Black River Group in the northern area is determined by correlating the lower part of the Trenton and upper part of the Black River in other regions and tracing the gamma ray log characteristics into northern Michigan (see Plates 7 and 21).

Two persistent marker beds in the Black River Group, indicated by lines BR-1 and BR-2 (see Plate 48), are useful in correlation. Tracing these marker beds shows the thinning and thickening of the Black River in various areas and also helps to identify the Glenwood. The Glenwood member is generally much more radioactive than most of the Black

River; but in certain parts of the basin (see Plates 14, 21 and Ik) this is not true.

Porosity zones in the Black River occur in some areas, and one such zone is shown on Plate 60. At the southern end of the Albion-Scipio Trend this porosity zone is most often called the Van Wert Zone.

St. Peter Sandstone

The St. Peter Sandstone underlies the Black River Group except where it has been removed by erosion. It is composed predominantly of well-rounded, subspherical, coarse to fine grained quartz. Coarse grained sandstone is generally found in the lower portion but the sand becomes finer grained in the upper part. Wherever calcareous cement is not present, the St. Peter is highly porous and permeable.

The formation appears to have been deposited on an erosion surface at the top of the Prairie du Chien Group. In western Michigan the thickness of the St. Peter is variable. The sandstone may be 200 feet thick in one well, but may be very thin or absent only a few miles away. The St. Peter thins to the east across the basin and is not present along the eastern rim.

The St. Peter Sandstone is not well defined by gamma ray log curves and therefore has not been correlated in this study.

Prairie du Chien Group

Prairie du Chien rocks of Early Ordovician age underlie Middle Ordovician sediments.

In the subsurface the group is divided, in descending order, into Shakopee Dolomite, New Richmond Sandstone, and Oneota Dolomite. These formations are usually not well-defined on electric logs, and in this investigation no attempt has been made to delineate them. Apparently the rocks of the Prairie du Chien Group are thickest in the western and central portion of the basin and have been removed by erosion in the east. In much of eastern and southeastern Michigan, all of the Prairie du Chien has been eroded away and Middle Ordovician rocks overlie the Cambrian.

The Shakopee Dolomite is the upper formation of the Prairie du Chien Group and is thickest in western Michigan, where it may be as much as 225 feet thick. It consists predominantly of medium brown to medium gray dolomite and sandy dolomite, with local occurrences of dolomitic shale. Some chert may also be present in the Shakopee.

The New Richmond Sandstone, underlying the Shakopee, is a relatively thin unit in Michigan. In Illinois as much as 200 feet of New Richmond Sandstone has been reported, while in western Michigan the formation is only 5 to 20 feet thick. It is composed of quartz sand and silt and is coarsest along the western portion of the basin, becoming finer grained to the east. The formation usually is well cemented by dolomite and has low porosity and permeability.

The Oneota Dolomite is the oldest Ordovician formation in the subsurface. It is by far the thickest formation of the Prairie du Chien Group. As much as 600 feet of Oneota has been reported in western Michigan, but 250 to 300 feet of beds is a more common occurrence. According to Syrjamaki (1977) the Oneota reflects a gradual thickening into the basin off the shelf area in Wisconsin with the depocenter located in west central Michigan. It thins toward the east and is absent in the southeastern portion of the basin. The unit in general terms is a light brown to light gray dolomite. Chert is a common constituent, and some of the chert may be oolitic. Small amounts of silty dolomitic shale are also present in the Oneota in certain portions of the basin.

According to Syrjamaki (1977), salient points substantiating an unconformity at the top of the Prairie du Chien Group are: 1) high relief at the contact; 2) the common occurrence of the basal St. Peter which is composed of chert conglomerate and sandstone; 3) the St. Peter Sandstone is usually thickest where the Prairie du Chien is thinnest, and conversely; 4) the top of the St. Peter Sandstone does not reflect the relief at the top of the Prairie du Chien; and 5) the St. Peter sometimes un-conformably overlies the upper Cambrian formations. This unconformity is often referred to as the Post-Knox Unconformity and it is a widespread stratigraphic break not only throughout the eastern United States, but also over many other parts of the world.

Selecting the top of the Prairie du Chien Group on gamma ray logs is difficult because of the presence or absence of the St. Peter and the unconformity below the Glenwood. Since the St. Peter has not been identified on the logs in these cross-sections, the top of the Prairie du Chien Group is arbitrarily placed at the base of the Glenwood.

Cambrian System

The Cambrian System occurs throughout the Michigan Basin. It is composed of the Trempealeau Formation and the Munising Formation. The Trempealeau, shown on Chart 1, is divided into three members which are, in descending order, the Jordan Sandstone, the Lodi, and the St. Lawrence. The Munising is made up of four members, the Franconia Sandstone, Dresbach Sandstone, Eau Claire, and Mt. Simon Sandstone. According to Chart 1, the basal formation of the Cambrian is the Jacobsville Sandstone. However, Fowler and Kuenzi (1978) have indicated that the Jacobsville may be late Keweenawan.

Most geologists working with electric log correlations in Michigan do not subdivide the Trempealeau into individual members. The Trempealeau consists predominantly of dolomite which may be sandy in certain areas. It also contains a minor amount of shaly dolomite and dolomitic shale. The Jordan Sandstone, where present and recognizable, may range from a sandy dolomite in the southern portion of Michigan to a quartz sandstone with well-rounded and frosted grains. The Lodi is usually a white to buff dolomite, sometimes slightly sandy. Purple dolomite may also be found in the basal part of the Lodi in some areas of the State. The basal member of the Trempealeau, the St. Lawrence, is basically a dark gray dolomitic shale and dolomite, with some gray sandy glauconitic dolomite in the basal portion. The Trempealeau is more than 500 feet thick in certain portions of southeastern Michigan.

The Munising is the lowermost formation of the Cambrian System in the basin. It is predominantly sandstone with abundant glauconitic in the three upper members, but little or no glauconite is found in the basal Mt. Simon member. All four members, shown on Chart 1, are usually indicated in electric log correlations. The members, in some areas of the basin, have sufficient diagnostic gamma ray characteristics to permit correlations with an acceptable degree of accuracy.

The upper member of the Munising in the subsurface is the Franconia Sandstone. According to Catacosinos (1973) it is defined as a highly variable zone of dolomitic sandstone, shale and sandy dolomite and is generally quite glauconitic. From areas where it can be identified, it appears to thicken westward to about 95 feet in Ottawa County.

Beneath the Franconia Sandstone is the Dresbach Sandstone, which was called Galesville by Catacosinos (1973). The Dresbach has been described as a light gray, medium grained, subangular sandstone. The upper portion contains some glauconitic, dolomitic sandstone, but throughout the remainder of the unit this glauconitic and dolomitic sandstone is absent. The Dresbach appears to be thickest in the southwestern corner of the State and thins eastward. Catacosinos (1973) reported that the Dresbach is not present in the area around Detroit.

The Eau Claire, the next unit encountered, was named for exposures at the mouth of the Eau Claire River in Eau Claire County, Wisconsin. Cohee (I945a) described it as sandstone, shale, and dolomite that is sandy and shaly in southeastern Michigan. The dolomite beds may be variously colored within the unit and glauconite is sometimes locally abundant. The Eau Claire is thickest around Calhoun and Kalamazoo counties, and Catacosinos (1973) believes that this member is confined to the lowest one-third of the State. Some variance of opinion exists as to where to establish the contact between the Eau Claire and Mt. Simon Sandstone.

The Mt. Simon Sandstone is the lowermost member of the Munising Formation. It is composed predominantly of medium to coarse grained sandstone with subangular to rounded grains. It is dominantly silica-cemented and generally light colored near the top, but may become more pink near the base, reflecting an increase in hematite and feldspar content. It is thickest in the western portion of the State, and thins gradually to the east. An important feature of the Mt. Simon, as well as some of the other Cambrian units, is usability in industry. Some industries need to dispose of liquid waste, and the depth, porosity, and permeability of Cambrian units are acceptable for this purpose. No commercial amounts of hydrocarbons have been found to date in Cambrian rocks in Michigan. But Cambrian tests in Michigan have been rare, and perhaps future exploration will find economically recoverable hydrocarbons.

Correlation of Cambrian formations and members in this study is offered as a guide for future efforts to delineate these units more accurately than is presently possible. More research is needed to determine the lithology and its application to gamma ray logs so that the units may be defined with a greater degree of accuracy.

The writer believes that the Cambrian units are defined fairly accurately in the sections for southwestern Michigan (see Plates 43, 49 and 55). These correlations were guided by correlations described by Ells (1967b) and by work conducted by Catacosinos (1973). Some Michigan wells were correlated with a well in Illinois in the study by Ells. As shown on Plate 49 in the Upjohn No. 3 well, the top of the Trempealeau is placed below the last high-radioactive zone of the Prairie du Chien and above the somewhat cleaner and less-radioactive sand of the Trempealeau. The top of the Munising Formation, Franconia member, is then selected as the first group of strata that shows higher radioactivity than the Trempealeau (see Plate 49, the BD No. 153 well). The Franconia includes all strata which maintain a higher radioactivity than the surrounding beds. Selection of the Dresbach member is generally based on its characteristic lower radioactivity than the surrounding formations; so the top is positioned at the base of the consistently higher-radioactive Franconia member. The Eau Claire member, shown on Plates 43, 49 and 55, is much more radioactive than the Dresbach and can usually be identified in the southwestern quadrant of the State. The base of the Eau Claire is chosen at the point below the last highly radioactive beds of the Eau Claire and at the top of the transitional, interbedded high- and low-radioactive zone. The base of the Mt. Simon is chosen at the top of the first Precambrian strata, which are generally identified by a more highly radioactive gamma ray response (see Plate 49).

In other parts of the State, correlations are considerably more difficult because relatively few wells have penetrated the Cambrian section and the wells are farther apart. In the southeastern quadrant of the State, considerable erosion of Cambrian rocks has occurred, as shown on Plate 75. In St. Clair County, southeastern Michigan, the Cambrian has been excessively eroded and only portions of the system remain above the Precambrian basement.

In northern Michigan even fewer Cambrian tests have been drilled than in southern Michigan. Comparisons of wells from the northern and the southern parts of the State are nearly impossible because of facies changes in the sediments and lack of well control. Some of these changes and the problems involved can be seen on Plate 8. For instance, in the State-Foster No. 1 well, located in Ogemaw County, much of the Cambrian indicates a high radioactive response, making correlation with some of the wells in southern Michigan difficult. An attempt was made, however, to correlate the Cambrian units from other wells to the State-Foster No. 1.

The deepest well drilled to date in the Southern Peninsula, the McClure Oil Company -Sparks, Eckelbarger-Whightsil No. 1-8 in Gratiot County, displays a unique Cambrian section. All of the Cambrian formations are thicker and show different radioactive responses than the same formations in southwestern Michigan.

All of the sections dealing with the Cambrian are more difficult to correlate because the units are thicker and less well-defined. The section for the McClure well has been separated into two parts, the first extending from the Glenwood to the middle of the Eau Claire member, and the remainder showing the section from the Eau Claire to the red beds, which show higher radioactivity and are thought to be Precambrian in age. The latter red beds are shown in more detail on Plate 83.

Precambrian

Only 30 Precambrian basement tests have been drilled in the Southern Peninsula of Michigan through 1978. The paucity of direct geologic information about the basement rocks in the subsurface has encouraged the use of geophysical methods, primarily gravity and magnetic, to determine the nature of these rocks (Hinze and Merritt, 19&9). Gravity and magnetic data suggest that mafic rocks are widespread throughout the basement of the Michigan Basin, although most of the basement drill holes have encountered granitic rocks.

According to Hinze and Merritt (1969), four major provinces are represented in the Southern Peninsula. These are: l) the Grenvilie province in southeastern Michigan, which is 0,8 to 1.0 billion years old; 2) the Central province in southwestern and southcentral Michigan, which is 1.2 to 1.5 billion years; 3) the Penokean province, 1.6 to 1.8 billion years old, underlying the northern portion of the Southern Peninsula; and 4) a rift zone transecting the Peninsula from northwest to southeast, which is 1.1 ±0.1 billion years old. The rift zone is connected with the source of the Mid-Continent gravity high through the Lake Superior Basin, and some geologists believe that it played a dominant role in the development of the Michigan Basin.

The McClure Oil Company deep test in Gratiot County penetrated further into Precambrian sediments than any other well drilled in the Southern Peninsula. The 5,000+ feet of red beds beneath the Mt. Simon sandstone are believed to be of late Keweenawan age. The only other well that has encountered red beds at depth in any significant quantity is the State-Beaver Island No. 1, shown on Plate 22. It is possible that these beds may be stratigraphically and genetically related to the red beds in the McClure deep test.

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Illustrations

Figure 1. General Bedrock Geology Map of Michigan.

Chart 1. Stratigraphic Succession in Michigan, Chart 1, 1964.

Plates **not included** available in print only

Plate	CS	From		To	Systems shown
Plate 1					Index map showing lines of cross-section
Plate 2	A-A1	Gratiot	to	Alpena	Pennsylvanian and Mississippian
Plate 3	A-A1	Gratiot	to	Alpena	Lower Mississippian to Middle Devonian
Plate 4	A-A1	Gratiot	to	Alpena	Middle Devonian
Plate 5	A-A1	Gratiot	to	Alpena	Middle Devonian to Upper Silurian
Plate 6	A-A1	Gratiot	to	Alpena	Middle and Lower Silurian
Plate 7	A-A1	Gratiot	to	Alpena	Upper and Middle Ordovician
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Plate 14	A-B	Gratiot	to	Emmet	Upper and Middle Ordovician
Plate 15	A-B	Gratiot	to	Emmet	Lower Ordovician to Precambrian
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Plate 18	A-C	Gratiot	to	Charlevoix	Middle Devonian
Plate 19	A-C	Gratiot	to	Charlevoix	Middle Devonian to Upper Silurian
Plate 20	A-C	Gratiot	to	Charlevoix	Middle and Lower Silurian
Plate 21	A-C	Gratiot	to	Charlevoix	Upper and Middle Ordovician
Plate 22	A-C	Gratiot	to	Charlevoix	Lower Ordovician to Precambrian
Plate 23	A-D	Gratiot	to	Leelanau	Pennsylvanian and Mississippian
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Plate 27	A-D	Gratiot	to	Leelanau	Middle and Lower Silurian
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Plate 29	A-E	Gratiot	to	Mason	Pennsylvanian and Mississippian
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Plate 31	A-E	Gratiot	to	Mason	Middle Devonian to Upper Silurian
Plate 32	A-E	Gratiot	to	Mason	Middle and Lower Silurian
Plate 33	A-E	Gratiot	to	Mason	Upper and Middle Ordovician
Plate 34	A-F	Gratiot	to	Oceana	Pennsylvanian and Mississippian
Plate 35	A-F	Gratiot	to	Oceana	Lower Mississippian to Middle Devonian
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Plate 38	A-G	Gratiot	to	Ottawa	Pennsylvanian and Mississippian
Plate 39	A-G	Gratiot	to	Ottawa	Upper and Middle Devonian
Plate 40	A-G	Gratiot	to	Ottawa	Middle Devonian to Upper Silurian
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Plate 42	A-G	Gratiot	to	Ottawa	Upper and Middle Ordovician
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Plate 44	A-H	Gratiot	to	Berrien	Pennsylvanian and Mississippian
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Plate 50	A-	Gratiot	to	Cass	Pennsylvanian and Mississippian
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Plate 57	A-J	Gratiot	to	Hillsdale	Upper and Middle Devonian
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Plate 59	A-J	Gratiot	to	Hillsdale	Middle and Lower Silurian

Plate	CS	From		To	Systems shown
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Plate 61	A-K	Gratiot	to	Monroe	Pennsylvanian and Mississippian
Plate 62	A-K	Gratiot	to	Monroe	Upper and Middle Devonian
Plate 63	A-K	Gratiot	to	Monroe	Middle Devonian to Upper Silurian
Plate 64	A-K	Gratiot	to	Monroe	Middle and Lower Silurian
Plate 65	A-K	Gratiot	to	Monroe	Upper and Middle Ordovician
Plate 66	A-L	Gratiot	to	Wayne	Upper and Middle Devonian
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Plate 75-	A-M	Gratiot	to	St. Clair	Lower Ordovician to Precambrian

Plate	CS	From		To	Systems shown
Plate 76	A-N	Gratiot	to	Sanilac	Pennsylvanian and Mississippian
Plate 77-	A-N	Gratiot	to	Sanilac	Lower Mississippian to Middle Ordovician
Plate 78	A-N	Gratiot	to	Sanilac	Middle Devonian
Plate 79	A-N	Gratiot	to	Sanilac	Middle Devonian to Upper Silurian
Plate 80	A-N	Gratiot	to	Sanilac	Middle and Lower Silurian
Plate 81	A-N	Gratiot	to	Sanilac	Upper and Middle Ordovician
Plate 82	A-N	Gratiot	to	Sanilac	Lower Ordovician to Precambrian
Plate 83	A-N	Gratiot	to	Sanilac	Lower Ordovician to Precambrian
Plate 84	A-0	Gratiot	to	Huron	Pennsylvanian and Mississippian
Plate 85	A-0	Gratiot	to	Huron	Lower Mississippian to Middle Devonian
Plate 86	A-0	Gratiot	to	Huron	Middle Devonian
Plate 87	A-0	Gratiot	to	Huron	Middle Devonian to Upper Silurian
Plate 88	A-0	Gratiot	to	Huron	Middle and Lower Silurian
Plate 89-	A-0	Gratiot	to	Huron	Upper and Middle Ordovician

Appendix 1 – Well Records Used to Create Cross-Sections

X	Well Name	PN	Sec	T	R	Township	County
A	McClure Oil Co. / Sparks, Eckel barger, S Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
A	Pure Oil Co. / Merton Emery #1	23849	21	13N	1W	Porter	Midland
A	Tribal Oil Co. / John Kucharski #1-32	29135	32	17N	3E	Mt. Forest	Bay
A	Charles J. Moskowitz / Minnie Biener #1	28907	13	20N	4E	Clayton	Arenac
A	Brazos-Sun-Superior / State Foster #1	25099	28	24N	2E	Foster	Ogemaw
A	Natural Gasoline Corp. / State-Hawes #1	24359	20	27N	8E	Hawes	Alcona
A	Amoco Production Co. / Garland #1	28546	16	28N	1E	Greenwood	Oscoda
A	Getty Oil Co. / Charles A. Cain #1-21	28866	21	31N	4E	Hillman	Montmorency
A	Shell Oil Co. / Shel don-State-Wel 1 i ngton #1-34	29571	34	32N	5E	Wellington	Alpena
A	Shell Oil Co. / Taratuta #1-13	29372	13	33N	5E	Metz	Presque Isle
A	Panhandle Eastern Pipe Line Co. / Ford Motor Co. #1-5	25690	5	31N	9E	Alpena	Alpena
B	McClure Oil Co. / Sparks, Eckelbarger, & Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
B	Pure Oil Co. / Merton Emery #1	23849	21	13N	1W	Porter	Midland
B	Tribal Oil Co. / Roy Nettleton #1-26	29066	26	19N	1W	Gladwin	Gladwin
B	Union Oil Co. of California / State-Beaver Creek #C-4	28110	21	25N	4W	Beaver Creek	Crawford
B	Union Oil Co. of California / State-Maple Forest #1-4	29602	4	28N	3W	Maple Forest	Crawford
B	Woody's Oil & Gas, Inc. / Saddler Unit #1-35	30349	35	31N	2W	Dover	Otsego
B	Shell Oil Co. / State-Nunda #1-3	27976	3	33N	1W	Nunda	Cheboygan
B	Pan American Petroleum Corp. / D. E. Draysey #1	27199	29	35N	2E	North All is	Presque Isle
B	Northern Mich. Explor. Co. & Tribal Oil Co. / State-Waverly #1-24	30682	24	35N	1W	Waverly	Cheboygan
B	Atlantic Inland Oil Corp. / E. G. White & T. R. Burns #1	28212	35	37N	4W	McKinley	Emmet
C	McClure Oil Co. / Sparks, Eckelbarger, & Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
C	Pure Oil Co. / Merton Emery #1	23849	21	13N	1W	Porter	Midland
C	Thomas H. Mall / Axel Johnson #1	31106	36	17N	4W	Grant	Clare
C	Sun Oil Co. / Mary Yake #1	22435	21	20N	4W	Frost	Clare
C	Sun Oil Co. / Enterprise Unit Tract #11-E3	30522	11	23N	5W	Enterprise	Missaukee
C	Miller Brothers / Clara Gibbons #1-26	29691	26	27N	6W	Excelsior	Kalkaska
C	C. J. Simpson / Lake Horicon Corp. #1	25873	2	29N	4W	Hayes	Otsego
C	Forrest H. Lindsay / Lawrence Wolgamott #1	22639	19	32N	8W	Banks	Antrim
C	Paul G. Benedum S MGU Dev. Co. / James E. Clark et ux. #1	29119	14	34N	7W	Hayes	Charlevoix
C	McClure Oil Co. / State-Beaver Island #1	23435	27	38N	10W	Peaine	Charlevoix
D	McClure Oil Co. / Sparks, Eckelbarger, & Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
D	McClure Oil Co. / Terry Childs et al. #1-22	29916	22	13N	4W	Lincoln	Isabella
D	Woods Oil Co. / Merrill Palmer School #1	27210	8	16N	6W	Coldwater	Isabella
D	Sun Oil Co. / Victor E. Lindberg #1	23216	19	20N	10W	Burdell	Osceola
D	Northern Mich. Explor. Co., Tribal, S Miller Bros. / St.-Spr ingville #1-31	29037	31	23N	12W	Springville	Wexford
D	C. J. Simpson / Robert & Cecelia Northrup et al. #1	24557	8	24N	13W	Cleon	Manistee
D	Shell Oil Co. / Henry #1-4	29258	4	25N	11W	Mayfield	Grand Traverse
D	Miller Brothers / Russell Lyons #3~32	28919	32	27N	10W	East Bay	Grand Traverse
D	Forrest H. Lindsay / Anne Kirt #1	22627	6	30N	11W	Suttons Bay	Leelanau

X	Well Name	PN	Sec	T	R	Township	County
E	McClure Oil Co. / Sparks, Eckelbarger, & Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
E	McClure Oil Co. / Betham-Clark Unit #1-26	30027	26	10N	7W	Sidney	Montcalm
E	Gene Miller, Inc. / C. F. Seaman #1	22918	15	HN	13W	Ashland	Newaygo
E	Thunder Hollow Oil & Gas Co. / Walter & Rosilea Thompson #1	26662	20	15N	14W	Beaver	Newaygo
E	Sun Oil Co. / Jacobson Unit #3	25053	14	18N	7W	Amber	Mason
E	Miller Brothers / Gore, Zak, Coerper #1-11	29370	11	20N	16W	Freesoil	Mason
F	McClure Oil Co. / Sparks, Eckelbarger, & Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
F	McClure Oil Co. / Betham-Clark Unit #1-26	30027	26	10N	7W	Sidney	Montcalm
F	Gene Miller, Inc. / C. F. Seaman #1	22918	15	HN	13W	Ashland	Newaygo
F	Hibbard Oil Corp. / Mary & Antoinette Rutkowski #1	28931	8	12N	17W	Montague	Muskegon
F	Tribal Oil Co. & Chapman Drilling Co. / John Garcia Unit #1	28203	20	14N	17W	Shelby	Oceana
F	MGU Dev. Co. / F. Bailly Unit #1-27	30169	27	15N	18W	Golden	Oceana
G	McClure Oil Co. / Sparks, Eckelbarger, & Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
G	Ambassador Oil Corp. / Samuel Ten-Cate #1	24619	34	7N	8W	Keene	Ionia
G	Ambassador Oil Corp. / John Ten Have #1	24826	6	8N	9W	Grattan	Kent
G	Beacon Resources Corp. / B. E. Goss #1	27296	35	9N	10W	Courtland	Kent
G	McClure, M.I.O., & Gordon / Vormittag #1	22852	9	8N	14W	Polkton	Ottawa
G	Parke-Davis & Co. / Brine Disposal #3 { 21 139 00114 80 00 }		20	5N	15W	Holland	Ottawa
H	McClure Oil Co. / Sparks, Eckelbarger, & Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
H	McClure Oil Co. / Wildman #1	23574	15	5N	7W	Odessa	Ionia
H	McClure Oil Co. / Schaibly #1	23572	20	4N	7W	Woodland	Barry
H	Battle Creek Gas Co. / BD #2-153 { 21 015 00153 80 00 }		14	1N	8W	Johnstown	Barry
H	Continental Oil Co. / Simpson #1	23685	10	2N	12W	Watson	Allegan
H	Upjohn Co. / Upjohn #3 { 21 077 00137 70 00 }		14	3S	11W	Portage	Kalamazoo
H	Turtle Drilling Co. / Kern #1	23524	34	4S	14W	Decatur	Van Buren
H	Security Oil & Gas Co. / Thalmann #1	26112	10	6S	17W	Berrien	Berrien
I	McClure Oil Co. / Sparks, Eckelbarger, & Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
I	McClure Oil Co. / Fox #1	27811	6	7N	1W	Ovid	Clinton
I	Hibbard Oil Corp. / R. A. Seibly #1	28929	33	2N	2W	Aurelius	Ingham
I	Mobil Oil Corp. / Gladys Kelly Unit #1	29117	24	2N	3W	Eaton Rapids	Eaton
I	M.I.O. Explor. Co. / Schneeberger-Murphy #1	28263	27	1N	5W	Walton	Eaton
I	Earl Midlam / Midlam #1	30468	13	1S	5W	Lee	Calhoun
I	Trenton Pet. & McClure Oil Co. / Bernloehr-Bole-Eitniear #1	22352	13	3S	8W	Leroy	Calhoun
I	Consumers Power Co. & Quintana Prod. Co. / Harvey Clark #1	29969	8	5S	8W	Sherwood	Branch
I	C. J. Simpson / Harold Walters #1 C.	24183	29	6S	9W	Colon	St. Joseph
I	A. Perry & Son / Wooden #1	23289	8	7S	14W	Calvin	Cass
J	McClure Oil Co. / Sparks, Eckelbarger, & Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
J	McClure Oil Co. / Fox #1	27811	6	7N	1W	Ovid	Clinton
J	Hibbard Oil Corp. / R. A. Seibly #1	28929	33	2N	2W	Aurelius	Ingham
J	Mobil Oil Corp. / Gladys Kelly Unit #1	29117	24	2N	3W	Eaton Rapids	Eaton
J	McClure Oil Co. / Crawford #1	26481	4	1S	3W	Springport	Jackson
J	Texaco, Inc. / Stella Konkol #1	26541	15	2S	2W	Sandstone	Jackson
J	McClure Oil Co. / Harlan J. Bellis et al. #1	23013	17	4S	2W	Hanover	Jackson
J	Jenkins & Woodruff, Inc. / Edwin Houseknecht #1	24378	31	5S	2W	Moscow	Hillsdale
J	Texaco, Inc. / Percy Edmonds #1	26078	10	7S	2W	Jefferson	Hillsdale
J	Glynn Trolz & Assoc., Inc. / L. Laser #1	25158	15	8S	1W	Wright	Hillsdale

X	Well Name	PN	Sec	T	R	Township	County
K	McClure Oil Co. / Sparks, Eckelbarger, & Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
K	McClure Oil Co. / Fox #1	27811	6	7N	1W	Ovid	Clinton
K	Mobil Oil Corp. / Jelinek-Ferris Unit #1	27907	5	5N	2E	Perry	Shiawassee
K	Patrick Petroleum Corp. / R. Kleinschmidt #1	28752	17	2N	3E	losco	Livingston
K	William R. Albers / Hannawald #1	28620	6	1S	3E	Lyndon	Washtenaw
K	A. E. Rovsek / Irma Grau #1	27472	8	3S	4E	Freedom	Washtenaw
K	Leonard Oil Co. / George & Rose Schwocho #1	26856	17	4S	5E	Saline	Washtenaw
K	Bell & Marks & Good & Good Drilling / Thurlow Heath #G G-l	23531	4	5S	7E	London	Monroe
K	McClure Oil Co. / Stotz-Wi11 Jams #1	25062	10	7S	7E	Ida	Monroe
L	McClure Oil Co. / Sparks, Eckelbarger, & Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
L	McClure Oil Co. / Fox #1	27811	6	7N	1W	Ovid	Cl inton
L	Mobil Oil Corp. / Jel inek-Ferri s Unit #1	27907	5	5N	2E	Perry	Shiawassee
L	Mobil Oil Corp. / Howard J. Messmore #1	27986	11	3N	5E	Oceola	Livingston
L	G. W. Strake / Manuel Lopez #1	24771	14	1N	6E	Green Oak	Livingston
L	A. E. Rovsek / Knudt Jorgensen #1	25714	26	2S	7E	Superior	Washtenaw
L	Consumers Power Co. / Consumers Power Co. #208	25538	22	1S	8E	Plymouth	Wayne
L	Panhandle Eastern Pipe Line Co. / Ford Motor Co. #1	25560	19	2S	11E	City of Dearborn	Wayne
M	McClure Oil Co. / Sparks, Eckelbarger, & Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
M	McClure Oil Co. / Fox #1	27811	6	7N	1W	Ovid	Cl inton
M	Mobil Oil Corp. / Jel inek-Ferri s Unit #1	27907	5	5N	2E	Perry	Shiawassee
M	Mobil Oil Corp. / Howard J. Messmore #1	27986	11	3N	5E	Oceola	Livingston
M	Reef Petroleum Corp. / Investment Administrators, Inc. #1-26	31304	26	5N	10E	Oxford	Oakland
M	Cedco Drilling Co. / Richard Noonan et al. #1-14	31064	14	4N	11E	Oakland	Oakland
M	Consumers Power Co. / Joseph Halmich #3"!	26214	1	4N	13E	Ray	Macomb
M	Michigan Cons. Gas Co. / Osterland et al . #1-14	30376	14	3N	15E	Ira	St. Clair
M	Bernhardt Oil & Gas Co. / Paul & Arelane Puzzuoli #1	25780	17	2N	16E	Clay	St. Clair
N	McClure Oil Co. / Sparks, Eckelbarger, & Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
N	Arch E. Turrentine / Robert Gage Coal Co. #1	23429	33	11N	?E	Swan Creek	Saginaw
N	Dugger-Herring & Wells / Hutchinson #1	24079	4	9N	8E	Forest	Genesee
N	Sunray Mid-Continent Oil Co. / H. G. Richardson #1	22534	18	6N	12E	Almont	Lapeer
N	Humble Oil & Refining Co. / Hoppinthal #1	25357	16	9N	15E	Fremont	Sanilac
N	McClure Oil Co. S Mich. Nat. Res. / Hewett & Shadd Unit #1-20	30974	20	12N	15E	Bridgehampton	San i lac
O	McClure Oil Co. / Sparks, Eckelbarger, & Whightsil #1-8	29739	8	10N	2W	North Star	Gratiot
O	Arch E. Turrentine / Robert Gage Coal Co. #1	23429	33	HN	3E	Swan Creek	Saginaw
O	Jack Mall / Leonard Elbers #1	22270	5	12N	6E	Blumfield	Saginaw
O	C. J. Simpson & Sun Oil Co. / B. & L. Sattelberg #1	23890	8	13N	9E	Aimer	Tuscola
O	C. J. Simpson / Novesta Township et al. #1	25609	16	13N	11E	Novesta	Tuscola
O	Mobil Oil Corp. / C. J. Volmering #1	29191	26	15N	15E	Sherman	Huron