STRATIGRAPHY SUMMARY
of the
SOUTHERN PENINSULA OF MICHIGAN

A Summary of the Stratigraphy of the Southern Peninsula of Michigan

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Cambrian

Cambrian rocks in the Southern Peninsula of Michigan consist of sandstone, dolomite, and some shale. These rocks, Lake Superior sandstone, which are of Upper Cambrian age overlie pre-Cambrian rocks and are divided into the Jacobsville sandstone overlain by the Munising. The Munising sandstone at the north is divided southward into the following formations in ascending order: Mount Simon, Eau Claire, Dresbach and Franconia sandstones overlain by the Trampealeau formation. This sequence of rocks correlates with the Reagan sandstone, Honey Creek limestone and the lower part of the Arbuckle group of Oklahoma and also the Hickory sandstone, Cap Mountain limestone, Wilberns formation and the lower part of the Ellenburger group of Texas.

The basal Cambrian sandstone in the Lake Superior region, the Jacobsville sandstone, is red, brown, and white arkosic sandstone mottled and striped with red and gray shale and is conglomeratic near the base. The sandstone occurs in the Keweenaw and Huron Mountain areas in the Northern Peninsula but its occurrence farther east in the Southern Peninsula of Michigan has not been definitely established. A few wells in the Michigan Basin have penetrated a red or pinkish sandstone overlying the pre-Cambrian which may correlate with the Jacobsville of the Northern Peninsula. A well drilled at Sault Ste. Marie, Chippewa County, Michigan penetrated about 1000 feet of sandstone and was still in Lake Superior sandstone at the bottom of the hole.

The Mount Simon sandstone is a medium to coarse grained white sandstone with sub-angular to rounded grains. It is about 300 feet thick along the line of the cross-section in southeastern Michigan but thins eastward toward Ontario and in places in southwestern Ontario it is absent due to thinning and truncation. The sandstone increases in thickness westward across Michigan.

The Eau Claire consists of sandstone, shale and dolomite that is shaly and sandy. The lower part of the Eau Claire is generally argillaceous sandy dolomite, dolomitic sandstone and shale. The middle part is generally sandstone with minor amounts of dolomite; the upper part is predominantly argillaceous and sandy dolomite. The dolomite beds in the Eau Claire may be gray to dark gray, pink to purple, red to brown color and the shale is also variously colored. Glauconite is generally abundant in the formation. The Eau Claire increases in thickness southward in the Southern Peninsula of Michigan where it becomes much more dolomitic.

The Dresbach sandstone is a fine to medium grained sandstone with well rounded and angular quartz grains. Thin beds of argillaceous dolomite may occur locally in the sandstone. It is about 100 feet thick in the Southern Peninsula of Michigan but is absent in Northern Indiana.

The Franconia sandstone is a fine to medium grained glauconitic and dolomitic sandstone. It is from 10 to 20 feet thick where present in the Southern Peninsula.

The Trempealeau is predominantly a buff to light brown dolomite with a minor amount of sandy, glauconitic dolomite and dolomitic shale in the basal part. Zones of sandy dolomite are in the Trempealeau in addition to the basal part. A small amount of chert may be found in various places in the formation.

Very small showings of gas were found in the top of the Mount Simon in several wells in southeastern Michigan.

Ordovician

Lower Ordovician. Lower Ordovician rocks in the Southern Peninsula of Michigan are the Prairie du Chien group overlain by the St. Peter sandstone in some parts of the Southern Peninsula. The Prairie du Chien group is divided, in ascending order, into the Oneota dolomite, the New Richmond sandstone and the Shakopee dolomite. The Prairie du Chien group is absent in parts of southeastern Michigan due to erosion that occured prior to deposition of the St. Peter sandstone.

The Oneota is a buff to light brown and very cherty dolomite with some oolitic chert. A light green to greenish-gray shale may be associated with the dolomite in some areas. In southwestern Michigan the Oneota dolomite is largely sandstone and dolomite with some shale.

The New Richmond sandstone is a thin unit overlying the Oneota dolomite and underlying the Shakopee dolomite. It is from 5 to 10 feet thick and has been recognized in drill cuttings in wells from southwestern Michigan.

The Shakopee dolomite in the southern part of the Southern Peninsula generally consist of a buff dolomite which may be sandy and cherty and shaly but northward and westward in the Southern Peninsula the Shakopee is largely sandstone, dolomite and some shale.

The St. Peter sandstone consists of well rounded quartz grains similar in character to those in Cambrian sandstones in certain areas. It is cherty and conglomeratic at the base in southwestern Michigan. The sandstone has a maximum thickness of 150 feet in southwestern Michigan. It unconformably overlies Cambrian and Lower Ordovician beds. The sandstone is irregular in its occurrence in the Southern Peninsula of Michigan.

A show of oil was found in the top of the Shakopee in two wells in Barry County, Michigan.

Middle Ordovician. When the Black River sea covered Michigan it transgressed sandstone and dolomite of Cambrian to Lower Ordovician age. The first Black River sediments included clastics that were derived from the surface of the underlying rocks. In many places the first deposits were sandstone and shale. A green and gray pyritic and sandy shale and dolomite is common in some places. These rocks have been correlated with the Glenwood shale in Illinois and Wisconsin. The Glenwood is from 10 to 100 feet thick in places and in some areas it is absent.

Black River and Trenton rocks generally consist of brown and gray crystalline limestone and dolomite with minor amounts of shale and argillaceous limestone. In some areas, particularly where structural deformation has occurred, zones of secondary dolomite occur in varying amounts in the Black River and Trenton limestones. The boundary between the Black River and Trenton limestones is easily distinguished in southwestern Ontario and parts of southeastern Michigan by the argillaceous character of the base of the Trenton. Westward across Michigan is more difficult to establish this boundary due to the transition into pure limestone and dolomite. In places some chert fragments may be in the upper part of the Black River. The area of greatest known thickness of Bkack River and Trenton rocks is in southeastern Michigan where as much as 965 feet have been recorded in wells.

The areas in which Black River and Trenton limestones contain secondary dolomite offer the best possibilities for oil and gas production. Production from the Trenton in Michigan is in the Deerfield field, Monroe County and in one and two well fields in Sumpter and Huron townships, Wayne County in the southeastern part of the State. These fields are on the northern extension of the Findlay arch into Michigan. Production is in the upper part of the Trenton limestone at depths of 10 to 75 feet below the top. The Black River and Trenton limestones are mostly limestone throughout the greater part of the Central Basin area in the Southern Peninsula.

Upper Ordovician. Upper Ordovician rocks in the Southern Peninsula of Michigan are dividided into the Utica, Lorraine and Queenston shales in ascending order. The Utica shale is dark gray to black and is approximately 150 to 200 feet thick in southeastern Michigan. The Lorraine shale consists of about 200 feet of gray shale with thin beds of limestone and dolomite, and the overlying Queenston shale is about 200 feet thick. It is similar to the Lorraine but contains red shale. The red shale in the Queenston increases in thickness eastward in Ontario and is almost absent in western Michigan. In western Michigan and in the northern part of the Southern Peninsula, it is difficult to subdivide Upper Ordovician rocks (Cincinnatian) due to thinning and lateral and vertical gradation of the shale and increasing amounts of limestone and dolomite. In the Northern Peninsula the Upper Ordovician rocks of the outcrop area are considered Richmond in age and are correlated with the Maquoketa shale of Wisconsin and Illinois.

In the Southern Peninsula of Michigan the known thickness of Upper Ordovician rocks ranges from 277 feet in western Michigan to 812 feet in eastern Michigan. Near the outcrop area in the Northern Peninsula the thickness of the Upper Ordovician rocks is 370 feet.

Silurian

Lower Silurian. The lower Silurian rocks in the Southern Peninsula of Michigan consist of the Manitoulin dolomite and the Cabot Head shale of the Cataract formation. The Manitoulin dolomite is buff to light brown and locally cherty with interbedded shale. The Cabot Head shale consists of green, greenish-gray and some red shale. As the contact between the Manitoulin and Cabot Head is gradational it is difficult to separate the two members in the subsurface. Local reefs in the Cataract cause considerable variation in lithology between wells. The cataract formation varies in thickness from 45 feet in western Michigan to 190 feet in eastern Michigan. The "White and Red Medina" and "Clinton" sandstones which produce gas in southwestern Ontario are of lower Silurian age. These sandstones are absent in Michigan.

Middle Silurian. The middle Silurian rocks of Michigan, the Niagara group, onsist of the Clinton formation ahd the Lockport dolomite. Early workers in Ontario ave the name the name Guelph to the uppermost part of the Niagara group. Later orkers upon finding Guelph fossils in the Lockport at Niagara River placed the uelph of Ontario in the Lockport. The Clinton formation as recognized kn New York tate extends across Ontario into southeastern Michigan where it is 40 feet thick n places. The Clinton commonly includes a gray shale 5 to 10 feet thick at the ase, a light brown dolomite from 5 to 10 feet thick and gray calcareous shale of ochester age at the top, which is from 10 to 15 feet thick.

The Lockport dolomite in the subsurface generally consists of white to buff and light gray dolomite overlain by light brown dolomite. It is cherty in part and contains argillaceous dolomite in the basal part in the northern part of the Southern Peninsula. Reefs are abundant in the Lockport and account for part of the variation in thickness in the Lockport from one area to another. In places in western and eastern parts of the Southern Peninsula pink and red dolomite is common in the Niagara group.

The thickness of the Niagara group in Michigan varies from about 65 feet in western Michigan to more than 700 feet in the northern tip of the Southern Peninsula. A broad thin area, where the Niagara group is less than 100 feet thick, extends east and west across southern Michigan. Southward from this thin area it increases in thickness in northern Indiana and in northern Ohio in the vicinity of Lake Erie.

occurs
Porosity/at varying depths in the Lockport and oil and gas shows have been reported in many wells. Many of the porous zones appear to be reef porosity. In the Howell gas field, Livingston County, Michigan, production is from the base of the Salina and from the top of the Lockport. A number of gas fields in southwestern Ontario are producing from the Lockport. Some of these fields are producing from reefs in the Lockport and others are producing from anticlinal folds or domes.

Upper Silurian. The Upper Silurian rocks consist of, in ascending order, the Salina and the Bass Island units. The Salina contains the thick salt measures of New York, Pennsylvania, Ohio, Ontario, and Michigan. Everywhere the salt has been leached from the outcrop zone and only the associated insoluble rocks can be studied at the surface. These rocks crop out on the St. Ignace Peninsula where they have been named the Pointe aux Chenes formation.

In the subsurface section of the Michigan Basin it is possible to divide the Salina into seven units which are arbitrarily labelled A to G. Unit A is a brown dolomite with two beds of salt aggregating 870 feet in thickness in the deeper part of the Michigan Basin. Maximum thickness of the unit is 100 feet. The A beds directly overlie the Niagara rocks and in the outcrop area of Ohio, where salt is not present, have been named the Greenfield dolomite.

B unit is almost a pure salt about 250 feet thick. Some dolomite may be present in thin layers. The C, D, and E sequence is readily recognizable. The C unit contains greenish gray shales and shaly dolomite from 60 to 160 feet in thickness. D is the middle salt, ranging from 25 to 65 feet in thickness. It is overlain by the E beds consisting of about 100 feet of gray or red shale with some interbedded dolomite. F unit is the youngest salt-bearing members. It consists of thick beds of salt separated by thinner beds of anhydritic shale, shaly dolomite and dolomite. The dolomite layers are gray, buff, and brown. The F beds are not recognizable at the surface due to the leaching of the predominant salt. Maximum recorded thickness of this member is 1230 feet in Bay County. G, the highest unit, consists of 40 to 100 feet of green to red shale.

Due to thinning toward the rim of the Basin, and to leaching and nondeposition of the salt members, the entire Salina formation is less than 100 feet thick in Berrien County in southwestern Michigan. Near the center of the Basin the thickness exceeds 4500 feet of which approximately 2000 feet is salt.

Gas is produced from the brown dolomite at the base of the Salina in the Howell gas field, Livingston County, Michigan. The pay zone is about 10 feet thick. A buff dolomite immediately below the lower of two salt beds in southwestern Ontario is a source of commercial gas in the Dawn, Chatham, and Zone fields of Lambton and Kent Counties. In the same counties some gas is obtained from a higher dolomite lying immediately below the upper salt beds. The Bateson well in Bay County, Michigan, struck a heavy flow of gas in a brown dolomite below the upper of the two salt beds in Unit A. Attempts to produce this gas have not as yet been successful.

A common feature in the Mackinac Straits region is the Mackinac Breccia which contains jumbled fragments of Salina, Bass Island, Onodaga, and Detroit River rocks. The brecciation was caused by collapse of the section extending from above the Salina salt caves. Collapse breccias are also around the rim in other parts of the Basin.

The type locality for the Bass Island is a group of islands of that name in western Lake Erie. The formations overlying the Salina that crop out in southwestern Ontario are referred to Bertie-Akron; the rocks occupying a similar position in the Mackinac Straits area have been named the St. Ignace formation.

In southeastern Michigan and northern Ohio the Bass Island beds were originally subdivided into the Greenfield, Tymochtee, Put-in-Bay and Raisin River units, in ascending order. More recently it has been suggested that the Tymochtee represents insoluble facies of the Salina evaporite section, and the Greenfield is the basal Salina carbonate rock.

The subsurface Bass Island is characteristically a buff dolomite, oolitic at the top in southeastern Michigan. Gray and brown dolomite layers and one or two gray shaly dolomites may also be present. Anhydrite is present inside the rim of the Michigan Basin. Bass Island rocks are everywhere between the outcrop zones, but this unit thins rapidly on the north flank of the Finlay arch extending from northeastern Michigan. Thicknesses range from 20 feet in Fulton County, Ohio to 570 feet in Bay County, Michigan. The thickness of the Bass Island in the Mackinac Straits region is estimated at 250 to 300 feet.

The Bass Island rocks are not productive of either oil or gas. In fact, the strata are so impermeable that water is scarce in this part of the section.

Devonian

Lower Devonian. Lower Devonian rocks of Michigan include in ascending order the Garden Islamd, Bois Blanc and Sylvania formations and the Detroit River dolomite.

On Garden Island in the Beaver group of islands in Lake Michigan the Bois Blanc rocks are underlain by a few feet of buff dolomite and dolomitic sandstone called the Garden Island formation. These rocks contain fossils characteristics of the Oriskany sandstone which underlies the Onodaga rocks in southwestern Ontario and New York. The Garden Island which is the oldest Devonian formation in Michigan has not been recognized in the subsurface, except possibly in the northernmost tier of counties in the Southern Peninsula.

The type locality of the Bois Blanc formation is the island of that name at the east end of Mackinac Straits. The formation is of lower Onondaga age and appears to connect beneath the waters of Lake Huron with the lower Onondaga rocks of Ontario.

The greater part of the Bois Blanc formation, on the outcrop and in well samples, is cherty and fossiliferous. Excepting the chert, which is most abundant in the lower part of the formation, the Bois Blanc consists of light colored carbonate rock. In some places it is all limestone, but dolomite is common in the lower part in the eastern half of the Southern Peninsula, and throughout the section on the western side.

Bois Blanc rocks are present throughout the Southern Peninsula except in the southwestern part and along the southern margin where they were apparently removed by pre-Sylvania erosion. This formation can also be traced in the subsurface records from the deeper part of the Michigan Basin across southwestern Ontario to the area of Onondaga outcrop.

The Bois Blanc thickness at the outcrop in northern Michigan is estimated to be about 300 feet. The formation thickens to nearly 1000 feet in a well drilled in southern Ogemaw County. It thins to the south and is absent on much of the south flank of the Basin.

No oil or gas have been reported in the Bois Blanc although the formation has several porous zones, especially in the lower very cherty part of the section.

The Sylvania formation crops out in the vicinity of Sylvania, Lucas County, Ohio, from which the formation gets its name, and in Monroe County of southeastern Michigan. It is not present in northern Michigan. The Sylvania is everywhere overlain by the Detroit River formation and is underlain almost everywhere by the Bois Blanc formation. In a small area in west-central Michigan and a large area in southwestern and southern Michigan and northern Ohio where the Bois Blanc formation has been removed by erosion, the Sylvania lies directly upon the Bass Island dolomite.

Sand is the dominant constituent of the Sylvania formation and occurs as beds of nearly pure sandstone and as scattered quartz grains through beds of dolomite and limestone. Chert fragments also are found in samples of the Sylvania formation in a few wells in the central part of the Michigan Basin. The sandstone beds are discontinuous lenses, and individual beds cannot be traced from one well to another unless the wells are very close. From one to six sandstone beds may be in the Sylvania. In a few places the Sylvania is composed entirely of sandstone, but where the formation is thickest limestones also are present. However, an area of "non-sandy Sylvania" is in southwestern Michigan. A bright greenish shale of possible Sylvania age in southwestern Michigan may correlate with green shale which is at the base of a sandy phase of the Sylvania formation farther east. Apparently this shale was deposited as a result of local conditions during Sylvania time.

Oil or gas in commercial quantities is not produced from the Sylvania formation although shows of oil and gas have been reported in wells penetrating this formation in several areas in the State.

The Detroit River is typically fine grained gray to buff thin bedded dolomite with abundant carbonaceous partins and with some limestone members, mainly in the upper part; anhydrite through; an evaporite series of dolomite, snhydrite, and several beds of salt are in the middle part in central Michigan where the formation is thickect; sandstone, sandy dolomite and chert in the lower part, and some black limestone members. The basal part is sandy and in places contains thin sandstone lenses consisting of frosted and well rounded grains of white sand, some of which are brownish and iron stained. This formation varies from a few hundred to 1300 or 1400 feet thick.

The subdivision of the Detroit River dolomite, commonly referred to as the "Upper Monroe", adopted from southeastern Michigan, are in ascending order; the Amherstberg dolomite and the Lucas dolomite, with Anderdon limestone lentil near the top. In central Michigan these subdivisions are not easily recognized in the subsurface, but a typical evaporite series is near the top beginning with the anhydrite and dolomite and grading downward into as many as three series of salt beds, with one or more typical black limestone members in the section below the evaporite series.

A porous zone is found in places at or near the contact of the Dundee and the Detroit River and in many wells black water is found but is not an important oil and gas producing zone. The most important oil and gas producing zone is commonly beneath the first 20 to 30 feet of the dolomite and anhydrite of the Detroit River. It is 30 to 35 feet thick and known as the "Reed City pay" zone. This zone is best developed in western Michigan. Another producing zone approximately 50 feet below the "Reed City pay" zone is less porous than the "Reed City pay" zone and in most places contains gas instead of oil. Scattered through 100 to 150 feet of anhydrite and dolomite in the lower part of the Detroit River is a zone of porosity which is known as the "Richfield pay" zone. Where best developed in northeastern central Michigan this "pay" section is about 1300 feet below the top of the Dundee-Rogers City limestone.

The Richfield dolomite of the Detroit River is recognized in rock samples from wells drilled in the deeper part of the Michigan Basin, and apparently has no recognizable outcrop. The areal distribution is coextensive with the distribution of the overlying evaporites of the Detroit River and it is therefore restricted to the counties lying in the north central part of the State. The thickest part of the evaporite depositional basin is near the southern boundary of Roscommon County. The Richfield can be recognized in subsurface within a radius of fifty miles from the center of this area.

Commercial oil production was first discovered in the "Richfield" zone on December 4, 1941, in the Sun Oil Company's Margrethe Bauman Tr. #1, located in Sec. 29, T. 24 N. R1 1 W., Richfield Township, Roscommon County, Michigan. The name Richfield is derived from the township name. Several pay zones were found in the 80-90 foot section of gray to buff crystalline dolomite occupying the interval below the basal anhydrite beds of the Detroit River evaporites, and above the underlying black limestone.

Three pools, Beaver Creek, Norwich and Enterprise, in various stages of development, have been found twenty miles west of the Richfield pool. In these pools, several pay zones are encountered in lensing dolomite stringers in the bottom 100 feet of the massive anhydrite beds directly above the Richfield member. These pays have been called "Richfield" but are actually above it.

The Rose City pool being developed in Ogemaw County, 10 miles east of the Richfield pool also has the "Richfield pay" zone. A few additional isolated commercial wells are producing on the flanks of Dundee producing structures in Clare, Osceola and Mecosta Counties. No Richfield production has been found on the top of any Dundee producing structure in Dundee wells deepened to the zone.

A flank well at the west end of the Fork pool, in northeastern Mecosta County, produces gas and considerable distillate from the Richfield. In the Norwich pool in northeastern Missuakee County, a gas cap is encountered in the structurally high wells in the Richfield and high gas-oil ratio wells are common. Most of the gas is recycled in this field. A similar gas cap is found at the eastern end of the Richfield pool in Roscommon County. Several gas wells drilled in this area are still shut in as no pipeline outlet is available.

Middle Devonian. Middle Devonian rocks of Michigan are divided in ascending order into the Dundee and Rogers City formations and the Traverse group.

The Dundee is a typical buff to light brown cherty limestone, dolomitic limestone, and dolomite varying from approximately 50 to 400 feet thick. It is very thin or absent in southwestern Michigan. A sandy zone or thin bedded sandstone is found in some places at the base in southeastern Michigan.

Excepting the southeastern part of Michigan were the Rogers City is absent, the Dundee is divided into two formations. The Rogers City has a typical dark colored brownish buff dolomitic limestone or dolomite at the base and is as much as 125 feet thick where it is best developed. The underlying Dundee formation restricted, consists typically of buff and light brown limestone, becoming more dolomitic and possibly even containing some anhydrite in the lower part in western Michigan.

Porous zones which contain oil and gas are in both the Dundee and Rogers City and may be anywhere from the top to 150 feet below the top of the Dundee-Rogers City. Porosity was caused by solution cavities in the limestone and dolomite including cavities produced by dissolved fossils and corals and stylolitic zones. Important occurrences of oil and gas are also found in both primary and secondary dolomite porosity. Some of the dolomitization that produced the reservoir rocks of narrow producing belts in northeastern Michigan is thought to be caused by ascending water rising along faults or fracture zones. Such zones of porosity are in the upper part of the Rogers City formation in areas where the common porosity zones in the Dundee-Rogers City sequence is 130 feet or more below the base of the overlying Bell shale. The porous producing zones of the Dundee are similar in character to those of the Rogers City, but are probably less dolomitic.

The Traverse group consists of gray to buff limestone, gray shaly limestone and shale. Many of the limestone beds are cherty, fossiliferous, and contain abundant corals and large coral reef structures and bioherms. In western Michigan some

nhydritie is found in the lower part. Where the Traverse is thickest the top 50 o 100 feet is predominantly shale, and the approximately lower 200 feet shale and haly limestone.

The Traverse group in the outcrop areas in Alpena and Presque Isle Counties was riginally subdivided into four units, in ascending order; the Bell shale, the Long ake limestone, the Alpena limestone, and the Thunder Bay limestone. The Bell shale ormation at the base of the Traverse group is a characteristic gray, soft shale aving several fossiliferous zones at the base. It outcrops in Alpena and Presque sle Counties and along Black River about four miles north of Tower, Cheboygan ounty. It thins into southwestern Michigan but varies from 30 to 80 feet in thick- ess, the usual thickness is from 60 to 70 feet. The Bell shale is overlain by the ockport Quarry limestone. The former Long Lake limestone stratigraphic sequence n northeastern Michigan is now subdivided in ascending order into the Ferron Point ormation, Genshaw formation, and the Newton Creek limestone. The characteristic lack Killians limestone member at the top of the Genshaw may be a formation as it is mappable unit found in the northeastern and north central Michigan sections. In orth central Michigan the Newton Creek limestone is named Koehler limestone. The me Alpena limestone is still retained for northeastern Michigan with the Dock treet clay in the upper part. In the outcrop area of the little Traverse Bay region n northwestern Michigan rocks equivalent to the Alpena are named Gravel Point for- ation or Gravel Point stage. As now subdivided from more detailed work in the northern part of the Southern Peninsula, the upper unit of the Traverse group in northeastern Michigan includes in ascending order the Four-Mile-Dam limestone, Norway Point formation, Potter Farm formation, Thunder Bay limestone and Squaw Bay limestone. In the outcrop area in northern central Michigan the upper unit is known s the Beebe School formation and in the Little Traverse Bay region in northwestern ichigan it is subdivided into Charlevoix stage and Petoskey formation.

A porous zone which may contain oil and gas is nearly everywhere near the top f the Traverse. In eastern Michigan this zone is commonly in the Squaw Bay, but n southwestern Michigan it is lower in the section. The porous zone may be in lolomite, cherty dolomite, or re-worked coralline materials. In western and south- estern Michigan it is in the top of the "Traverse limetone" and in rocks possibly f Thunder Bay age. Overlying the "Traverse limestone" in this area is a shale nd shaly limestone sequence that varies from 40 to 70 feet in thickness, that has een called the "Traverse formation". These rocks are in the basal part of the ntrim. Porous zones containing oil and gas are also in the Alpena limestone in me areas. In western Michigan a porous zone from 100 to 200 feet above the base the Traverse is known as the "Lower Traverse Pay".

Upper Devonian and Basal Mississippian

The rocks occupying the stratigraphic interval from the top of the Traverse, f Hamilton (Devonian) age, to the base of the Coldwater shale of Kinderhook Mississippian) age, include the Antrim, Ellsworth and Sunbury shales in western ichigan and the Antrim shale, Bedford-Berea sandstones and shales, and the Sunbury hale in eastern Michigan. The names Bedford-Berea and Sunbury are used in Michigan or rocks lithologically similar to and occupying the same stratigraphic position s formations so named from outcrops in Ohio. These rocks are not continuous from hio to Michigan, and no paleontological evidence has been found which definitely

establishes that the age of the Michigan and Ohio units is the same. The question regarding the correlation of these units between the two areas is partly due to the absence of surface outcrops of the Bedford-Berea or the Sunbury in the Michigan Basin. The maximum interval from the Traverse to the base of the Coldwater shale is a little over 950 feet in northern Lake County and southern Wexford County, Michigan.

The Antrim underlies the Southern Peninsula of Michigan from Charlevoix, Cheboygan, Montmorency and Alpena Counties at the north, southward as far as Pulaski, Fulton, Whitely, and Allen Counties in northern Indiana, Paulding, Henry and Lucas Counties in northwestern Ohio, and eastward under Kent, Lambton, Middlesex, and Elgin Counties in Ontario, Canada. The Antrim is essentially black carbonaceous shale with several thin gray shale members in the lower part and is characterized by an abundance of spore cases reported as Sporangites huronensis. It contains pyrite, disseminated and in concretions, and large anthraconite concretions in various places. Apparently the Antrim lies on the eroded Traverse limestone surface in the western and southwestern parts of the State, but elsewhere the contact appears to be conformable. The greenish gray Ellsworth shale of the western half of Michigan overlying the black shale of the Antrim is contemporaneous with and interfingers with the upper Antrim of central and eastern Michigan. The Devonian-Mississippian boundary has been placed at different positions in the Antrim-Ellsworth sequence by various workers but generally the upper part of the Antrim is considered Mississippian in age. Further data are needed to establish the Devonian-Mississippian contact in Michigan. The Ellsworth is greenish-gray dolomitic shale with Sporangites huronesis common near the zone of interfingering with Antrim shale. However, west of this area of interfingering Sporangites are rare. As the Antrim and Ellsworth are known to be contemporaneous and the lower boundary of the Ellsworth is gradational with the Antrim it is impossible at this time to give a maximum thickness of either of these formations. Together they have a thickness of 920 feet in northern Lake County and southern Wexford County, Michigan. The source of the Ellsworth sediments was very likely from the Wisconsin area, west of the Michigan basin.

The Antrim shale contains quantities of "shale gas" in the southeastern, northeastern, and north central part of the State. However, it has not been developed as an important producer of gas in Michigan.

The Bedford and Berea cannot be satisfactorily subdivided in the subsurface. These rocks consist of gray shale, sandy shale, siltstone, and sandstone, and lie conformably on the Antrim. From the Bedford-Berea pinch-out line approximately north and south near the center of the Southern Peninsula of Michigan these sediments thicken eastward at the rate of about 100 feet in 25 miles to a maximum thickness of 325 feet in northern Huron County. The lower half of the section is essentially composed of gray shale and sandy shale; the upper half contains fine-grained sandstone and varying amounts of gray shale and siltstone.

Oil and gas are produced from the Berea sandstone in a few fields in eastern Michigan in Arenac, Bay, Midland and Saginaw Counties. The Berea sandstone has not been one of the important oil and gas producing formations of the State. In western Michigan commercial gas production was obtained from the so-called "Berea" dolomite at the top of the Ellsworth shale in fields in Muskegon, Ottawa and Kent Counties.

The Sunbury shale is a black shale less carbonaceous than the Antrim and lacking the abundance of spore cases so characteristic of the Antrim. It overlies the Bedford-Berea, the Antrim or the Ellsworth in different parts of the State. It pinches out in Allegan, Barry, Kalamazoo and St. Joseph Counties and is absent in Berrien, Cass, and Van Buren Counties, Michigan. The Sunbury extends a short distance into the Steuben County of northeastern Indiana and Williams and Fulton Counties of northwestern Ohio. Over most of the central part of Michigan the Sunbury rarely exceeds 40 feet in thickness, but in eastern Michigan it thickens rapidly from approximately 40 feet from a north-south line extending through central Tuscola County to 140 feet in eastern Huron County along Lake Huron.

Mississippian

The Mississippian rocks of Michigan are rocks of Lower Mississippian age. The formations above the Sunbury shale are the Coldwater shale, Marshall sandstone, Michigan shale, dolomite and anhydrite and the Bayport limestone in ascending order.

The Coldwater is blue to greenish gray shale with subordinate thin lenses and beds of dolomite, sandstone, and siltstone. It is from 500 to 1100 feet thick. In the central part of the Michigan Basin the average thickness is 1050 feet. The Coldwater shale is widely distributed in the southern part of the Southern Peninsula of Michigan from Otsego County southward into Indiana and Ohio.

This section of gray shale has several persistent beds which are easily recognized: near the base of the formation the "Coldwater Red Rock" unit is easily recognized over a large area and has more than one bed of red rock in the western part of the State. It grades from a non-calcareous shale to a shale having increasing amounts of calcium carbonate and magnesium carbonate into a crystalline limestone and dolomite that ranges from a few feet to about 30 to 40 feet in thickness. The shale above the "Red Rock" can be divided into two facies. In the western part of the Michigan Basin it is predominantly gray shale with numerous beds of gray to brown dolomite which are very fossiliferous in places. The "Coldwater Lime", about 20 to 30 feet thick, an impure dolomite with a speckled or "salt and pepper" appearance, is one of the best recognized calcareous beds. It is well represented in the western and southwestern part of the State. The speckled appearnace is due to darker colored grains of dolomite and grains of glauconite. Beds of gray to brown dolomite that grade to dolomitic shale are in the section. Brown sideritic material, which may be drilled up concretions, is observed in well cuttings and in large concretions in the outcrop. The eastern facies is gray shale with subordinate amounts of siltstone and sandstone. The shale in the upper part of the formation is predominantly red in color, which makes it practically impossible to determine the base of the overlying Marshall formation and suggests that the base of the Marshall is transitional with the upper Coldwater formation. The red sandstone and siltstone are best represented in Huron, Genesee, Saginaw and the surrounding counties.

The Marshall formation consists of gray to pink to red sandstone that ranges from coarse grained to very fine grained sandstone and siltstone having high percentages of dolomite as cementing material. The thickness of the formation ranges from 100 to 400 feet; the average thickness is about 275 feet in the Central Basin area. The Marshall is in the central part of the Southern Peninsula and is absent in the northern and southern parts of the State due to non-deposition and erosion in the north and to erosion in the south. It is the oldest Paleozoic formation entirely within the boundary of Michigan.

The lower part of the formation is characterized by sandstones commonly red in color. The sandstone, which is cemented with varying amounts of dolomite, is very shaly and dolomitic near the base. In eastern Michigan where it is difficult to distinbuish the lower part of the Marshall from the underlying Coldwater in the subsurface, coarse grained sandstones and conglomerates of Coldwater-lower Marshall age are common.

The upper part of the Marshall, the Napoleon sandstone, is commonly white to gray in color and is coarser grained than the lower Marshall. In some areas it is pink and red. The top or upper part is very shaly and dolomitic and produces gas in several fields in the Central Basin area where it is known as the "Michigan Stray sandstone".

The Michigan formation consists of dark gray shale, sypsum, dolomite and limestone with some sandstone. In areal distribution it covers the central part of the Southern Peninsula, about 40 percent of the Michigan Basin. The thickness ranges from a few feet to about 500 feet with an average of about 350 feet. The lower part of the Michigan averages about 110 feet thick and consists of dolomite, shale, sandstone and a subordinate amount of gypsum. This unit includes all rocks from the top of the "Brown dolomite" to the top of the Marshall sandstone. The "Brown dolomite" is a persistent and easily recognized bed of wide distribution.

The upper part of the Michigan is characterized by an abundance of gray to pink gypsum. In some places as much as 40 percent of the rock sequence is gypsum.

Lying unconformably above the eroded Michigan and unconformably below the thick black shale of Pennsylvanian age is a section of sandstone, limestone and dolomite of Meramecian age -- the youngest Mississippian rocks of the Michigan Basin. These rocks, which are from a few feet to about 300 feet thick, can be divided into four parts in the Central Basin area. The basal part is about 30 feet thick and consists of a tan to brown dolomite or limestone, sandy in parts, which is usually correlated with the Bayport or Point Au Gres limestone that crops out in the Saginaw Bay area. Above the basal dolomite are gray to white sandstone beds composed of medium, angular to sub-angular quartz grains. The sandstone and the underlying dolomite or limestone is recorded in some well logs as "Parma-Bayport" although the Parma sandstone as defined at the outcrop is of Pottsville age.

Overlying the "Parma-Bayport" is a gray to green to red shale with interbedded thin stringers of sandy dolomite. The thickness of this shale unit ranges from 50 to 300 feet. Above the shale unit is a gray limestone about 30 to 50 feet thick which occurs in most of the Central Basin area. The rocks above the Bayport limestone which do not crop out at the surface have received little attention from the subsurface workers in the State.

Pennsylvanian

The Pennsylvanian system occupies an area of about 11,000 square miles in the central part of the Michigan structural basin. It is exposed at few places in this area. The principal exposures are near Jackson, Grand Ledge, Williamston, Corunna and Owosso. Subsurface information has been obtained from many mines located principally in Tuscola, Saginaw and Bay Counties. Wells which were drilled in search of brine and oil in the central part of the basin penetrate the Pennsylvanian and indiate a maximum thickness of about 550 feet.

The system is commonly separated into four division which, in order from oldest to youngest, are Parma sandstone, Saginaw group, Grand River group and "Red Beds".

The type locality of the Parma sandstone is northeast of Parma, a village eight miles west of Jackson, and it is exposed in outcrops of small areal extent as far northwest as section 2, Sheridan township, Calhoun County four miles north of Albion. The formation is a clean white sandstone which unconformably overlies the Bayport limestone. Sandstone of similar character, and apparently similar stratigraphic position, is also exposed in Rifle River east of Omer, Arenac County. Between these widely separated localities, occurrences of white sandstone at the base of the Saginaw are reported in wells. It appears likely that as a result of the pre-Saginaw erosion, the basal beds of the Saginaw may commonly be in contact with Mississippian sandstone. In the absence of easily recognized Mississippian beds, the determination of white sandstone as Parma, or pre-Parma is in doubt.

The Saginaw group consists predominantly of clastic sediments with a small amount of coal and limestone. The best exposures are in the vicinity of Grand Ledge, Eaton County, Michigan. At this locality the sediments may be subdivided into seven cyclothems. The cyclothems in this area and in other areas in Michigan are characteristically incomplete. Typical of the cyclothems of Michigan is the Grand Ledge cyclothem, which overlies a plastic black "Lingula" shale and consists of irregularly laminated sandy shale and shaly sandstone, overlain by a hard fine textured under clay. The under clay is overlian by coal, above which are the basal beds of a younger cyclothem.

The surfaces between the successive cyclothems are commonly irregular and some of the inter-cyclothem unconformities in the Grand Ledge area are known to have a relief of 25 feet in a horizontal distance of about 100 feet. Exploration for coal near Chester, Mason, Williamston and Corunna has shown inter-cyclothem unconformities similar to the one at Grand Ledge. The maps of several mines in the Saginaw area suggest accumulation of coal in valleys existing in Pennsylvanian time. The conditions for deposition appear to have been interrupted frequently by erosion.

The detailed lithology of the different members of the Saginaw can be summarized briefly. The sandstone beds are commonly argillaceous, fine grained with considerable mica on the bedding planes. The heavy minerals in the sandstone are relatively few in number, the principal ones are tourmalines and zircon. The lithology of the shale beds varies considerably. Included in the Saginaw are black plastic shale members of marine origin, which contain little or no gritty material. Much of the light colored shale is apparently of terrestrial origin as indicated by the common presence of plant remains. The plants are fragmental and are commonly on the bedding planes of the shale slthough some are in clay ironstone layers. The coal seams, in general, are thin. The thickest seam observed by the writer is four feet thick and is very restricted in its distribution. The coal is classified as bituminous, and commonly has a high sulphur content.

Only one limestone bed has been observed in the Saginaw which was named -- the Verne limestone which was found in the Verne mine southwest of Saginaw, Michigan. It is nowhere more than a few feet thick and is black, highly argillaceous and grades upward into a calcareous shale. Fossils are relatively scarce, but include rare forms; the total faunal list has about fifty species. The common forms include the coral, Lophophyllidium, the brachiopods, Derbya crassa, Dictyoclostus morrowensis,

the snails, Worthenia and Macrochilina, and the cephalopod, Pseudorthoceras. Fossils and samples of the rock collected and saved from the Verne limestone in the Verne mine are identical with those fossils found at Grand Ledge. Between the two localities the fauna has been recognized in limestone exposures at Flushing, Six-Mile Creek near Owosso, and Williamston. The limestone is upper Pottsville in age and its fauna is more closely related to the fauna of the Pottsville in Illinois than to fauna of the same age in Ohio. The Verne limestone affords some interesting information on the structure of the Pennsylvanian system of Michigan as the plotted elevations of the outcrop areas suggest that the Saginaw formation conforms, at least in part, with folds in the Michigan Basin.

The Grand River group includes coarse grained sandstone and associated shales and lignitic coal exposed in three widely separated localities in Jackson, Eaton and Ionia Counties.

The oldest unit is known as the Woodville sandstone. Exposures of this sandstone have not been seen in place, but fragments found on the dumps of abandoned mines in the vicinity of the original Woodville mine, suggest an outlier of post-Saginaw beds.

The Eaton sandstone, which is the upper massive sandstone exposed at Grand Ledge is irregular in occurrence and may have been continuous with the Woodville sandstone. No definite evidence as yet establishes this correlation. The lower boundary of the Eaton sandstone is very irregular. The sandstone occupies channels cut into shale and sandstone of the Saginaw group. The basal member is conglomeratic, and contains angular blocks derived principally from the unerlying Saginaw. Quartzite pebbles, derived either from the pre-Cambrian to the north in Ontario or from the quartzite pebbles in the eroded conglomerates of the Marshall formation, occur sparsely at the base of the Eaton. Pennsylvanian plant remains are found in the Eaton. The Eaton sandstone is characteristically cross-bedded, and consists of quartz grains of distinctly coarser texture than quartz grains in the underlying Saginaw. Argillaceous material is present in minor amounts, and persistent beds of shale are absent. Mica is present, but is less common than in the Saginaw. Heavy minerals include tourmaline and zircon.

The Ionia sandstone is exposed in abandoned quarries in the valley of Grand River between Ionia and Lyons, Ionia County. The sandstone is cross-bedded, slightly argillaceous, and weathers to deep red and purple colors. Heavy minerals include zircon, tourmaline, and less commonly, garnet.

The same type of sandstone has been found in water wells in Clinton County. It is probable that future systematic sampling will show that the Eaton is a brown weathering facies of the Ionia. No paleontologic data has been found to establish the age of the Ionia.

The descriptive term "Red Beds" is used for red colored rocks including gypsum which are encountered in several wells in the central part of the Michigan Basin. They do not outcrop at the surface and a diversity of views on the origin of the Red Beds" is held. Some geologists believe that they are of glacial origin, and that they were secondarily derived from the erosion of the gypsum beds of the Michigan series. In recent years systematic sampling of water wells in the central part of the basin indicates that the "Red Beds" are not of glacial origin but represent red-rock of post-Ionia age, which may belong in the Permian system.

The only oil and gas production from Pennsylvanian rocks in Michigan was from the Parma sandstone in southeastern Gratiot County but it was of little importance.

Oil Production

More than 99 percent of the crude oil produced in Michigan to January 1, 1948, has been from limestones and dolomites of Devonian age. The Dundee and Rogers City have produced 68 percent of the oil, the Traverse 19 percent and the Detroit River 12 percent. The remainder of the oil produced in the States was from the "Michigan Stray" and Berea sandstones of Lower Mississippian age and the Trenton limestone of Middle Ordovician age.

The important Dundee producing area of the State is in the Central Basin area. Dundee fields produce at depths ranging from 2000 feet to 3900 feet. Oil recovery from 20 representative fields with sufficient production to be significant is from 2100 to 8500 barrels of oil per acre. The average oil recovery from the Dundee is probably about 4500 barrels per acre.

Three important fields, North Adams and Deep River in western Arenac County and Pinconning in northern Bay County produce from very porous dolomite in the upper part of the Rogers City limestone. Production in these fields is along narrow strips where there is secondary dolomitization of the Rogers City. As of January 1, 1948, the North Adams field, which was discovered in 1940, has produced 7,659,870 barrels of oil from 410 acres or nearly 19,000 barrels per acre. The Deep River field, discovered in 1944, had produced 7,476,604 barrels from 1010 acres or 7406 barrels per acre. It is expected that the ultimate recovery per acre in the Deep River field will approach that of the North Adams field. The Pinconning field, discovered in 1944, was extended late in 1947 by a second well and the field is being further developed. As of January 1, 1948, the discovery well had produced more than 100,000 barrels of oil.

The most important Traverse producing area of the State is in southwestern Michigan, however, scattered areas of production are found in the Central Basin area and in western Michigan (Fig. 1). Oil recovery in 15 representative Traverse fields in southwestern Michigan has been between 1000 and 4500 barrels per acre with an average of about 1800 barrels. These fields produce at depths ranging between 1000 and 2000 feet.

The Headquarters field in Roscommon and Clare Counties, discovered in 1941, is the most important Traverse field in the Central Basin area. The field includes about 1600 acres and had produced by January 1, 1948, 4,189 barrels per acre. Depth to the pay, which occurs 90 to 100 feet below the top of the Traverse, averages about 3380 feet.

The Detroit River, which is growing in importance as a producing formation in Michigan had produced nine percent of the crude oil in Michigan to January 1, 1946, but by January 1, 1948, this percentage had increased to 12 percent.

The Reed City field, one of the most important fields in Michigan producing from the Detroit River, was discovered in 1940 and as of January 1, 1948, it had

produced 34,626,329 barrels of oil, 32,091,329 barrels of which was from the "Reed City pay" zone in the upper 30 feet of the Detroit River. Recovery from this "pay" has been almost 6100 barrels per acre. Other Detroit River fields which are producing from the basal part of the formation are not developed enough to provide adequate figures regarding possible recoveries.

It is apparent from the rather widely spaced area of production and showings of oil in the Detroit River that the entire section is potentially productive where porosity, permeability and structure are favorable.

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The above summary accompanies a geologic cross-section* of the Southern Peninsula of Michigan prepared under the auspices of the Michigan Geological Society for the Paleozoic District Committee for the Eastern Interior, Committee on Geologic Names and Correlations, American Association of Petroleum Geologists.

Usuage of geologic names excepting Bass Island conforms to the Lexicon of Geologic Names of the United States, Bull. 896, 1938. Names such as Trempealeau, Cabot Head, Manitoulin and others have been accepted by the U. S. Geological Survey since publication of the Lexicon. Bass Island (for Bass Islands) and names of Silurian, Devonian, and Pennsylvania formations proposed since 1938 are accepted by the Michigan Geological Society.

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* Geologic Cross Section of Paleozoic rocks, [illegible] Mississippian to Northern Michigan, prepared under the auspices of the Geologic Names committee of the A.A.P.G. Edited by Carl A. Pratt and Helen Martin, M.G.S. Southern Peninsula of Michigan, Michigan Geological Society.

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