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Geology of Allegan County

by

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THE GEOLOGY OF ALLEGAN COUNTY

By C. H. Riggs[1]

INTRODUCTION

The following report on the geology of Allegan County is not complete. It represents a compilation of data and is intended as an aid in the study of the geology, and in the development of the resources, particularly of oil and gas, of this area. Data have been collected from the field and from a study of well samples and insoluble residues. Structure maps made on data available in July 1938 represent the writer's interpretation and should be regarded as tentative and subject to change as later data become available from more extensive drilling and testing.

GENERAL GEOLOGY

Size and Location of County

Allegan County, Michigan, borders the eastern coast of Lake Michigan, about 50 miles north of the Michigan-Indiana state line. The county comprises 24 townships of 864 square miles, and is 36 miles long east and west and 24 miles wide north and south. The south line is about 125 miles northeast of Chicago; the north line 15 miles south of Grand Rapids.

The county is served by three railroads; two branches of the Pere Marquette from Holland to Grand Junction and Allegan in the west, and the New York Central from Allegan, Hopkins, and Dorr to Grand Rapids, and the Pennsylvania from Plainwell, through Wayland to Grand Rapids in the east.

The roads in Allegan County are almost uniformly good. U.S. 31 along the west coast and U.S. 131 in the eastern part of the county are the main arteries from southern cities to vacation centers in the northern part of the State. State and county roads include many miles of concrete, tarvia, and good gravel. Principal cities are Allegan, the county seat and farm center, Saugatuck, and Douglas, resort centers on Lake Michigan.

Land Utilization

Land cultivation in Allegan County does not exceed sixty per cent of the area and is probably decreasing. In the western part, once covered by glacial lakes, the soil is very sandy and but thirty or forty per cent of the land is under cultivation. Much of this land is being retired by

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the Federal Resettlement Administration. In this area are many acres of oak woods which provide game cover and recreational facilities. The shores of Lake Michigan and of the inland lakes are now used for resort purposes. On the moraines and till plains (Plate 1) cultivation approaches eighty per cent and the principal crops are corn and wheat, except in the southwestern part where some fruit and oats are raised. Poultry and eggs in the western part and dairy products in the eastern part of the country are important secondary agricultural resources.[1]

Topography

The topography is typical of much of the glaciated areas of Michigan, and the principal topographic features are of glacial origin. Sand dunes line the shore of Lake Michigan and extend inland two or three miles. Many lakes dot the surface in the morainic belt, where water has become impounded behind clay hills. Elevations vary from 582 feet, lake level, along the shore of Lake Michigan to 900 feet above sea level in Gun Plains township. The principal river is the Kalamazoo with its tributary, Rabbit River. The Kalamazoo River flows through the towns of Plainwell, Otsego, and Allegan, where it provides water power for light and manufacturing, and empties into Lake Michigan at Saugatuck. The Black River flows through the southwestern part of Allegan County to Lake Michigan at South Haven. The Kalamazoo River was an important outlet for melting ice during glacial times, discharging into the enlarged Lake Michigan, just west of the city of Allegan. The sandy silt plain south of the Kalamazoo River in Valley Township is a delta of the glacial stream.

Glacial Features

The northeast-southwest alignment of moraines in Allegan County indicates that ice movement, at least during the last glaciation, came from the west and northwest, from the Lake Michigan Lobe. Three stages of glacial retreat are shown by three moraines with their outwash plains to the east and southeast. The Kalamazoo River, which probably antedated glaciation in this area, has cut through these three morainic ridges. A rough but significant parallelism exists between the present land surface and the pre-glacial land surface. It is evident from interpretation of well records that a pre-glacial Kalamazoo River occupied nearly its present position with a deep valley through the cities of Plainwell, Otsego, and Allegan. Tributary branches extended through Martin and through Hopkins on either side of a lobe of the Marshall formation. The valley of the Rabbit River evidently extended through Diamond Springs towards Dorr, with a branch through the Salem field where the removal of the Marshall over the structure provided an easily eroded valley. A well marked ridge extends from Dunningville, north of Monterey to the southwestern part of Dorr township, more or less in the position of the middle moraine. The pre-glacial topography was controlled by the areal extent of the Marshall formation and by the structure of the underlying rocks. Evidently where the folding was intense the Marshall was removed by erosion and valleys were developed in the softer Coldwater shale at the crests of the folds. Where folding was more gentle, the top of the Marshall was retained and the folds caused ridges in the pre-glacial land surface, in some places exaggerating the underlying structure.

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[1] County Agricultural Agent - Personal communication.

STRATIGRAPHY

The surface formations in Allegan County are Marshall sandstone and Coldwater shale, with a small patch of Michigan formation south of Wayland. Unfortunately these formations are everywhere covered by from 50 to 400 feet of glacial drift, and our knowledge of them is based on records and samples from wells.

Michigan Formation

At this date (September 1938) the Michigan formation in Allegan County is known only from the Puritan Oil Corporation - Gere No. 1 well, located in the $N\frac{1}{2}$ $NW\frac{1}{4}$ of Section 13, T.3N., R.12W., 300 feet from north and 300 feet from west line of the quarter section. In this well 50 feet of gypsum and sandy shale were recorded. It is probable that two other wells in this vicinity have encountered some Michigan shales but have driven drive pipe through without recording it. The presence of the Michigan formation seems to be due to its deposition in a basin in the Marshall, since here the Marshall is much thinner than in other wells in Allegan County.

Marshall Formation

The Marshall Formation covers the northeastern part of Allegan County extending southward into Watson and Monterey townships in two broad lobes. The greatest thickness, 171 feet, was recorded just west of Wayland. The Marshall is absent over the greater part of the Salem field and the limit of the outcrop corresponds rather closely with the structure on top of the Traverse limestone. Where the Marshall is present in the southwestern part of the Salem field, its top reflects underlying structure. The absence of Marshall in a belt from the eastern part of the Salem field into the Dorr field suggests that there may be a fold in this direction, but as yet drilling has failed to locate commercial oil production. The Marshall is present in a narrow band in the eastern part of Dorr township on a narrow pre-glacial ridge. It is absent over the southern and western parts of the Monterey field. In the eastern part of the Monterey field, as much as 60 feet of the formation has been recorded. The Marshall was removed in a pre-glacial valley which lies between Hopkins and Hillards. The Centennial Geological Map of Michigan, issued in 1937, shows the Marshall in Overisel and Fillmore townships, but according to data available to this writer, there is no Marshall in this area, west of the broken line (Plate 2).

The Napoleon (Upper Marshall) is present in the northeastern part of Allegan County as shown in samples from two wells, one in Hopkins and one in Wayland townships. Unfortunately, samples were not saved from other wells in this vicinity. The record of the Napoleon from the Lentz and Miller - Morgenstein well - west of Wayland is:

The fauna from the Waverly quarry sandstone has been correlated with the Coldwater of Point Aux Barques and with the Racoon shales of Ohio. Lane holds that Marshall deposition in this area preceded deposition in the eastern part of the State.[1]

The irregularity of the surface of the Coldwater shales has suggested that an unconformity exists between Coldwater and Marshall. Hake suggests the possibility that apparent irregularities may be due to an oscillating shore line and local sand bars on low mud flats.[2] However, a probable gradual rise in land surface brought about the deposition of the coarser grained sandstones of the Napoleon.

Coldwater Formation

The Coldwater is a formation of light gray or bluish gray shales with beds of calcareous sandstone and dolomitic shale. As now defined the lower limit of the Coldwater is the base of the "Red Rock." In the southwestern part of Allegan County top beds are absent below the drift, but where overlain by Marshall sandstone, the thickness of the Coldwater, as recorded in well logs, varies from 700 feet in Overisel township to 860 feet in Hopkins township.

The beds immediately below the Marshall are soft, flaky and contain considerable muscovite. Common drilling practice where the Marshal is absent is to drive pipe into the shale to the first sandy layer. In Monterey, Salem and Dorr townships a calcareous sandstone 10 to 18 feet thick is 50 to 80 feet below the Marshall. The composition of this sandstone varies from well to well. In Monterey township the sandstone resembles lower beds of Marshall but with the additional grains of dark gray and brown dolomite. Some grains are re-worked hard dolomitic sandstone. In Salem township the zone is more calcareous and contains fragments of bryozoa and coral. In Hopkins and Wayland townships a similar zone is also calcareous, but is apparently lower in the section.

The shales below the sandstone contain much foreign material, notably smooth water worn pebbles of brown cherty and argillaceous dolomite. These pebbles are not recognizable in unwashed drill cuttings but often may be the only hard material present after washing samples. Galena and siderite have been found in these pebbles.[3] Cores from a test well in Fillmore township showed chert nodules and chert zones 2 to 8 inches thick composed of fossil fragments and argillaceous dolomite. It seems probable that deposition of shale took place in relatively quiet waters near shore, but that transportation of material greatly increased at periodic intervals to redeposit parent material without much decomposition.

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1 Lane, A. C. and Seaman, A. E. - The Geological Section of Michigan, Michigan Geological Survey Annual Report, 1908

2 Hake, B. F. and Maibeus, J. B. - Lithology of the Traverse Group - Michigan Academy of Science Papers - Vol. XXXIII, p. 447, 1937

3 Editor's note: On the Coldwater outcrop in Branch County galena is found in concretions. Are these "pebbles" similar concretions?

The "Coldwater limestone" which is 350 to 400 feet below the base of the Marshall is the first continuous bed in Allegan County.

It is predominately a cherty shale with included dolomite crystals and thin bands of chert. Beds of dolomitic sand composed of rounded grains of oolites of dolomite in a limestone matrix are logged in some wells. In Laketown and Fillmore, Heath, and parts of Salem townships the "Coldwater limestone" is 80 to 100 feet thick and an upper more cherty zone can be distinguished from a lower more dolomitic zone. Where the lower part is dolomitic it contains small amounts of salt water. In the eastern townships the lower zone is absent and the total thickness at the "limestone" is no more than 10 feet.

In the southern part of the county the shales below the "Coldwater limestone" are slightly dolomitic and contain very fine crystals of dolomite. These shales thin decidedly to the west. In many wells, near the base of the Coldwater there are thin beds of soft red shale. In cores from Fillmore township, five beds of red shale were identified. In drill cuttings 2 or 3 beds are recognized. Generally the top of these red shales is of little value as indications of structural conditions, but in a small area in Dorr township the upper red shale is 55 to 60 feet above the true "Red Rock."

The "Red Rock" has long been used as a structural marker in Western Michigan, although its value as a marker in Allegan County is doubtful. Its thickness varies from 10 to 30 feet. The top 5 or 7 feet is a dark reddish brown argillaceous limestone containing many crinoid stems, and underlain by a white or light red, finely crystalline limestone or dolomite. Logs of wells in Trowbridge, Allegan, and Overisel townships record some dolomitic sandstone in the lower red dolomite and in the light gray dolomites below. This sandstone differs from other sandstones in the Allegan section, as the grains are uniform in size, well rounded and deeply frosted. Newcombe has suggested that an unconformity exists in the "Red Rock[1]". The presence of this sandstone and the variation in thickness of the light gray dolomites seems to prove the contention. It seems probable the upper red beds are reworked material derived from the lower dolomite.

The presence of Sunbury shale in Allegan County is doubtful, although two wells have been drilled through a dark gray or brown shale which is in the stratigraphic position of the Sunbury shale. The Vanderleest-Berens well in Overisel township drilled through 10 feet of dark grayish brown shale 10 feet below the base of the"Red Rock." The Borough Cavanaugh well in section 5, Watson township, drilled through 8 feet of dark brown pyritiferous shale at the base of the "Red Rock" and above the light gray dolomite.

Ellsworth

The Ellsworth shales as now defined are those shales between the "Red Rock" above and the Antrim shale below.[2] Further studies may prove

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[1] Newcombe, R. B., Oil & Gas Fields of Michigan - Michigan Department of Conservation, Geological Survey Division - Publication 38, 1933.

[2] Newcombe, R. B., Op. Cit.

that part of the red dolomite may belong in the Ellsworth shale. Recorded thickness of the Ellsworth shale varies from 350 feet in Wayland township to 550 feet in Laketown township. The upper 30 to 80 feet is dolomite or dolomitic shale with some chert. Lower beds are thinly bedded greenish gray, locally cherty or dolomitic. Chert in the Ellsworth shale differs from the chert in the Coldwater and Traverse formations. It is gray or dark gray and breaks with a fine pebbly or grained fracture. The relative amount of chert varies from well to well. At its base the greenish gray Ellsworth shale is interbedded with dark gray shales. Sometimes these bands of light and dark gray shale are less than 1/16 inch in thickness. The top of the Antrim, as now determined, is marked by a gradual increase in number and thickness of the dark gray shale beds. This zone is not in the same position in all wells, and additional work may prove that the upper Antrim shale should be included in the Ellsworth.

Antrim

The upper Antrim shales differ little except in color, from the Ellsworth. Chert in this zone has the same fine pebbly appearance as that in the Ellsworth. The lower 70 to 100 feet is black or dark brown and differs in texture from the upper 100 to 130 feet. Some gray shale is often near the base. In most wells the lower 20 feet contains variable amounts of dark brown crystalline dolomite. This dolomite may be a correlative of a concretionary zone recognized in the Antrim outcrops.

Traverse Formation

The Traverse formation has been variously subdivided by many students of the surface outcrops. That these divisions do not always extend basinward from the outcrops and so be useful for subsurface work was pointed out by Hake[1] who was, however, able to correlate some surface formations with subsurface formations in central and eastern Michigan, but these divisions have been difficult to identify in western Michigan, and in this study no attempt has been made to correlate subsurface beds in the Traverse with surface beds of the formation. However, when sufficient work is done on detailed examination and analyses of samples from wells and from surface rocks, it may be possible to trace beds from the outcrops in the Traverse Bay region to wells in southwestern Michigan.

In Allegan County the Traverse formation consists of 50 to 80 feet of shale and shaley limestone above 200 to 300 feet of limestone which contains beds of cherty limestone and dolomite.

Traverse Shale

The so-called "Traverse shale" lies between the dark shales of the Antrim above and the solid limestone below. The top of this shale is

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1 Hake, B. F. and Maibeus, J. B. - Lithology of the Traverse Group, Michigan Academy of Science Papers - Vol. XXXIII, p. 447, 1937

generally readily discernible by a change in color and an increase in lime content. However, in some wells the change is not so evident - the zone seems to be gradational, due perhaps to some Traverse shales being included in the Antrim during deposition. Possibly the gradation is only made apparent by imperfect sampling. A thin layer of limestone is at the top of the Traverse shale in Trowbridge township. In Salem, Dorr and Monterey, this limy streak is near the crest of the structure. Kirkham[1] has pointed out that an unconformity exists at the top of the Traverse shale. An unconformity is not very evident in Allegan County, but might be inferred from the absence of this limestone in many places.

The thickness of the Traverse shale varies considerably over small areas. In Salem and Monterey townships the shale thickens markedly off structure, is thinnest at the break of the fold, and thickens slightly above the flat top of the folds. Likewise, many of the irregularities in the Traverse limestone structure above the fold are reflected by a thinning and a thickening of the shale. A bed of argillaceous limestone or calcareous shale 15 to 20 feet thick and 10 to 30 feet below the top of the formation, is fairly uniform over most of the county and can be traced in wells through Kent County and into Montcalm County, where it merges with the limestone below. It is common practice to set the producing string of casing on this limestone. As a structure marker in small areas, this limestone is probably more satisfactory than the base of the Antrim, although the shale below it varies considerably in thickness. In many places this limestone is difficult to distinguish and may grade laterally and vertically into gray shales.

In many wells, especially in Dorr township, a thin layer of dark gray or brown shale 3 to 5 feet thick is at the base of the Traverse shale. Possibly more careful sampling would reveal the shale in all wells. This shale may represent a disconformity and may be a contact shale produced by weathering of the limestone during a period of erosion prior to deposition of the Traverse shale.

Traverse Limestone

For the sake of convenience, the limestone is divided into five zones on the basis of lithologic content. Although some of these zones may be recognized in the untreated samples, they are best determined from acid insoluble residues. In this zoning, all previous examinations and formation tops, were discarded and samples from old and new wells were reexamined. In order to be more certain of proper correlation, examinations were made of samples and records from wells in Ottawa and Kent counties and the zones traced across Kent and into Allegan County. (fig. 7)

Zone 1: The top fifty to eighty feet of the Traverse limestone is a fairly consistent zone, which may be recognized in wells in southwestern Michigan It consists of dolomite, chert, and cherty limestone and contains both upper and lower pay zones in the oil fields, and is therefore well known. It has been noted that the top dolomite is thin or absent in many wells, which are structurally high in Salem and Monterey townships. At the time of writing not enough samples are available to permit

[1] Kirkham, V. R. D. - Unconformity at the top of the Traverse Formation in Michigan. Geological Society of American Bulletin - Vol. 43, 1931

any conclusions about the presence, thickness, or absence of the dolomite in the Dorr field. It seems probable that this dolomite is of secondary origin and was formed by leaching of calcium carbonate during an interval of erosion when an outlying limestone and a part of the dolomite was removed. This dolomite is not in wells in Kent County northeast of Byron Center, but is in many wells elsewhere in western Michigan. A thin layer of limestone below the dolomite and overlying the chert may represent an undolomitized portion of the same bed. Below the dolomite and limestone layers are a series of chert and cherty limestone beds. The top of the first chert is easily recognized in samples and probably represents a definite stratigraphic horizon more consistent with the beds below than with the top of the limestone. The thickness of the top chert bed varies from 8 to 15 feet. Samples from it often have fifty percent to seventy percent of chert in a dense light gray limestone. Cores from the top of the Traverse limestone from wells in Salem field show thin layers of shale above and below the chert. Below the top chert bed two or three cherty limestone beds separated by beds of more nearly pure limestone are recognized in some places. In the Salem field the second pay zone occupies a position between the first and second cherty layers. In places a third pay or water zone is below a third thin chert. In a few wells in the northern and central part of the county, beds of argillaceous limestone are between chert layers. Most of these limestones are nearly pure, with but five or six percent of insoluble residues. In the northeastern part of the county the base of the first zone is marked by a bed of sugary or earthy chert, light brown in color in many samples.

Zone II: Zone II consists of from 30 to 80 feet of nearly pure light gray and white finely crystalline limestone. If it is true that much of this zone is reef-coral, the extreme variation in thickness may be accounted for, although determinations of the upper and lower limits of the zone may be in error. At least the variability in thickness of the zone seems to have little effect on the total thickness of the limestone. No oil or water have been found Insoluble residues seldom exceed five percent and are usually two percent of a sample

Zone III: Argillaceous and cherty limestones easily recognized, particularly in the southern part of the county, make up the third zone. The zone correlates with the middle shaly zone recorded in central Michigan wells and with the anhydrite zone recorded in Muskegon, Ottawa and Oceana counties. Considerable anhydrite is in this zone in the East Shore Dewitt well in Laketown township in the northwestern part of the county. The thickness of the zone varies from 35 feet in Trowbridge township to 80 feet in the East Shore Dewitt well. In Salem township the top of the zone is marked by a gray dolomite.

The first marker in the zone is commonly a slightly argillaceous limestone which shows in residues as a brown shale. Several thin beds of fairly pure limestone have been recognized in the middle of the zone. Oil shows or water have been noted in at least two wells. Below is a thick zone of shaly limestone and dark gray chert which shows as a gray shale in residues. This shaly limestone is often mistaken for the equivalent of the Bell Shale, but careful correlation across Kent County shows its position to be in the middle of the Traverse limestone. The lower part of the shaly limestone contains an abundance of siliceous corals.

Zone IV: The top of this zone, a light buff crystalline limestone with many fragments of corals, has often been identified as Dundee limestone in wells in southwestern Michigan. It is possible that, like Zone II, it is reef coral limestone. Its thickness varies from 50 feet in the southern part to 70 feet in the northern part of the county. In the middle and lower part of the zone are beds of lime sand, fragments of limestone, rounded by wave action and recemented. A bed of fine white sand 5 or 8 feet in thickness is shown in samples from a few wells. Many workers doubt the existence of the bed and think the presence of the sand in the samples may be explained by contamination. But it appears to the writer that, given an abundance of siliceous corals containing quartz crystals and conditions under which a lime sand could form, that concentration of quartz sand would form a natural sand deposit. Water, and sometimes oil, have been recorded from the top 10 to 40 feet of this zone, and in a few wells a bituminous shale is indicated in the insoluble residues. Residues in this group seldom exceed three percent of the sample, except in samples from the sand. In the extreme western part of the county all of Zone IV, and in places part of the overlying Zone III, is a crystalline dolomite.

Zone V: The lower part of the Traverse lime contains some dolomitic chert, many siliceous coral fragments, and in some places argillaceous limestone. Siliceous residues are not abundant in samples from wells in the northwestern part of the county where correlation is rather difficult and uncertain. However, the shaly limestone which may be a representative of the Bell shale, is more evident in wells in the southeastern than in the northern part of Allegan County. The recorded thickness of this zone varies considerably but the variations may perhaps be due to discordant correlation of the top and bottom parts. It is possible that some of the beds of the zone were never deposited in southern Allegan County.

Considerable evidence indicates that some folding occurred during Traverse deposition. The thinning of the Traverse and Dundee sections above broad northeastward pitching folds is shown in figures 5 and 8. At least part of the thinning is at the top of the Traverse limestone. The thickening of the Traverse shale offstructure is indicated in figure 14. At least part of the thickening is at the base of the shale. We have evidence also that a period of erosion preceded deposition of the Traverse shale in this area. The absence of some of the top beds on structure has already been noted.

Dundee

The Dundee formation is in most of Allegan County, but seems to be of little importance to the oil industry. As yet no oil has been recorded from the formation and water has been noted in only a few wells. Because of the difficulties in determining its top, no accurate measurement of the thickness of the Dundee in Allegan County has been made. However, the thickness apparently varies from 15 to 59 feet, and the Dundee may not be in the East Shore Dewitt well in Laketown township. (fig. 8). The top of the Dundee is generally determined by a decrease in the insoluble residues from 12 or 15 percent to 2 or 3 percent. However, in most well samples these insoluble residues do not differ from the insolubles in the lower part of the Traverse. Their presence may be due to contamination of the samples and it

is possible that in general the top of the Dundee has no characteristic residues. In Kent County and northeastern Allegan County, a small amount of sand has been noted in the top of the Dundee.

The Dundee, where not dolomitic, is a dense or finely crystalline light buff limestone. The upper beds in some places contain fine bands of dolomite. The lower beds contain small light brown dolomite crystals. At present the evidence is not sufficient to indicate whether the Dundee thins at the top or at the bottom. It is probable that any limestone layer close to an unconformity becomes dolomitic by the action of magnesium waters. Likewise the dolomitic limestone near the base of the formation may be due to concentrations of magnesium on a weathered surface of Detroit River (Upper Monroe) and may not always represent the same bed. Brown gypsum crystals have been found in the lower stratum of the Dundee, but they may be residual material derived from the Detroit River (Upper Monroe). In the extreme western part of Allegan County, all strata from the middle of Zone III of the Traverse formation to the top of the Detroit River formation are dolomitic.

It is possible that most of the Dundee was deposited in quiet, deep waters well removed from shore. Fossils which are found in the formation in central and eastern Michigan have not been found in the Dundee of Allegan County.

Detroit River

The Detroit River or "Upper Monroe" formation contains beds of brown, light brown, buff or gray dolomite and white and light bluish gray anhydrite. The top of the Detroit River is generally easily recognized in the greater part of Allegan County by a change from limestone to dolomite. In the extreme western part of the county where both Traverse and Dundee are dolomite, the dolomites in the top of the Detroit River are light buff and gray and finely crystalline whereas the dolomite in the Dundee and Traverse are light brown and more coarsely crystalline. Insoluble residues show brown gypsum crystals in the Dundee and small amounts of white and light bluish gray anhydrite in the top of the Detroit River. In some places a heavy bed of anhydrite is at the top of the formation but in most places 5 or 10 feet of dolomite are above the first anhydrite bed. Below the anhydrite bed is a dark brown coarsely crystalline dolomite, which usually contains water. In many wells, a bed of sand and anhydrite has been encountered below the brown dolomite. No attempt has been made to correlate dolomite beds below the first sand and anhydrite as they do not seem to be consistent over any considerable area. Where beds are predominately dolomite, they contain twenty to thirty percent of brown crystals of gypsum. The Detroit River waters probably contained much sulfate at all times and deposited anhydrite where restricted and subject to evaporation but deposited crystalline gypsum in deep waters during dolomite deposition. The interbedding of anhydrite and dolomite suggests frequent connections with and withdrawals of the sea.

Sylvania

The Sylvania sandstone has not been definitely identified in

Allegan County, but a sandy anhydrite which is from 150 to 200 feet below the top of the Detroit River in western and southern parts of the county can be correlated in five wells. This white, gray, and light amber sand is made of partially rounded and slightly frosted grains. The sand may be of aeolian origin which fact may account for the extreme irregularity of its thickness and occurrence.

Beds below the sandy anhydrite do not differ markedly from those above which contain light buff crystalline dolomite. Evidently restriction and evaporation of the sea preceded sand deposition in this area. From 30 to 50 feet below the last sandy anhydrite a marked change in color and texture of the dolomite probably represents the top of the Bass Island formation.

Bass Island

The Bass Island ("Lower Monroe") is known in Allegan County from four wells, but only one well penetrated more than a few feet into the formation. The top beds seem to be dense light gray to white dolomite suggesting that relative quiet waters lay over southwestern Michigan during Bass Island time with deposition of dolomite from original magnesium rocks. Below the dolomite are beds of light gray and light buff limestone, argillaceous limestone and a little cream colored chert.

Formations below the Bass Island have not as yet been reached in drilling in Allegan County.

STRUCTURE

The structure of the rocks in Allegan County is rather complex and not yet perfectly understood. The county lies on the southwestern rim of the Michigan Basin where the strike of the rocks is N. 50°- 60°W. Dips on top of the Traverse limestone vary from 25 to 36 feet per mile.

Apparently two very definite trends of folding cross Allegan County. In the northeastern part of the county, two well marked northwest-southeast folds have been identified; the Salem-Dorr Fold and the Diamond Springs-Monterey Fold. The Salem-Dorr Fold has been traced northwestward into Ottawa County and may extend southeastward into Wayland township. The greatest known relief is 160 feet in Salem township. Although the northeastern flank of the Salem township fold is not well defined, dips to the northeast are apparently less than dips to the southwest. Thus the fold resembles structure in Ogemaw County rather than those folds in Michigan which have the steepest dip basinward. The entire fold is greatly modified by northeast-southwest cross folds.

The Diamond Springs-Monterey Fold, four miles southwest of the Salem-Dorr Fold may extend northwestward into Holland township, Ottawa County, and southeastward into southeastern Monterey township. This fold is about two miles wide and its greatest known relief is 80 feet near Diamond Springs. A third parallel fold may possibly underlie Heath and Allegan townships.

Northeast-southwest folds are less well defined but are indicated by many wells, particularly in southern Allegan County. Parallel alignment of moraines, pre-glacial ridges and the Coldwater-Marshall contact suggest a possible relationship with these folds.

Where folds cross, structures favorable to the accumulation of petroleum are produced. Commercial production has been obtained from probable cross folds in Overisel, Salem, Monterey and Dorr townships. Widely scattered wells located near the crest of folds have found small amounts of oil, but the most favorable areas for commercial production will be at the junction of known folds or their extensions. Such favorable areas are indicated in southeastern Monterey township, southeastern Hopkins township, eastern Watson township and northeastern Wayland township. Further drilling may indicate other favorable areas in townships now but partially explored.

The northwest-southeast system of folding is well known in Michigan and the generally accepted theory is that this folding was more intense in northeastern Michigan and became progressively weaker to the southwest until it died out somewhere in Allegan County. However, folds in northeastern Allegan County show more relief than any known folds in western Montcalm or Kent counties, but data for wells drilled now do not seem to show northwest-southeast folds in central and southern Allegan County. On the other hand, northeast-southwest folds are not known in Central Michigan but seem rather apparent in Allegan County.

The northeastern part of Allegan County is very near the edge of the Salina salt basin.[1] It is possible that extreme down warping of the center of the basin in Salina time may have produced radial folds on the edge where sediments are thinner. The writer suggests that these radial folds have been reflected in upper formations by differential settling. From the rather meager information available, the Dundee and Traverse evidently thin over the northeast-southwest folds. Some evidence indicates a disconformity following the deposition of the Traverse limestone. In Salem and Monterey fields, upper beds of the limestone are apparently absent over northwest-southeast folds and the lower beds have been changed from limestone to dolomite on structure. Northeast-southwest folds are more apparent in contour maps drawn on top of the Traverse limestone than in maps drawn on upper formations. The "Traverse shales" thicken decidedly off structure - in some places as much as 70 feet. At least part of this thickening is in basal beds of the shale and evidently deposition took place first around structural "highs." Intervals between the top of the "Red Rock" and the Traverse limestone increase decidedly off structure to the northeast and southwest in Salem and Monterey townships and between folds in Salem township.

The majority of Michigan geologists agree that the northwest-southeast system of folds in Michigan occurred after Marshall deposition, and that the movement from the Canadian Shield was southwestward towards the Kankakee Arch. Here, as in mountain building, the thicker sediments in the basin may have been more closely folded than thinner sediments on the flanks. It is possible that radial folds in southwestern Michigan

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[1]Newcombe, R. B. - Op. Cit.

(produced by settling of basin sediments) acted as stiffening rods to prevent cross folding in southwestern Allegan County, to concentrate northwest-southeast folds along the northeastern edge of the area and so caused more intense northwest-southeast folds and buckled the ends of earlier northeast-southwest folds.

ECONOMIC GEOLOGY

Oil development in Allegan County dates from the latter part of the nineteenth century when the Allegan Gas, Oil and Mining Company, a local concern, drilled three wells in and near the city of Allegan. These wells produced a little oil from the top of the Traverse limestone but were soon abandoned as unprofitable. Later in 1912 the Northern Oil and Gas Company drilled two wells in the same vicinity with like results.[1] In 1916 a well drilled near Saugatuck proved unprofitable.

After the discovery of the Muskegon oil field in 1928 several test wells were drilled in Allegan County. At the same time some of the larger companies drilled core tests and located structures in the northern and northeastern part of the county. However, oil tests proved unsatisfactory and active interest in the county was abandoned.

During the period of 1931 to 1936 several wells were drilled by local companies. Many of these wells found shows of oil in the Traverse limestone. In February 1937, Lentz and Miller completed their Rabb No. 1 well for about 100 barrels and the Salem field was opened.

Salem Oil Field

At first the discovery well in the Salem field failed to attract the attention it deserved. It was not until April 13th that another well was completed nearly one half mile from the discovery well. This well flowed 220 barrels after acid treatment. Development followed rapidly during the summer of 1937. Now - September 15, 1938 - 85 wells are producing approximately 2,000 barrels of oil daily.

The Salem oil field is structurally rather complex and may be interpreted in several ways. It is apparently located on two small northeast-southwest folds at their junction with a northwest-southeast fold. Marked synclines lie to the northeast, southwest and southeast. The steepest dips are to the west and northwest. The total closure is approximately 100 feet of which the top 50 or 60 feet are productive. The 920 foot contour line marks the lower limit of production on the west side of the field, but on the east end production is limited approximately by the 905 foot contour. Evidently water encroachment is greatest from the east. Recently drilled wells (April 1938) show a rise of about 5 feet in the oil water contact. The total productive acreage in the field will probably not exceed 1,150 acres with perhaps sixteen more locations, most of which will be in sections 15 to 21.

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[1] Smith, R. A. - Publication 14 (1912) - Oil and Gas in Michigan - Michigan Geological Survey.

Two areas northwest of the field will warrant further testing. Recently wells drilled in this vicinity have found encouraging shows of oil.

Reservoir Conditions

In general, oil is found in two pay zones in the Salem oil field, a first pay in the top of the limestone and a second pay from 17 to 30 feet below the top of the limestone. In a few wells, particularly along the edge of the field, an intermediate productive zone has been recorded 10 to 15 feet below the top, and at 35 to 40 feet below, scattered wells on structure have oil but wells off structure have water at this level.

The first pay zone is a dolomite, which has a maximum thickness of 5 feet on the flanks but thins 1 foot or is absent on top of the structure. The dolomite is brown or light brown, rather dense in cores, but showing crystal clusters and cavities. Porosity is evidently due to leaching and may not exceed twelve percent. Two of the first wells drilled encountered a strong flow of gas in this zone but the gas was soon exhausted. In the southeastern part of the field one well flowed a quantity of oil from this top pay, but in general, production is slight.

The second pay zone is composed of coarsely crystalline limestone and lime sand consisting of loosely cemented fossil fragments, principally corals. Possibly the chert capping the limestone prevented complete circulation and cementation and thickness of the pay zone may bear some relationship to the thickness of the chert. Thickness of this pay varies from 2 to 12 feet with an average of 7 feet. No measurements of porosity have been made, but apparent porosity varies greatly from well to well.

Drilling and Producing Practices

The slight depth to oil and the comparatively easy drilling has favored the use of drilling machines in Salem field and Allegan County. In general, the wells are placed in the center of ten acres, but where property acreage is small, wells are closer together. From 50 to 200 feet of 10 inch drive pipe is set through the drift. Where the Marshall sandstone is present $8\frac{1}{4}$ inch casing is set to shut off fresh water. Often additional $8\frac{1}{4}$ inch casing is set to prevent caving of the soft shales above the "Coldwater limestone." In some wells a little water is found in the Coldwater limestone. The producing string of casing, 6 5/8 inch or in some wells 5 3/16 inch, is set in the shaly limestone above the Traverse limestone at 1550 feet. It is seldom cemented or set on a packer. Wells are drilled in with control head and oil saver and bottomed at approximately 1,600 feet. Drilling time averages from twenty to thirty days and drilling costs from $5,000 to $6,000. It is common practice to treat wells once or twice with 1,000 gallons of acid shortly after completion. Acid treatments usually increase production from two to ten times. Initial productions vary from 50 to 500 barrels daily. No dry holes are within the proved area.

As the gas pressure is slight the flowing life of the wells is short. Now (July 1938) the best wells flow about two months, but many wells are put on the pump immediately on completion. A few wells are pumped from central power plants but the majority of wells are pumped with individual powers. A few wells are pumped with purchased electric power.

A few of the edge wells in the Salem field produce small amounts of water. The lack of water drive and deficiency of gas may tend to leave much unrecovered oil in the pay zones unless some artificial recovery methods are employed. Accumulations of paraffin in tubing and surface lines, particularly during cold weather, tend to increase lifting costs.

Owing to the extreme variability in thickness and porosity of pay, recovery estimates are difficult. Assuming the average thickness of the pay zone to be 7 feet, the average porosity fifteen percent, and the recovery factor thirty percent, then recovery should be about 2,700 barrels per acre. Other Traverse wells in western Michigan show an average production of only 1,000 barrels per acre.

A rough estimate of the economics of an average well in the Salem field might be as follows:

Costs

Drilling costs, including casing	$5,500.00
Treating costs - - - - - - - - - - -	500.00
Pumping equipment,rods,tubing,etc.	1,500.00
Lifting costs-27000 bbls.@ 15¢ bbl.	4,050.00
Incidental expense - - - - - - - -	2,000.00
Total	$13,550.00

Returns

Total production- - - - - - - - -	27,000 bbls.
Land owner's Royalty - - - - - - -	3,379 bbls.
Value 23,621 bbls. at $1.12 - - -	$26,555.00

Production curves show a rapid decline during the first four months after discovery and a flattening of the curve thereafter. Compilation of production records from several good leases show an average recovery of 1,486 barrels (to July 1, 1938). By August 1, 1938 the field had produced approximately 1,022,000 barrels of oil from 85 wells located on 830 acres, or an average of a little over 1,200 barrels per acre.

The oil from the Salem oil field has an asphalt[1] base and an average gravity of 40° Be.; gasoline content is forty percent and kerosene content eleven percent. The bulk of oil is refined in Muskegon by the Naph-Sol and Old Dutch Refineries; some is refined in Grand Rapids and Grand Ledge. Oil is either trucked from loading racks in the field or from pipe line loading racks in nearby towns. During the early life of the field market facilities were limited and wells were prorated, but since October 1, 1937 wells have been produced nearly to capacity.

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[1] Naph-Sol Refinery Chemist - Personal communication.

Monterey Oil Field

The Monterey Field was opened in February 1938, a little over a year after the discovery in the Salem field. The Hood Oil Company Wright No. 1, located in the NE¼ SW¼ SW¼ of section 9, T.3N., R.13W., came in unexpectedly, flowing at the rate of approximately 300 barrels daily before acid treatment. The second well, an east offset, was rather small when drilled in, but responded well to acid treatment. At the present time 19 wells are producing about 2,200 barrels daily.

Structurally, the Monterey Field is located on a northeast-southwest fold. It differs from the Salem field in that cross folding is less evident, although a northwest-southeast cross fold may be in the southwestern end of the field. The northeastern end of the fold is as yet not well defined and offers the best possibility for extension of production. As in the Salem field, the steepest dip is on the northwest side of the fold. Total closure may be 80 feet, of which the top 70 feet are productive. At the west edge of the field the 880 foot contour line on the top of the Traverse limestone represents approximately the lower limit of production but as in Salem field, the eastern limit is higher, at 858 feet. Approximately 360 acres are now proved with 23 producing wells.

As yet only one pay zone has been recorded in wells in the Monterey Field. This is a dolomite in the top of the limestone much like the top pay of the Salem Field, but containing more chert. Recorded thicknesses vary from 1 foot to 5 feet with an average of 4 feet. Off structure the top of the Traverse limestone is represented by a dense or slightly dolomitic limestone, indicating that the structure existed at time of dolomitization. In a few wells a slightly porous zone below the first cherty limestone is recorded in a position corresponding with second pay zone in the Salem Field. This zone is non-porous in wells on the west side of the field, but it shows greater porosity in wells to the east and northeast. It is possible that wells drilled on the northeastern end of the structure may produce from both zones.

Drilling and producing practices are essentially the same as in the Salem Field with the exception that the producing string of casing is often set on top of the Traverse limestone and is sometimes cemented. This practice gives better results in acid treatments where considerable pressure is required to force the acid back into the dolomite. At the present time all but the edge wells are flowing. Lack of markets and transportation facilities have caused production to be curtailed. Recent oil discoveries nearby may cause further proration and price decline. Data are too few to make any recovery estimates, but it seems probable that recovery will be less than in the Salem Field. The absence of water in edge wells indicates that wells will not produce much water nor will they have the benefit of a water drive to aid recovery.

Dorr Oil Field

Dorr township has long been considered to be structurally favorable for oil accumulations. Core tests drilled in 1929 and 1930 proved the presence of a fold in the southwestern part of the township. However, it

was not until after the discovery of the Salem Field that many wells were drilled in Dorr township. The discovery well was drilled in March 1938 by the Eureka Development Company on the John Widenfeller property in the NE¼ NW¼ SE¼ of section 29. Initial production from a pay zone in the top of the Traverse limestone was 250 barrels daily following acid treatment.

The Dorr Field differs in a number of ways from the other Allegan fields. Greatest elongation of the field is along a northwest-southeast fold. Apparently three separated productive areas lie on three small cross folds. These cross folds are small features on the top of the broad fold which runs northeast through Allegan and Dorr townships. The antiquity of this fold is shown by the thinning of the Traverse and Dundee above it. (Plate 11). Total closure may be 60 feet, of which no more than 17 feet have as yet been found to be productive of oil. Like other Allegan fields, the steep dip may be to the south. At the west edge the 885 contour line on top of the Traverse limestone represents the lower limit of production. At the eastern end, wells find water instead of oil where the Traverse limestone is deeper than 860 feet below sea level. Northeast of the present producing area the structure is not defined, but the writer believes this is the most favorable area for future development.

The top pay zone in the Dorr Field resembles that of the Monterey Field. It is a crystalline dolomite with considerable chert. Thickness of the zone varies from 1 foot to 5 feet with an average not much over 3 feet. In the eastern and central parts of the field a layer of dense cherty dolomite overlies the pay. This dolomite may be part of a bed which has been removed from the top of the higher folds of other fields. The Columbia Gas and Oil Company Siewald No. 1 found a slightly porous zone and more oil from 22 to 26 feet below the top of the Traverse limestone. Other operators in this vicinity have been reluctant about drilling wells to a second pay and perhaps into water. However, where the two pay zones are separated by dense cherty limestone it is probable that if no water is in the upper pay zones the lower zone is dry also.

Although some new wells flow for a few days, all of the 18 wells now producing are being pumped with individual powers. Nearly all of these wells make a little water with the oil and probably as the oil is withdrawn the water will increase. Initial production from wells with a thick pay zone was as high as 400 barrels daily. Now no wells are making over 100 barrels daily.

Although the field is new and data are not sufficient to permit estimates of recovery, it is probable that the Dorr Field will not produce more than 1,000 barrels per acre. At this time about 500 acres are proved with little evidence that the total producing acreage may be extended.

The oil from the Dorr Field, having a gravity of 41° Be., has better qualities for refining than the crude from either Salem or Monterey. The Simarall Pipe Line Company and Commonwealth Pipe Line Company are the chief purchasers of Dorr oil production. Drilling and producing conditions are essentially the same as in the Salem and Monterey fields.

Trowbridge Township

In 1930 and 1931 the Johnson Oil Refining Company drilled three test wells in Trowbridge township. One of these wells on the Forster property found some oil in the top of the Traverse limestone, but was abandoned because of water difficulties. In June 1937 James E. Flannigan drilled a well on the Clair farm in section 29 which produced about 40 barrels of oil following an acid treatment. Several oil wells were drilled in this vicinity and now (September 15) 7 wells have been drilled, four of which are producing oil.

Wells in Trowbridge township are located on a northeast pointing structural nose which has little or no closure to the southwest.

The oil is in a light brown dolomite, 4 or 5 feet thick, 1 to 3 feet below the top of the Traverse limestone. Two wells have found shows of oil or water 23 to 33 feet below the top of the limestone in a position corresponding to the second pay in the Salem Field. This zone is composed of finely crystalline limestone with less chert than layers above and below. Average thickness of the pay zone in this area will not exceed 4 feet. Of the 7 oil wells only the most northerly has produced oil in any appreciable quantities. This well produced nearly 100 daily barrels for several months. At the present time all wells are pumped with individual powers. These wells produce from 1 to 10 times as much water as oil.

Water disposal has always been a problem in this field. Some water was used for a time as a dust settler on roads. Attempts to dispose of brine by returning it to the Coldwater limestone was successful in only one well. Efforts to dispose of brine by returning it to Traverse limestone in an edge well were also unsuccessful. Experiments are being made in returning the brine to a gravel layer in the base of the drift.

Diamond Springs

The Diamond Springs Field was opened July 18, 1938, by the William Cline Aldrich No. 1 well, $NE\frac{1}{4}$ $SW\frac{1}{4}$ $SE\frac{1}{4}$ of section 36, T.4N., R.14W., which was drilled to a depth of 1,461 feet and then flowed 100 barrels of oil in 45 minutes from the Traverse limestone. Development has proceeded very rapidly and now (September 20, 1938) 37 wells have been completed, 30 of which are producing oil.

The structure is a relatively small northwest-southeast trending anticline which apparently is caused by a small northeast-southwest cross fold pointing toward the lower end of the Salem oil field. Total closure may be nearly 80 feet, of which no more than the upper 50 feet are productive of oil. At this time the field is limited by dry holes on the east, north and west, but is not defined on the south and the greatest drilling activity is now along the southern edge of the field. Approximately 500 acres are proved and it is possible that the total producing acreage may be 750 acres.

Oil is produced from a light brown crystalline dolomite in the top of the Traverse limestone. Reported pay thicknesses vary from two to nine feet, but sufficient samples are not available for accurate determinations. Possibilities of finding a second pay zone have not been tested on structure.

The eastern side of the field lies in the town of Diamond Springs and wells are close together on small pieces of property. Wells along the eastern edge are put on the pump as soon as completed but wells along the northern and southern edges are permitted to flow for a short time after completion. Rapid dissipation of energy by drilling wells on town lots will undoubtedly result in the loss of recoverable oil. Edge wells are now beginning to make some water and water disposal may become a serious problem.

Overisel Field

On August 17, 1938 the Stewart Oil Company, Oldebeking No. 1, SE¼ SE¼ of section 21, T.4N., R.14W., began producing oil at the rate of 20 barrels per hour from one foot in the Traverse limestone at 1478 feet. The well is located northwest of Diamond Springs Field on the Diamond-Springs-Monterey fold. Now (September 20) 7 wells have been completed in this area, 5 of which are producing oil. The logs of these wells and of wells now drilling indicate an elongated dome which may be larger than the Diamond Springs Field.

The pay zone is evidently the same crystalline dolomite in the top of the Traverse limestone which produced in other Allegan County fields. As yet it is too early to make any estimates as to thickness and extent of the zone.

FORMATION TOPS, OIL, GAS AND WATER ZONES AND CASING IN ALLEGAN COUNTY WELLS

By Townships

Permit	Company, Well and Location	Elev.	Drft.	Redrock	Trav.	Lime	Oil	Water	Dund.	Oil	D.R.	Water	Sylv.	B.I.	T.D.	10"	8¼"	6-5"	5-3"
	T.2N. - Allegan Township - 13W.																		
None	Allegan G.O.& Min. SE NW 28	632	*120	*580-615	*1195	*1260	1264	1264							1400				
None	Allegan " 2 SW SW 21						1328												
None	Allegan " 3 NW SE 21						None								1411				
None	Northern-Thomas #1 SE NE 32	698	355	650-60	1270	1318	1320								1388				
None	Northern-Moore #2 SE SW 21	630	87	630-40	1220	1287	1287	1292							1340				
4914	LaBlanc-Schafer #1 NW NE 2	734	205	*824-38	*1500	*1564		1564	*1796			1747			1825		208		1528
1160	Irvine-Allegan #1 SW NE 28	631	100	560-85	1199	1232	1295	1300							1367	100		1271	
1035	Manion-Tobin #2 NW SE 16	739	260	765-67	*1377	*1430	1430	1435		1570					1669	272			
3430	R.Sapp-Hudson #1 NE SW 29	711	400	662	*1295	*1348	1398	1355	*1580	1695	*1610	1712	*1825	*1857	1875	400	800		1820
4429	Andrews-Perrigo #1 NE NW 28	621	*130	*613-20	*1209	*1273	1271	1577	*1502		*1532	1600			1600	156	350	1209	
4550	Vahue-Chadbourne SE NE 28	621	110	*600-07	1145	*1270	1274	1276							1475	106		1325	
4089	Champion-Detling SE SE 35	744	327	800-15	*1385	*1457	1457	1653	*1676	1718	*1718	1630			1753	120	327	1400	
	T.1N. -Cheshire Township - R.14W.																		
571	Kimmell-Hamilton NE SW 5	684	365	*627-40	*1236	*1290		1290	*1525		*1540	1575	*1685		1800	227	457	1675	
4938	Hubbell Oil-Kage NW NE 24	731	*200	*660-78	*1258	*1317	1427	1442							1446	120	250	1270	
5071	McIntosh-Shantz NW NE 14	710	267	659-72	1270	1326	1330	1330							1449	267		1326	

*Tops from Sample Examination

FORMATION TOPS, OIL, GAS AND WATER ZONES AND CASING IN ALLEGAN COUNTY WELLS

By Townships

Permit	Company, Well and Location	Elev.	Drft.	Marshall	Redrock	Trav.	Lime	Oil	Water	Dund.	D.R.	Water	T.D.	10"	8¼"	6-5"
	T.4N., - Dorr Township - R.12W.															
3823	Caldwell-Goslin #1 NW SE 10	729	160	160-240	1037-47	1646	1701		1780				1828	214		1680
5020	Gordon-Bank NW SE 17	685	120	120-30	912-34	*1535	*1598	1601	1602	1858	*1900	1620	1933		150	400 (5-3" 1557)
4723	Lenoran-Delegowski NW SW 22	698	121	121-28	*935-50	*1552	*1609	1430	1791	*1848	*1915	1901	1936	129	270	1847
1956	Pure Oil-Beukema SW SW 27	714	111	111-132	944-58	1540	*1600		1610		*1912	1823	1954	138	436	1912 (5" 1581)
4727	Eureka-Widenfeller NW SW 29	738	*220	None	*945-51	1550	1617	1623					1626	154	170	239 (5-3" 1891)
4896	Gulf-Widenfeller SW NW 29	720	225		*925-37	*1531	*1594	1610	1629	*1858	1895	1915	1932	222		1564
4903	Leonard-Bachman SW NE 30	697	*164	None	*900-10	1515	*1570	1578					1584	173	256	(5" 1536)
4887	Swanson-Rucinski NE NW 30	684			885-94	*1501	*1566	1568	1567				1600	148	302	1566
4916	Regal Dutch-Commons SE SW 32	740	193		953-65	*1647							1724	196	335	
4872	Lentz & Miller-Troike NE NW 33	758	90	90-155	*960-79	*1559	*1617	1619	1622				1622	101	221	(5" 1586)
4981	Musk. Dev.-Fritza NW NW 33	748	*134	*134-55	*940-60	*1546	*1611	1612	1613	*1887	*1921	1894 2015	2061	145	375	1569
4786	Lentz-Malleck SE NE 33	729	215		*945-75	*1540	*1605	1609	1611				1613	215	300	(5-3" 1510)
4647	Lentz-Hitzler NW SW 34	748	*238		*965-80	*1575	*1633	1635	1680				1683	246	310	1628
5129	Fleming-Niemczyk NW NE 31	712	185	None	924-40	1512	1616	1618	1620				1650		207	
5198	Michigan-Kubiac #1 NW NW 31	671			902-10	1515	1575	1576	1578				1588	168	326	

*Tops from Sample Examination

Per-mit	Company, Well and Location	Elev.	Drft.	Marshall	Redrock	Trav.Lime	Oil		Water	T.D.	10"	8¼"	6-5"	5-3"
					T.3N. - Monterey Township - R.13W.									
5026	Hughes-Cram #1 SE SW #1	739	175	175-260	1055-75	*1665	*1710		*1710	1729	175	340	1581	
4935	Lee Brown-Spray SW SE 3	703	115	115-150	895-920	*1616	*1670	1670		1730	160	340	1582	
5106	Diamond Springs-Jones SE SW 4	705	122	122-138	873-902	1580	1622		1640	1651	158			
4979	Murley-Schmidt #1 SW SW 5	701	*104	*104-209	*937-951	*1578	*1638	1639	1639	1641	128	258	1611	
4991	Wicklund-State L -#1 NE SE 5	698	*160	*160-198	962-980					1250	114	260		
4944	Norton Stewart-Boehn SE NW 8	734	67	67-195	*936-945	*1593	*1655			1708		200	1058	
4842	M. D. C. - Miller NE SE 8	766	*196	None	*912-922	*1580	*1629	1629		1632	194	313	1588	
4973	Hood O&G.-Wright #3 NW SW 9	799	219	None	920-928	*1575	1629	1628		1656	219		1626	
4921	Musk. Dev.-Swanders #2 SE SW 9	818	124	124-187	*936-956	*1576	*1641	1642		1667	203	285	1627	
4988	Sprenger-Brenner #1 SE NE 10	753	124	124-165						197	136	195		
4949	Stewart Oil-Watkins NW NW 15	824	190	190-266	1010-35	*1718	*1773	*1775	1808	1808		209	400	
4792	Sprenger Bros.-Miller SE SE 15	863	270	None	*1061-80	*1675	*1736	1736	1738	1743	288	341	755	
4835	McIntosh-Dalrymple NW NW 16	824	163	163-173	937-949	*1552	1635	1636		1642	179	309	1633	
4865	R. E. Olds-Ryk Riksen SE NW 16	870	219	None	1020-50	1710	1772	1778	1835	1840	219	320	350	
4251	Swanson Cons.-Granger SW NE 17	847		None	*936-946	1616	1728		1760	1790	230		1691	
4904	W.E.Ross-Skinner #1 NW NE 17	782	232		*875-887	1552	*1640	1645		1649	233	280		1597
4878	Voorhees-Wuis #1 NE NE 21	917	*340	None	*1090-1118	*1754	*1820	1821		1935		352		1823
4913	Sprenger Bros.-Buck SW SE 22	824	200	None	*934-946	*1562	*1622	1621	1641	1680	208		621	1603
4924	Caldwell-Dendel #1 SE SW 27	925	328	None	1000-30	1703	1785	1787	1857	1865	328	735	1746	

Per-mit	Company, Well and Location	Elev.	Drft.	Marshall	Redrock	Trav.	Lime	Oil	Wat.	Dund.	Wat.	D.R.	T.D.	10"	8¼"	6-5"	5-3"
							T.4N., -Salem Township - R.13W.										
4455	Bangs Hirzel-Palmbos NE SE 4	718	294	*294-306	*1055-80	*1713	*1761	1763					1808	294	400		
4552	Regal-Campaigner SW NE 7	666	*100	*100-205	*882-904	*1542	*1586	1603					1604	116	206	1577	
4351	Victor McB-Harmsen SE NW 8	694	121	121-296	1028-58	*1688							1716	123	321		
4452	Eureka-Flesser SE SE 8	713	*190	*190-265	*1090-23	*1662	*1712	1810					1820	180	295		
963	Nat.Min.-Commissaris NE NE 9	712	151	151-191	940-53	*1550	*1600	1605	1614	*1928	1860	*1960	1968	151	465	1743	
3038	Pioneer Dev. " SW NE 9	710	*176	*176-203	*947-58	*1606	*1654	1655	1685				1688		183	298	1572
4425	Wicklund-Winchester SW NW 13	668	150	None	930-42	*1567	*1633		1698				1745	129	270	1596	
4558	Ross-Bredewig SW SW 15	679	131	None	858	*1511	1585	1587					1635	131	328		
4399	Mich.D.Co.-F.Smith SW SW 15	651		None	802-37	1478	1527	1534					1569	209	248	1504	
4243	Kreiser-Moored #1 NE SE 16	700	80	80-130	900-	*1575	*1632		1664	*1935			1950	90	150	1675	
4757	Salem Oil-Rabb #1 SW NW 16	687	107	None	*876-96	*1480	*1560	1561	1608				1610	123	220		1490
4324	Lentz & Miller-Sebright NW SW 16 #2	683	150	None	846-65	1485	1554	1564					1601	159		1555	
4140	Musk.Oil-Berens #1 NE SW 17	675	*110	*110-132	882-92	*1530	*1600	1605	1625				1649	132		1561	
4746	Mich.Dev.-Sebright #2 SE SE 17	670	90	None	831-49	1510	1580	1595		*1870	1946	*1929	2000	90	216	1536	
4587	Ide O.& G.-Brenner #2 NE NE 17	720	208	None	922-45	1580	1644	1644	1662				1695	226		1597	
4273	Ypsilanti-Englesman SW SE 18	681	112	None	893-916	*1637	*1698		1704				1705	104	148		
4898	Regal Dutch-Lampen NE NE 20	686	85	None	847-54	1540	*1617	1623					1635	103		1583	
4213	Cochran-Nieneker NW NW 21	665	109	None	825-40	1524	1623	1629	1629				1640	109		1536	
4234	Vahue-Hoppenrath SW SE 21	653	54	*54-82	*835-65	*1510	*1595	1595	1595				1597	74	106	1555	

*Tops from sample examination

Permit	Company, well and location	Elev.	Drft.	Marshall	Redrock	Trav.	Lime	Oil	Wat.	Dund.	Wat.	D.R.	T.D.	10"	8¼"	6-5"	5-3"
	T.4N. - Salem Township - R.13W.																
4642	Lima Oil-Nahr #1 SE NW 22	667	174	None	855-59	*1500	*1576		1578				1602	173	302	1538	
4968	Musk.-Oil-Ostrander NW SW 22	662	80	80-105	860-74	1505	*1559	1562					1584	80	150	1527	
5003	Alma Allen-Howard NW NE 24	668	118	118-137	878-908	1525	1591	1591					1692	138		1592	
5044	Mesel-Mellish #1 NE SW 25	681	246	246-50	915-19	1580	1647	1649	1651				1651		248	253	1609
4585	Northcott-Dowling NE SW 27	653	167	167-195	968-975								1550	100	166	267	
4417	Heinig-Kleinbrink NW NE 29	637	*150	None	*875-900	*1560	1637		1641				1641	135	150		1570
5188	Gordon-Perkins SW SW 31	646			770-80	1403	1459	1460					1462		95		1434
5233	Gilde-Lampen NE NW 32	655			908-38	1585	1644		1645				1650	140	230		
	T.1N. - Trowbridge Township - R.13W.																
4760	Dapar-Kent SE SW 4	733	388		*720-30	*1310	*1369	1373	1375				1404	100	387	451	
4283	Hubbell-Madalinski NE SW 18	744	254		660-80	*1280	*1338	1341	1341				1387	255		1280	
4539	Springer-McCarn NE NW 19	731	275		665-70	*1260	*1314	1321	1485	*1521	1611	*1567	1645	135	350	1335	
4531	Copley-Odell NW SW 20	773	342		690-95	*1300	*1358	1355	1357				1412	290	342	1310	
1107	Johnson-Holland SW SW 26	755	190		731								731	190			
4661	Gladstone-Emmons NE NE 28	749	205		*689-93	*1299	*1348	1351	1352				1369	206	399	1345	

(Carried forward)

Permit	Company, Well, and Location	Elev.	Drft.	Marshall	Redrock	Trav.	Lime	Oil	Wat.	Dund.	Wat.	D.R.	Sylv.	T.D.	10"	8¼"	6-5"	5-3"
							T.1N. - Trowbridge Township - R.13W. (forward)											
4350	Flannigan-Brown NE NE 29	803	*185		*780-83	*1338	1386	1389	1391					1391	221	304	1388	
4442	Rose-Bartholoman NW NW 28	749	250		690-700	*1273	1337	1337	1338					1345	250	352	1320	
4639	Flannigan-Bridgeman SW NW 29	764	265		700-10	*1280	1335	1337	1503	*1545		1612		1624	274		1341	1586
1121	Johnson-Forster NE NW 32	758	204		705-18	1280	1348	1349	1555					1557	214			1507
							T.2N. - Valley Township - R.14W.											
None	Shell Test K-310 NW SW 18	668	255		640-55									748				
4757	Vahue-Merrill & V. NE SE 25	752	?		720-730	*1330	*1393	1392	1442	?		1875	*1660	*1818	1929	173	256		1817
4349	Arlon-Barnicle NE SW 33	685	113		640-55	1251	1310	1335	1339					1381	113	288		
							T.2N. - Watson Township - R.12W.											
4999	Borough-Cavanaugh NE NE 5	849			*1089-95	*1748	*1811		1814					1903		226	689	1739
5047	Rose & Jones Alma SE SE 32	707			760-80	1379	1484	1484		*1657		1730	*1703	1735	305			1406
							T.3N. - Wayland Township - R.11W.											
5027	Wayland-Carpenter SE NE 7	760			*1035-70	*1658	*1729			*1988		2064	*2030	2064	162	300		
5028	Fowler-Birchard NW SE 20	880	298	*298-400	*1277-92	1840	1903		1904					1956		296	625	
4861	Wayland Synd.-Kline SW SE 10	784	198	*198-354										630		188		

Permit	Company, Well and location	Elev.	Drft.	Redrock	Trav.	Lime	Oil	Wat.	Dund.	D.R.	Wat.	Sylv.	B.I.	T.D.	10"	8¼"	6-5"	5-3"
	T.4N. - Fillmore Township - R.15W.																	
	Shell Test K-302 SE SW 10	678	115	785-812										878				
	Shell Test K-304 NE NW 3	672	180	*787-800										845				
	T.1N. - Gun Plains Township - R.11W.																	
718	Wiser Oil-Humphrey NW NW 21	728	130	*845-60	*1375	1450	1725	1600	*1682	*1697	1726			2010	130	425	1846	
5051	Henry Honeysette SW NE 27	861		970-80	1435	1512		1582						1770		285	1477	
872	Wiser Oil-Allen NE NE 33	733	382	875-90	1405	1455	1610	1585		1685	1715			1715	169	190	381	
	T.3N. - Heath Township - R.13W.																	
5196	Gordon-Scholten NW NE 1	646	80	740-50	1385	1445	1445							1448		94	135	1431
5064	Sutherland-Klein NW SW 10	673		735-52	1465	1523	1528	1554						1567	133	264	1490	
2243	Bear Creek-Fors 1 NE SE 29	650	157	*655-700	*1327	1400	1400	1400		1650	1750			1950	158	300	1547	
4674	Heinig-Lundberg SW NE 29	667	186	*695-714	1343	*1398	1402							1500	185		1361	
	Sinclair-Gerber NE SW 30	602	305	510-35										1200	80	180		
2629	Heath-Terpstra NW SE 34	676	*80	726-44	*1371	*1414		1567	*1661	*1693		*1952	*1968	2121	196	283	2060	
	T.3N. - Hokpins Township - R.12W																	
4485	L.& M.-Morgenstein NW SW 1	730	*144	1153-68	*1740	*1800		1798		(Mar.144-315)				1808	144	336	1760	
886	Puritan Oil-Gere NW NW 13	731	*140	1125-35	*1720	*1790	1927		*2045	*2085	1965	(M.190-285)		2115	139	470	1927	
5025	L.Chulski-Tuttle 1 NE SE 22	737	124	1050-65	1650	1720	1727	1729		(Mar.124-230)				1729		245	1682	
4715	Stallard-Schaffer NW NW 29	715	242	*885-92	*1500	*1549	1775	1551			1850			1850	208		1524	

Permit	Company, well and Location	Elev.	Drft.	Mar.	Redrock	Trav.Lime	Oil	Wat.	Dund.	D.R.	Wat.	Sylv.	B.I.	T.D.	10"	8¼"	6-5"	5-3"
					T.4N. - Laketown Township - R.16W.													
647	E. Shore-Dewitt SE SW 11	661	193		*623-40	*1340	*1422 1614	1465		*1732	2050	*1922	*2042	2056	192		1900	
4586	Cochran-Arnold SW NW 26	708	150		685-705	*1420	*1444	1462						1464	167	260		
					T.1N. - Lee Township - R.14W.													
5096	United Pet.Co.-Low SW SW 24	675	235		*545-60	1103	1161							1295	235			
					T.2N. - Martin Township - R.11W.													
935	East Shore-Nyland NW NE 26	742	208		*960-80	*1600	*1656			*1900	*1934	1992		2000	208	500		
5102	Hubbell Oil-McVean SW NW 19	832			1000-20	1556	1635	1635	1656					1860	314		1573	
					T.1N. - Otsego Township - R.12W.													
2479	Crystal Syn.-Jewell NW NE 3	753			*840-65	*1449	*1512	1512						1545		172	1407	
4088	Miller Cook-Wood SE SW 3	746	189		860-90	1435	1498	1504	1680					1753		224		1501
4331	Champion-Young NW NE 26	714	300		760-75	*1325	*1390	1423	*1617	*1639	1690			1804	285	375	1651	
					T.4N. - Overisel Township - R.14W.													
928	Pure Oil-Hoeve NE SE 2	676	93	93-130	857-75	*1500	*1573	1624	*1875	*1895	1912	*2273	*2278	2600	150	(14" 94') 1899	2191	
2786	Venderleest-Berens SE SE 26	670	72	72-85	*820-50	1550	*1598	1601						1602	73	102		
4748	Carscallen-Van Dam NW SW 3	651	142		763-87	*1412	*1510	1684	*1800	*1825				1940	142		1510	
5127	Wm.Cline-Aldrich SW SE 36	645	108	108-10	746-63	1405	1460	1461						1461	112		1441	
5199	Stewart-Oldbekking SE SE 21	656	152		762-69	1410	1477	1477						1478		160	1426	
5224	Trexler-Yonkers SW SE 25	631	150		723-37	1482	1562	1571						1571	172			
5181	Cline-Pol NE SE 35	626			774-94	1444	1503	1544						1547	109		1468	

SUMMARY

Wells drilled for oil in Allegan County have penetrated Paleozoic sediments of Mississippian, Devonian and Silurian ages. Folds and cross folds in these sediments have produced structures favorable for petroleum accumulation. Oil is in a secondary dolomite near the top of the Traverse limestone and locally in a porous zone 20 to 30 feet below the top. Excepting in the Dorr Field, wells do not produce much water with the oil. Recovery estimates vary from 1,000 to 2,700 barrels per acre, but much oil may be lost unless secondary recovery methods are employed. Lower formations have not been thoroughly tested but a porous dolomite in the top of the Detroit River formation may contain oil where the structure is favorable. Other structures may be located along known anticlinal trends.