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OIL AND GAS FIELDS OF MICHIGAN

A DISCUSSION OF DEPOSITIONAL AND STRUCTURAL FEATURES OF THE MICHIGAN BASIN

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Chapter I. OIL AND GAS STRUCTURES

PRINCIPLES OF OIL AND GAS ACCUMULATION

Although the fundamental principles that govern oil and gas accumulation are now rather common knowledge, it seems appropriate at this point to outline briefly some of these principles. The anticlinal theory of accumulation had its inception among American geologists in 1859, when T. Sterry Hunt[1] recognized in Ontario that there was a direct relationship between oil and gas pools and anticlinal folds. Independently, E. B. Andrews[2] in West Virginia, F. W. Minshall in Ohio, and H. Hoefer in Austria arrived at similar conclusions and added new evidence from the districts with which they were most familiar. During the period from 1859 to 1885, the theory was developed and elaborated until in the latter year, I. C. White[3] came out with a clear and concise statement of the principles which stamped him as the "father of the anticlinal theory".

The practical application of this theory that structure controls oil and gas accumulation was not greatly developed until the discovery of oil pools in the plains area of the Southwest. Drilling in the Mid-Continent region of Kansas, Oklahoma, Arkansas, Louisiana, and Texas was largely guided by studies of geologic structures, and the period from 1910 to 1920 proved to operating oil companies that the search for domes and anticlines was an important factor in reducing prospecting risks. A voluminous literature on structure and accumulation grew out of these studies, and the works of E. R. Lilley[4] and W. H. Emmons[5], and others have summarized the geology of oil and gas fields.

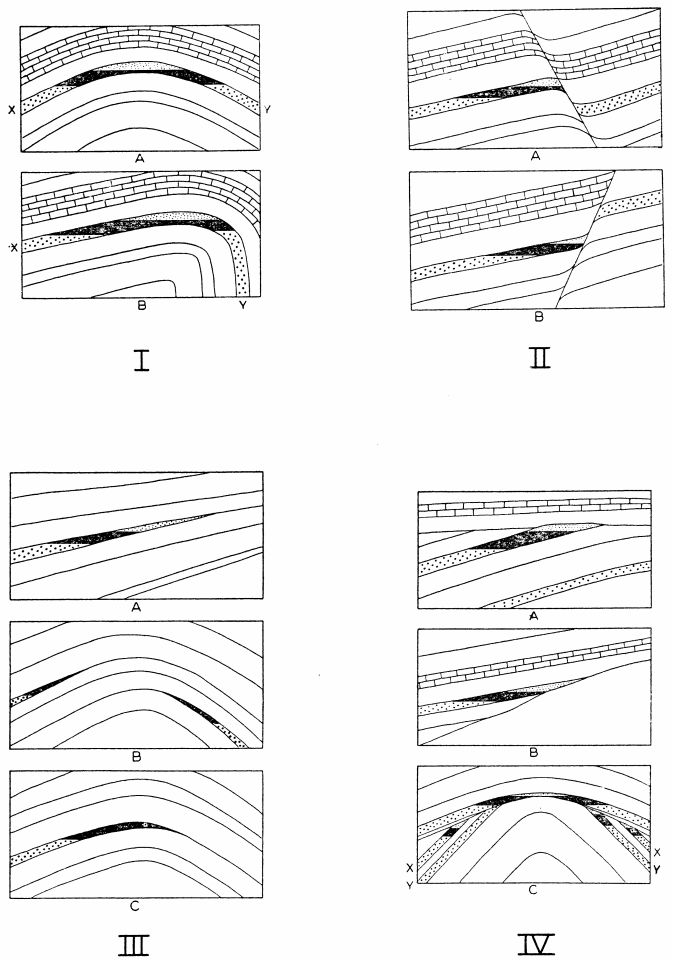

Figure 25. Generalized cross-sections of different classes of oil and gas producing structures (after Lahee).

The role of geological structure in the accumulation of oil and gas has been excellently and briefly stated by F. H. Lahee[6] in a recent article:

"An oil pool is strictly and wholly a geological phenomenon. It occurs within some kind of porous reservoir rock. It is definitely associated with some type of geological structure, which, in most cases, comprises strata inclined from the horizontal. It exists because, in its relations to this structure, the upward and lateral escape of the petroleum is prevented by impervious rocks which seal the reservoir. Within the reservoir the oil is commonly associated with gas and water. Gas occurs dissolved in the oil and if, under the conditions, there is an excess of gas, it may occur in a free state. These three fluids, water, oil and free gas, are distributed in the reservoir in the order of their specific gravities, the gas above or updip from the oil, and the water below or downdip from the oil. They are under the influence of certain forces of compression, due chiefly to the weight of the column of rock overlying the pool and to hydrostatic pressure within the reservoir rock, operating from some distant region. These several conditions which pertain to the oil pool, namely, the

geologic structure and the reservoir rock, the oil, gas and water, and the pressures acting on these fluids within the reservoir may be classified as rock factors, fluid factors, and energy factors, all of which are of primary importance. Together they constitute the geological framework of the oil pool.

". . . . . A majority of the known producing structures fall tinder one or another of these four classes: (1) Domes and closed anticlines; (2) fault structures; (3) lensing reservoir rocks; and (4) unconformities. In Figure 25 I is a dome in cross section. It may be symmetrical like A, or asymmetrical, like B. The arch may be relatively high or low. The main point is that any vertical cross section through the top will show the beds bent in an arch. Assuming that the reservoir rock, X, Y is uniformly porous throughout, oil, free gas, and water will be distributed in this type of structure as indicated.

"Figure 25 II illustrates cross sections of fault structures. Oil, gas and water are represented -in their usual relations. In A retention of petroleum is accomplished by downward bedding (drag) and sealing of the reservoir rock at the fault. In B, accumulation of oil and gas depends wholly on sealing of the reservoir bed in the fault, since the structural relations are such as to facilitate escape up the fault plane.....

"Figure 25 III shows three examples of lensing reservoir rocks. In A, the reservoir pinches out updip in a series of tilted beds. In B, pay sands pinch out on an anticline, but some distance below the crest. In C, the reservoir rock passes over the top of an anticline and pinches out downdip, but at a level higher than the water-oil contact on the structure.

"In Figure 25 IV are several conditions which may be encountered in association with unconformities ..... An unconformity is simply an old erosion surface, like our present land surface, covered up and deeply buried by a later series of deposits. In Figure 25 IVA, a porous reservoir bed is unconformably overlain by an impervious layer in the lower part of the younger rock series. In B, the reservoir rock is in the younger series. Its updip edge is sealed where it abuts against the uneven surface at the top of the older series. In Figure 25 IV C more complicated relations are shown. Bed X is capped by an impervious layer on each side of the anticline. Bed Y is similarly capped on the right, but on the left it is in contact with porous basement sand in the overlying series, thus permitting escape of oil and gas into this basement sand. For purposes of demonstration we may suppose that closure both above and below the plane of the sketch has allowed accumlation in bed Y on the right.*

"In the four figures outlining geologic structures, we have assumed that the reservoir rock is uniformly porous; but this is almost never true of pay beds in actual experience. In the first place the reservoir may be a true sand, composed of granular particles of quartz and other hard minerals, or it may be a limestone or a dolomite. Rarely it is some other kind of rock. Within a sandstone or a limestone or dolomitic reservoir the pore spaces may differ in size, in distribution within the rock, and in continuity. We need not go into the causes of these differences. The significant facts to bear in mind are that such variations in porosity are common and that they have a very definite bearing (1) on the distribution of oil and gas on a structure and (2) on the permeability of the reservoir rock.

"Permeability, in this connection, refers to the ability of the rock to yield the fluids within its pores. There is a most important distinction beween porosity and permeability. A fine sand composed of small grains of equal size and a coarse sand composed of large grains of equal size may both have the same porosity, or total pore space, but the permeability of the coarse sand may be many times that of the fine, due to the freer movement of fluids through the large open spaces. Permeability is sometimes called 'effective porosity'. The efficiency of the energy available within the reservoir is largely dependent on the permeability of the pay rock."

In discussing structure in the accumulation of petroleum, Clapp[7] has given eight criteria which he considers fundamental if a locality is to be geologically favorable for commercial oil pools:

"1. Are the rocks of sedimentary origin?

2. Is the age of the strata (in part at least) similar to that of oilfield strata in some known oil or gas field?

3. Does a possible source of origin exist? If this be not apparent, may it nevertheless be present?

4. Do porous beds or 'reservoirs' exist in which oil may be held in commercial quantity?

5. If so, does sufficient cover exist above the reservoir beds to prevent the oil or gas from escaping to the surface and being lost?

6. Are the strata so slightly metamorphosed by heat or pressure that the oil has presumably not been driven out?

7. Does 'geologic structure' exist suitable for concentrating oil in commercial quantity?

8. Are the hydrostatic conditions such as will not prohibit the accumulation of oil in pools?"

It will be observed at once from the discussion of both Lahee and Clapp that favorable structure is only one of the conditions that must be fulfilled before commercial pools of oil and gas can form. There must be a source, a reservoir, and a barrier to migration—these three additional factors are also necessary. Source rocks are generally shales dark in color but may be certain types of bituminous, fossiliferous limestones. Reservoirs are strata containing communicable openings and may be porous honeycombed limestones and dolomites, sandstones, or fractured rocks of any type. Barriers to migration may be any dense rock bed which prevents escape of the oil and gas into other rocks less porous than the reservoir bed or to the surface.

However, the search for oil and gas is still essentially a search for favorable structures. This is the starting point from which other types of geological investigation in oil finding must begin. The classification by Clapp[8] gives very fully the different kinds of structures in which oil and gas have been found:

"I. Anticlinal structures
  (a) Normal anticlines
  (b) Broad geanticlinal folds (or 'regional uplifts')
  (c) Overturned folds.
II. Synclinal structures
III. Homoclinal structures
  (a) Structural 'terraces'
  (b) Homoclinal 'noses'
  (c) Homoclinal 'ravines'
IV. Quaquaversal structures or 'domes'
  (a) Domes on anticlines
  (b) Domes on homoclines and monoclines
  (c) Closed salt domes
  (d) Perforated salt domes (or '*diapir*' structures)
  (e) Domal structures caused by igneous intrusions
V. Unconformities
VI. Lenticular sands (on any type of structure)
VII. Crevices and cavities irrespective of other structure
  (a) In limestones and dolomites
  (b) In shales
  (c) In igneous rocks
VIII. Structures due to faulting
  (a) On the up-thrown side
  (b) On the down-thrown side
  (c) Overthrusts
  (d) Fault blocks (or *horsts*)"

*In using any of these diagrams one should remember that they represent only one section across the structure. Vertical sections taken in other directions might reveal somewhat different relations.

OIL AND GAS STRUCTURES OF MICHIGAN

The concentration of explorations for oil and gas in areas where productive domes were discovered has locally furnished detailed subsurface structural information. The producing oil fields in Michigan are near Saginaw, Saginaw County; Mount Pleasant, Isabella and Midland counties; and Muskegon, Muskegon County. These fields are called the Saginaw Field, Mount Pleasant Field, and Muskegon Field. The center of activity at the present time is the Mount Pleasant Field where developments have spread out to include a district in central Michigan covering portions of several counties. This entire producing district has come to be known as the Central Michigan Area.

Oil in small quanties has been found near Port Huron, and Blaine, St. Clair County; Dundee, Monroe County; Howell, Livingston County; Owosso, Shiawassee County; Bannister, Gratiot County; Union, Cass County; Decatur, Van Buren County; Allegan, Allegan County; White Cloud, Newaygo County; Hart, Oceana County; Walhalla, Mason County; and Manistee, Manistee County. Gas wells have been found near Ashley, Gratiot County; St. Clair, St. Clair County; north and west of Mount Pleasant, Isabella County; near Clare, Clare County; Barryton, Mecosta County; Evart, Osceola County; and Walhalla, and Freesoil, Mason County. These showings of oil and gas have not yet been developed into large sized fields, but they indicate the widespread favorable structural conditions which may afford accumulations of commercial importance.

The largest known anticlinal structures which have not been adequately developed are the Howell structure, Livingston County, and the West Branch structure, Ogernaw County. The northwest and southeast trends of the known "highs" in Isabella and Midland counties are also areas where prospecting will be necessary to determine the location of new producing domes. The regional structural contour map drawn on the top of the Traverse formation (see pl. III) gives some idea of the possible extensions of proved structures. This map, although provisional in many details, may assist in guiding future "wildcat" drilling.

Some of the important characteristics of local anticlinal structures in Michigan are the small width (usually 1½ to 2 miles), the asymmetrical cross section, the steep dip generally toward the basinward side, the sharp cross-folding along the crest, the arcuate or "pistol-shape" outline, the irregular porosity of the "pay" zones, and the thinning or absence of Michigan, series (Lower Grand Rapids) and Napoleon (Upper Marshall) beds on the crest. The synclinal structures are wide and flat in comparison to the anticlines and thick deposits of gypsum in the Michigan series are concentrated in these "lows." Faulting has probably taken place along the steep side of some of the larger anticlinal structures.

The Port Huron, Deerfield, and Saginaw anticlines and the Allegan structure have been previously described[9] and geological maps of these districts have been published. Detailed progress maps for the Muskegon, Mount Pleasant, and Howell structures have been released in blueprint form by the Michigan Geological Survey, but the folds have only been partially described in published reports[10]. For this reason, these three districts will be discussed in detail.

[1]Hunt, T. Sterry, On some points in Chemical Geology: Canadian Nat., Vol. 4, pp. 414-425 (with additions) (1859).

_____, Notes on the History of Petroleum or Rock Oil: Canadian Nat., Vol. 6, pp. 241-245 (1861).

_____, Contributions to the chemical and geological history of bitumens and pyrochists or bituminous shales: Am. Jour. Sci., 2d series, Vol. 35, pp. 157-171 (1863).

[2]Andrews, E. B., Rock oil, its relations and distribution: Am. Jour. Sci., 2d series, Vol. 32, pp. 85-91 (1861).

[3]White, I. C., The Geology of Natural Gas: Science. Vol. 5, pp. 521-522 (June, 1885); Vol. 6, pp. 43-44 (July 1885).

_____, Petroleum and Natural Gas: West Virginia Geol. Survey, Vol. 1, pp. 167-175 (1899).

[4]Lilley. E. R., The Geology of Petroleum and Natural Gas: D. VanNostrand Company, Inc. (1928).

[5]Emmons. W. H., Geology of Petroleum: McGraw-Hill Book Co., Inc. (1931) 2d edition.

[6]Lahee, F. H., Importance of Geology in New Conception of Unit Pool Development: Oil and Gas Jour., Vol. 31, No. 2, pp. 38, 39 (June 2, 1932); Oil Weekly, Vol. 65, pp. 27-29 (June 6, 1932); Am. Pet. Inst. Production Bull. No. 209, Proc. A. P. I., pp. 4-7 (June 1932).

[7]Clapp, F. G., Fundamental Criteria for Oil Occurrence: Bull., Am. Assoc. Pet. Geol., Vol. 10, pp. 1227-60 (1926).

_____, Role of Geologic Structure in the Accumulation of Petroleum: Structure of Typical American Oil Fields; A Symposium; Vol. II, pp. 669-670 (1929).

[8]Clapp, F. G. The Use of Geological Science in the Petroleum and Natural Gas Business: Proc., Eng. Soc. W. Pennsylvania, Vol. 26, pp. 87-120 (1910).

_____, Revision of the Structural Classification of Petroleum and Natural Gas Fields: Bull., Geol. Soc. America, Vol. 28, pp. 553-602 (1917).

_____, Role of Geologic Structure in the Accumulation of Petroleum: Structure of Typical American Oil Fields. A Symposium, Vol. II, pp. 671, 672 (1929).

[9]Smith, R. A., The Occurrence of Oil and Gas in Michigan: Michigan Geol. & Biol. Survey. Pub. 14, Geol. Ser. 11, pp. 50-67; 170-176; 126-135 (1912).

Newcombe, R. B., Oil and Gas Development in Michigan: Michigan Geol. Survey, Pub. 37, Pt. 3, pp. 166-186; p. 203 (1928).

Carlson, C. G., Geology of the Saginaw Oil Field, Michigan, and a Discussion of Michigan's Oil Prospects: Bull., Am. Assoc. Petroleum Geologists, Vol. 11, No. 9, pp. 359-365 (1927).

[10]Newcombe, R. B., Op. cit., pp. 215, 255.

Chapter II. MUSKEGON STRUCTURE

INTRODUCTION

The Muskegon structure is in the west-central part of Muskegon County, which borders Lake Michigan about one hundred miles from the south line of the State. The highest part of the fold is on the north side of Muskegon Lake, a large harbor extending inland 4 miles long east and west. The producing structure extends around the northeast corner of the lake in an arcuate fashion and has a length of approximately 6 miles. The region of the dome is confined to Muskegon and Laketon townships, and a part of the field is within the city limits of North Muskegon.

The city of Muskegon is accessible to Chicago by rail, water, and excellent paved roads. Direct connections may also be made with Grand Rapids and Detroit by the Pennsylvania and Grand Trunk Western lines. Three different paved highway routes lead to Grand Rapids, which is 40 miles away. According to the 1930 census, Muskegon had a population of 41,390, but "Greater" Muskegon, including suburban cities, has more than 58,000 inhabitants. Cultural facilities are entirely adequate for the needs of a growing industry. The city is the county seat and the location of several important manufacturing plants, including the Continental Motors Corporation and the Brunswick-Balke-Collender Manufacturing Company.

PHYSIOGRAPHY

The area of the Muskegon structure is included in the Muskegon, Twin Lake, and Montague topographic quadrangle sheets, which were surveyed in 1929, soon after the oil field was discovered. The base for these maps was compiled from airplane photographs and ground control. These photographs show many of the features of the oil field and the base map used for subsurface structural contours has been corrected in conformity with the aerial pictures.

The topography shows 70 feet of relief, with well elevations ranging from 586 to more than 650 feet. The immediate region of the oil field is relatively flat, the variation in relief being caused entirely by a terrace, which has an elevation ranging from 40 to 50 feet above the level of Muskegon Lake and the valley flat formed by the flood plains of Muskegon River and Cedar Creek.

The surface of the region is almost entirely composed of sandy lake beds which form poor soils and the land is only infrequently farmed. The valley flat is mucky and celery raising is carried on locally. The only hills of the region are the high dunes which form an almost continuous scalloped topped sandy ridge that fringes the Lake Michigan shore.

The land is not heavily timbered. The typical growth consists of scrub oak which is in some places very thick. There are also a few small coniferous second growth trees. The side roads are generally sandy, but the main roads are in good repair and suitable for heavy trucking.

HISTORY

At one time Muskegon was the leading lumber center on the west side of Michigan. Early drilling operations in the State were largely fostered by the lumber industry, because the waste material from the saw mills afforded ready fuel for the evaporation of brines in the manufacture of salt. Rominger[1] records in 1876 that several deep borings had been made in Muskegon and mentions that the Whitney well was 1,230 feet deep. Lane[2] states that this same boring was the oldest in the community and that it possibly reached 1,600 feet. Rominger[3] comments that another hole at Muskegon penetrated to 2,627 feet, the deepest well in the State at that time. The drill never reached sufficient depth in these first operations to strike rock salt; therefore, the attempts were fruitless.

Several of the first wells, including the Mason well drilled during 1872-1875, were described by Lane, who mentioned the discovery of small quantities of oil in the region. At that time, Lane[4] recognized the flattening of the dip indicated by the Ryerson well at the east end of Muskegon Lake. In 1903, Lane[5] again mentioned the structural irregularities in the vicinity of Muskegon and suggested the possibilities of oil and gas in the Dundee

horizon in an anticline which might exist in the area north across the lake. In these recommendations, he was fundamentally correct, but the sections mentioned (Secs. 15 and 16, Laketon township) were proved later unproductive. Geological conditions and oil possibilities at Muskegon were further discussed by Smith[6] in 1914.

The discovery well in the field (Chas. Reeths No. 1, NW.¼ NW¼ sec. 9, T.10N., R.16W.) was located by Hugh D. Crider, then resident geologist for the Dixie Oil Company, Inc. This well came in on December 8, 1927, at 1,640 feet in the upper part of the Traverse formation, making 494,000 cubic feet of gas per day. On December 21, deepening was continued and an initial production of 300 barrels of oil per day resulted. The ensuing field was developed rapidly[7] and in 1928 a more prolific oil horizon was discovered in the Dixie Oil Company's A. and O. Becker No. 1, SE.¼ SW.¼ sec. 4, T.10N., R.16W., from porous beds considered by many to be of Dundee age. The large producing oil and gas wells obtained from this formation brought many operators to the scene of development and by August, 1929, the field had reached its peak of production of 18,570 barrels daily. In May, 1932, the average production of the Muskegon district had declined to 1,160 barrels per day. The largest oil well produced about 3,000 barrels daily and the largest gas well had an initial flow of over 25,000,000 cubic feet.

STRATIGRAPHY

The rock formations penetrated in wells in the Muskegon field include beds ranging from the Lower Marshall formation of Mississippian age to the St. Peter sandstone of Ordovician age, encountered at a depth of 4,710 feet. The upper formations to about 2,050 feet are best known because most of the wells do not go below this depth. This section, as previously described[8], is as follows:

"The record of the discovery well drilled by the Dixie Oil Company on the A. and O. Becker farm (Fig. 26) may serve as a type section for the Muskegon area. Generalized data furnished by other wells in the field are included in this figure in order to show variations in thickness and conditions peculiar only to certain wells. The bedrock is covered by 190 to more than 300 feet of glacial drift, which consists largely of lake clay and dune sand. The first beds encountered are the fine-grained gray and pink sandstones of the Lower Marshall formation. This formation is everywhere water-bearing, and the water is usually brackish.

"The Lower Marshall sandstone is underlain by the blue-gray shales and calcareous shales of the Coldwater formation. One calcareous phase of the Coldwater is a gritty granular limestone, which is persistent throughout the field at a depth of about 270 feet below the top of the formation. At many places, it contains oil and gas and here and there some water. In the lower part of the Coldwater there is a bed of red, shaly fossiliferous limestone, which can be so easily recognized that it is the most useful horizon marker in the field. It has not yet yielded determinable fossils. Oil and gas are found in considerable quantities at this horizon in some parts of the producing area.

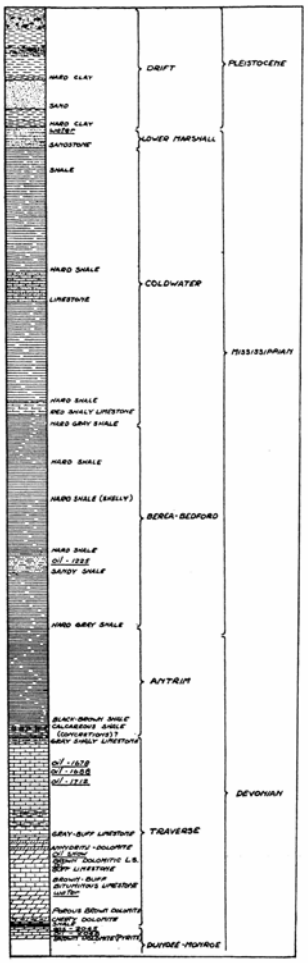

Figure 26. Typical well record in Muskegon oil field. (Dixie Oil Company's A. and O. Becker well No. 1, sec. 4, T.10N., R.17W., Muskegon township, Muskegon County. Elevation 631.8 feet).

"The Berea can not be definitely identified at Muskegon. The varicolored greenish gray and gray beds of sandy shale found about 30 feet below the red limestone probably represent beds nearly equivalent to the Berea-Bedford (*Ellsworth shale*) of eastern Michigan. In their porous parts in the Muskegon field, they contain small quantities of oil. Near the bottom of the group, these beds become less sandy and their color changes to a darker gray.

"The Antrim shale, which overlies the Traverse, is usually considered Upper Devonian, but the exactness of this correlation is still in controversy. The formation, consists of brown and black pyritous shale containing abundant *Sporangites huronensis*. A concretionary zone near the bottom of the Antrim shale generally logged by drillers as limestone is probably nearly equivalent to a like zone observed at Kettle Point, in Ontario; at Paxton, in Alpena County; and at Norwood, in Charlevoix County, Michigan.

"The Traverse group at Muskegon includes an average of about 430 feet of strata. Of this thickness, 60 to 70 feet should be classified as Upper Traverse (Thunder Bay), 200 to 210 feet as Alpena-Petoskey limestone, 160 feet as Lower Traverse, (Long Lake), and from 5 to 10 feet as Bell shale. The Bell shale is at many places split into two beds by a layer of limestone from 3 to 12 feet thick. At the top of the Lower Traverse, there is a 30-foot bed of anhydrite and dolomite. This bed was probably formed at the end of Long Lake time, when the sea was shallow and the land was a desert in which there was considerable evaporation and consequent concentration of sulphate. The re-working of the Monroe-Salina deposits may also have contributed to this concentration.

"The oil-bearing beds include one (20 to 30 feet thick) in the Alpena-Petoskey limestone; one at the top of the Lower Traverse, below the bed of anhydrite; and one (ranging in thickness from a few inches to several feet) below the base of the Bell shale. The water-bearing beds are associated with the oil-bearing beds and are also about 100 feet below the top of the Lower Traverse.

Location: NE. ¼ of NE. ¼ sec. 8, T. 10 N., R. 16 W., Muskegon County. Permit No. 309. Elevation: 636 feet above sea level. Drilling Contractor: Buckeye Drilling Co. and K. S. & W. Drilling Co. Record compiled by O. F. Poindexter and R. B. Newcombe from driller's log and samples. Completed to "Dundee" March 29, 1929; began deepening August 6, 1930; completed as dry hole February 27, 1931. Casing: 245 feet of 12½; 335 feet of 10; 2,231 feet of 8¼; 4,675 feet of 6⅝-inch.

Formation.	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene:		
Sand	245	245
Mississippian:		
Lower Marshall and Coldwater Formations:		
Shale, blue	355	600
Limestone	50	650
Shale, blue	201	851
Limestone, red	20	871
Ellsworth Formation:		
Shale, blue	309	1,180
Sandstone, limy	10	1,190
Shale, blue	62	1,252
Shale, blue	128	1,380
Devonian:		
Antrim Formation:		
Shale, brown	220	1,600
Traverse and Dundee Formations (Undivided):		
Shale, light	47	1,647
Limestone	53	1,700
Limestone	75	1,775
Limestone, gray	165	1,940
Limestone	60	2,000
Shale	5	2,005
No record	8	2,013
Shale	3	2,016
Shale and limestone	2	2,018
No record	5	2,023
No record	15	2,038
Detroit River (Upper Monroe) Formation:		
Dolomite, brown	32	2,070
Dolomite, light brown	30	2,100
Dolomite, buff gray and brown, sandy	6	2,106
Dolomite, light brown	54	2,160
Dolomite, buff, brown and gray; little anhydrite	40	2,200
Dolomite, brown and gray; little anhydrite	20	2,220
Dolomite, brown and brownish buff, variegated	15	2,235
Dolomite, light brown (show gas 2,244—2,265)	35	2,270
No sample	3	2,273
Dolomite, gray; anhydrite	8	2,281
Dolomite, brown; anhydrite	19	2,300
No sample	10	2,310
Dolomite, brown; anhydrite	20	2,330
Dolomite, limy, brown and buff	5	2,335
Dolomite, gray and light brown; anhydrite	10	2,345
Dolomite, brown and buff	10	2,355
Anhydrite; little gray, buff and brown dolomite	73	2,428
Anhydrite; buff, gray and brown dolomite	27	2,475
Dolomite, buff; anhydrite	5	2,480
Anhydrite; brown, variegated dolomite	15	2,495
Dolomite, brown, variegated; anhydrite	45	2,540
Dolomite, brown, variegated	35	2,575
Bass Island (Lower Monroe) Formation:		
Dolomite, gray, argillaceous	25	2,600
Dolomite, gray, argillaceous; a little pink gypsum	30	2,630
Dolomite, gray and brown, argillaceous; little anhydrite	15	2,645
No sample	5	2,650
Dolomite, gray, argillaceous; little anhydrite	5	2,655
No sample	5	2,660
Dolomite, brown and gray; little anhydrite	15	2,675
Dolomite, brown and gray; argillaceous	20	2,695
Dolomite, gray and brown, argillaceous; a little gypsum and anhydrite	15	2,710
Dolomite, brown and gray	20	2,730
Dolomite, gray and brown, argillaceous	60	2,790
Dolomite, gray and brown, argillaceous; little pink gypsum	25	2,815
Dolomite, gray and brown, argillaceous; with a little reddish dolomite and pink gypsum	25	2,840
Dolomite, gray, argillaceous	5	2,845
Dolomite, brown and gray, variegated, argillaceous	40	2,885
Salina Formation:		
Salt	45	2,930
Dolomite, brown and gray	10	2,940
Limestone, light brown	15	2,955
Limestone, brownish buff	10	2,965
Limestone, brown	5	2,970
Limestone, dark gray brown, semi-lithographic	65	3,035
Dolomite, gray, argillaceous	20	3,055
Limestone, gray, buff and brown, argillaceous	25	3,080
Salt	260	3,340
Dolomite, brown to dark brown (show oil 3,370-3,375)	50	3,390
Salt	200	3,590
Limestone, brown, salty	5	3,595
Limestone, brown, variegated (show oil 3,601)	5	3,600
Limestone, buff gray and brown	10	3,610
Limestone, buff gray	5	3,615
Burnt Bluff Formation:		
Limestone, buff gray with red oolites (?)	35	3,650
Limestone, buff gray	30	3,680
Limestone, buff gray and dark red	15	3,695
Limestone, dark red and buff gray	5	3,700
Limestone, dark red, buff and dark gray	15	3,715
Limestone, buff, gray and dark red	5	3,720
Limestone, buff, brown, dark gray and red	5	3,725
Limestone, brownish gray and light gray	5	3,730
Limestone, buff to brownish gray, to grayish brown cherty	45	3,775
Limestone, grayish brown	15	3,790
Limestone, grayish brown and gray shaly	15	3,805
Mayville Formation:		
Limestone, dolomitic, grayish buff to grayish brown	5	3,810
No sample	5	3,815
Limestone, dolomitic, buff to brown	5	3,820
Cataract Formation:		
Cabots Head Shale Member:		
Shale, dark red ferruginous	15	3,835
Shale, dark red ferruginous and gray	10	3,845
Manitoulin Member:		
Shale, gray	5	3,850
Shale, gray; dolomite, gray shaly	70	3,920
Dolomite, gray shaly and white	25	3,945
Dolomite, gray shaly and white, sandy; shale, gray	10	3,955
Dolomite, gray shaly, white, and brown crystalline	5	3,960
Dolomite, brown, crystalline	15	3,975
Ordovician:		
Cincinnatian Series (Undivided), Richmond in part:		
Dolomite, brown crystalline, and hard sandy dolomite	5	3,980
Dolomite, hard gray sandy	5	3,985
Dolomite, hard gray, sandy; gray shale	5	3,990
Shale, hard gray; and hard gray dolomite	20	4,010
Dolomite, gray; shale, gray	10	4,020
No samples	15	4,035
Dolomite, gray; shale, gray	25	4,060
No sample	20	4,080
Shale, gray; dolomite, gray	30	4,110
Shale, gray; some gray dolomite	25	4,135
No samples	30	4,165
Shale, gray	65	4,230
Utica Formation:		
Shale, darker gray	85	4,315
Trenton Formation:		
Dolomite, brown; shale cavings	5	4,320
Limestone, brown dolomitic	5	4,325
Limestone, brown	15	4,340
Limestone, brown, variegated; shale cavings	25	4,365
Limestone, brown, variegated	165	4,530
Limestone, gray brown, variegated	30	4,560
No sample	5	4,565
Limestone, brownish buff to brown	10	4,575
Limestone, brown and buff	5	4,580
Limestone, brownish buff to brown (water at 4,575—2,500 feet in hole)	15	4,595
Limestone, light brown; no sample	5	4,600
Limestone, gray and white; no samples	68	4,668
Limestone, brown; no samples	17	4,685
Limestone, brown and black sandy	25	4,710
St. Peter Formation:		
Sandstone, white (hole full water)	25	4,735
Total depth		4,754

Table VIII. Log of Muskegon Oil Corporation's (Muskegon Deep Well Syndicate's) H. Heinz No. 5.

"The base of the so-called Dundee has not been distinguished clearly enough to show accurately the thickness of that formation, which is probably variable but may at some places reach 20 or even 30 feet. It was once supposed that the water found about 100 feet below the top of the Lower Traverse (see fig. 26) represented the base of the Dundee, and that the Bell was absent, but studies covering a wide area, a close observation of the pay horizon, and the discovery of some fossils in the Bell shale furnish evidence that is strongly adverse to this supposition. It is possible, however, that the lowest fossiliferous productive bed beneath the Bell shale may be the Anderdon limestone, of Detroit River age."

The deeper rocks in the Muskegon district are known from the well drilled by the Muskegon Deep Well Syndicate in 1930 (see table VIII). This boring encountered gas in a horizon of the Detroit River dolomite at approximately 200 feet from the top of the formation. The top of the Salina salt was penetrated at 2,885, the top of the Niagaran series at 3,600, the Trenton limestone at 4,315, and the hole was abandoned at a total depth of 4,754 feet. A showing of oil occurred in the Salina dolomite beds at 3,370, and in the Manistique formation at 3,601 feet, brine in the

Trenton limestone at 4,575, and in the St. Peter sandstone at, 4,735 feet.

STRUCTURE

General Features—Muskegon County is on the west side of the Michigan synclinal basin, where the general regional dip is northeastward. The approximate strike of the beds is N.40°W., although in the northwest corner of the county the strike veers almost to north. The district is evidently in a broad regional syncline which is marginal to the larger basin including the entire southern peninsula of Michigan. This regional syncline causes the dip of the rocks to change from northeast in the southern part of the county to east in the northern part. The Muskegon anticline seems to be a product of the structural factors which control the change in the direction of the regional dip.

As rocks are not exposed in Muskegon County, our knowledge of conditions of structure is based on subsurface data obtained from drilling. Two contour maps have been prepared to show the size and outlines of the anticline in the vicinity of the city of Muskegon. In the first of these, (see fig. 27), the persistent fossiliferous shaly red limestone in the lower part of the Coldwater strata is used as the key bed. This bed is present throughout the field and, though in few places no more than 20 feet thick, it can be recognized easily. The discovery of the field resulted from deductions made from comparisons between wells with this horizon as a basis.

"Coldwater" structure—The anticline is elongated east and west, although the axis or top of the fold is an arc which bends southeast. There are several small domes on the fold, and the amount of closure is between 60 and 70 feet. The steeper flank of the structure is on the northeast side. It has a maximum dip of slightly over 100 feet per mile, and the other limb dips approximately 50 feet per mile.

The highest part of the Muskegon anticline is in sections 8 and 9, Muskegon township, near the intersection of two axes of folding. The arch with the northwest-southeast axis shows the sharpest dip and is probably the controlling feature. The east-west axis is narrow and this cross fold probably trapped the largest quantity of oil, as shown by the more productive wells on the west side of the structure. The largest Dundee gas wells were on the highest parts of the structure, but local porosity determined some of the largest Traverse wells.

The numerous sharp reentrants shown by the structural contours indicate that secondary movement occurred along the crest of the fold. The regularity of the occurrence of these reentrants suggests a relation to jointing or faulting. At first they were considered to be the product of erosion at a surface of disconformity. The persistence of these features through the deeper beds, however, suggests that they may have been caused along the directions of prominent joints by slump faults resulting from solution of rock salt in the Salina formation beneath. Structure of this type has been observed in many places in New York.

"Dundee" structure—The structure in the Devonian rocks conforms closely with that of the Mississippian beds above. The Muskegon anticline, contoured on the base of the Bell shale or the top of the so-called "Dundee" formation, is shown in Figure 28. The similarity between this map and the previous one on the "Red bed" is striking. The sharp reentrants do not correspond exactly, but their direction is very similar. The highest parts of the structure are nearly the same, and the dips are about the same intensity on the northeast limb. The dips on the south side of the anticline are somewhat steeper than shown by the contours drawn on the top of the Coldwater red horizon. This apparent sharpening of folding in the deeper beds may be due to the recurrence of deformation along the same axis and possibly to some compaction of the beds. The structural closure in the "Dundee" beds is not much more than 60 feet. This suggests that the steepening of the fold in the deeper rocks is only local and that there is actually very little difference between the effects of deformation in the Mississippian and the Devonian strata.

"Niagaran" structure—There is a pronounced change in the amount and localization of folding beneath the Salina beds. The nature of this change is not known because only two wells have been drilled deep enough to go through the Salina section. One of these wells (K. Savacool No. 1, SW.¼ SW.¼ sec. 2, T.10N., R17W., Laketon township) is low on the "Dundee" structure, and the other (H. Heinz No. 5, NE.¼ NE.¼ sec. 8, T.10N., R.16W., Muskegon township) previously described, is structurally high, as shown by comparing the "Dundee" elevations. In spite of the fact that the Heinz well is 60 feet higher than the Savacool well, as contoured on the "Dundee," (see fig. 28), the Niagaran beds are 60 feet lower, making a total difference of 120 feet in structural elevation. The correct explanation of this change of structure with depth is of vital importance in problems of the persistence of folding beneath the Devonian rocks elsewhere in Michigan.

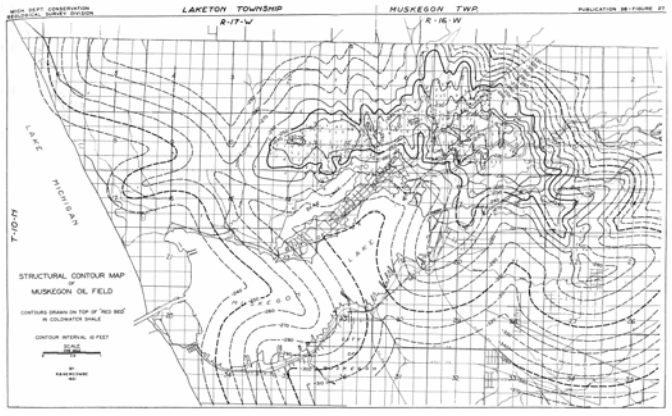

Figure 27. Structural contour map of Muskegon field drawn on top of red bed in Coldwater shale. Contour interval 10 feet.

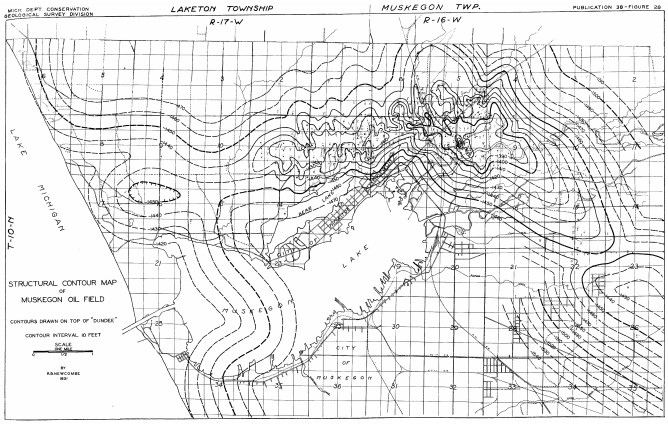

Figure 28. Structural contour map of Muskegon field drawn on top of “Dundee” formation. Contour interval 10 feet.

The thick salt beds and important stratigraphic "breaks" between the "Dundee" and Niagaran rocks probably explains the structural discrepancy, but several hypotheses might possibly account for the change with depth. These include the following:

1. The mechanical adjustment of structure with depth because of the thickening of the Monroe-Salina rocks, including the salt beds, toward the center of the "basin." This condition might cause a shallow fold to be represented in the lower beds by a terrace or plunging nose with insufficient closure to trap any oil and gas. It might also shift the anticline one way or another in the deeper rocks.

2. The deposition of sediments over a hill formed during an erosion period in some of the beds above the Salina. This hill might result either from erosion of the beds themselves or solution of the rock salt beneath. The natural dip of the beds away from the hill would be sufficient to form a dome or anticlinal structure, but differential settling around and over the hill would increase the height of the structure. This theory would account for the seeming absence of the fold at depth and the thinning of the salt beds off the flanks of the structure.

3. The existence of a fault beneath one of the formational "breaks" between the Dundee limestone and the Niagaran series. The resulting escarpment would probably be on the downthrown side of the fault and the topographic ridge would be structurally low rather than high. Deposition over this ridge might cause a fold which would be synclinal on the upthrown side of the fault.

4. The solution of salt along planes of faulting and fracturing at some time after salt deposition, but before the overlying load was very great and the beds were sufficiently competent to hold cavities. This process might result in a slight arching which would increase in intensity by the additional amount of solution.

5. Flowage of relatively weak incompetent salt beds as the result of the folding of competent beds above, thus accounting for the thickening of the salt series "on structure" and the decrease in the amount of folding at depth. If the salt beds accommodated themselves to the warping by flowing rather than bending, the structural disturbance occurring beneath the salt would be different from that above it.

Lane[9] has also suggested the possibility that, in the warping of the strata, they acted like a downward bent beam in which the upper beds were slightly folded due to compression while the lower beds were in tension; thus, less affected. The first hypothesis seems more plausible. Theories 2 and 3 give conditions requiring a compaction fold in the shallow rocks in which folding increases in intensity at depth. The two structure maps (see figs. 27 and 28), showing approximately the same amount of closure in the Mississippian and Devonian rocks, suggest that the deformation is not due wholly to compaction. This evidence tends to refute theories 2 and 3. The conditions of theory 4 would result in secondary faulting, for which some proof exists, but the conditions of the hypothesis are so exacting that the theory seems untenable. The circumstances required by theory 5 probably exist to a certain extent. The "salt plugs" of southeastern Utah and southwestern Colorado show some of the conditions[10] resulting from the sharp arching of strata containing salt beds. Nevin[11] states that salt layers observed in the mines near Ithaca, New York, show ample evidence of the flowage of salt, and the formation acts as a very plastic, incompetent bed. Gliding planes parallel with the faces of some of the crystals are present in the rock salt obtained from Michigan at the Oakwood mine of the Detroit Rock Salt Company. These facts seem sufficient evidence to show that some flowage has probably occurred. The presence of thick competent beds of dolomite beneath the salt and the gentleness of the folding seem to discount the significance of the explanation given in theory 5.

The thickening of the salt beds and the Silurian-Devonian rocks from Muskegon into the central part of the Basin area is very great. The rate of thickening of these beds between the two Muskegon County wells (K. Savacool No. 1 and H. Heinz No. 5) practically accounts for the loss of structure in the deeper beds. The general change in attitude of the lower strata caused by disconformity and overlap apparently explains the absence of folding in the deeper rocks similar to that in the shallower formations.

Muskegon County is close to the border of the salt-bearing rocks and this region in post-Salina time must have been an area of great solution and slumping. This may explain the change in the strike of the rocks across the county. The east-west down warp in the northern part (see pl. III) suggests some relation between the regional structure and the south border of the region underlain by Salina salt beds.

Comparison with other Michigan folds—The generalized features of the Muskegon anticline are similar to those of most of the other domes found in the State. The major axis, almost parallel with the regional

strike, the steep dip on the basinward side of the arch, and the wide comparatively flat-bottomed syncline adjoining are features typical of Michigan folding. The sharp northeast dip is similar in intensity to that on the southwest flank of the Saginaw structure in eastern Michigan. A strong narrow east-west cross fold on the gentler dip side of the dome is also found on the Mount Pleasant structure in Greendale township, Midland County, central Michigan. (See pls. IV and V.) The northwest-southeast axis of the structure is parallel with the trend of other folds in the State and suggests that this direction is the more important of the two lines of folding which contributed to the formation of the dome. The occurrence of large quantities of gas is typical of anticlines near the margin of a major basin. Greater earth pressures because of nearness to the old rising land mass of the "Wisconsin Island" may have also aided in the formation of the relatively large quantities of gas in this field. Another explanation would be the possible long distance up dip migration of the gas in the "Dundee" reservoir rock which pinches out westward until it is absent at Milwaukee.

WATER CONDITIONS

The chemical properties of the oil field waters from Muskegon show some interesting comparisons. In Table IX, the "Dundee" brines in general have a higher concentration of total solids than the shallower Traverse brines, but the deep waters from the Trenton and St. Peter horizons are less concentrated than those from the "Dundee." The total solids in ten samples range from 253,000 to 415,000 parts per million and the specific gravity in five of them from 1.181 to 1.200. A certain composition-depth relationship seems to persist as in the brines from other parts of Michigan. (Compare table XV). The chemical composition of waters in the deeper horizons show a downward increase in calcium and magnesium, a decrease in sodium plus potassium, and an increase in both bromine and iodine. According to the analyses of brines from other parts of the State, potassium would probably also show an increase if it were calculated separately from sodium. A few of the samples are radioactive and some contain small quantities of strontium. The primary salinity of the brines varies from 60 to about 80 percent, secondary salinity from 20 to 30 percent, chloride salinity usually over 99 percent, and primary alkalinity normally less than 1 percent.

The edgewater in the "Dundee" followed up the sides of the structure with the depletion of the oil and gas, and coning sometimes resulted where large wells were produced at full capacity. In some places along the margin of the field, the water drive exercised a certain amount of pressure control over the remaining gas in the reservoir because the rock pressure in a few edge wells toward the end of the decline was higher than normal. The water encroachment did not take place regularly up the flanks of the structure because the porosity of the limestone was irregular and the water followed the more porous channels. During the early life of the field the water level, however, was comparatively uniform. On the south edge of the structure, it stood at about 1,459 feet below sea level and, before extensive encroachment set in, it was from -1,453 to -1,462 feet on different sides of the producing district. Later, after the decline of pressure from "pulling" the wells had brought about channeling and abnormal water conditions, it was from -1,433 to -1,448 feet. Regionally higher on the west side of the structure, several wells penetrated water in the "Dundee" at -1,444 to -1,450 feet.

	1	2	3	4	5	6	7	8	9	10
Total Solids	260,000	257,000	400,000	365,280	333,800	348,920	415,000	253,000	276,000	272,000
Specific Gravity			1.200	1.197			1.200		1.188	1.181
SiO_2			104				160			
Fe_2O_3	5.0			86	42		0.4			
Ca	17,340	19,510	28,600	25,700	28,250	27,650	29,200	23,810	36,000	33,000
Mg	3,730	4,260	5,600	5,450	1,120	1,058	5,900	4,620	8,360	6,280
Na+K	76,038	72,012	63,400	104,000	77,266	93,000	75,700	65,006	54,627	59,385
Cl	158,000	157,000	164,000	222,000	172,000	195,000	185,000	154,600	172,000	168,000
SO_4	201	277	411.4	366	675	403	321	282	422	390
HCO_3	14	23	82	33.5	80	102	58	38	48	28
CO_3							48			
Bromine	630	580						600	1,293	1,228
Iodine	1	1						1	5.8	6.3
Strontium	580	610						670		

1. Johnson Oil Co.—Cihak No. 1—Upper Traverse water
2. Muskegon Pipe Line Co.—Cook No. 1—Upper Traverse water
3. Johnson Oil—Adams No. 1—Dundee Water
4. Reed Oil—Torrent No. 1—Dundee water
5. Goldboss—Marquart No. 1—Dundee water
6. Dixie Oil Co.—Becker No. 1—Dundee water
7. Johnson Oil—Savarcool No. 1—Dundee water
8. Johnson Oil—Grotefeld No. 1—Dundee water
9. Muskegon Deep Well Synd.—Heinz No. 5—Trenton water
10. Muskegon Deep Well Synd.—Heinz No. 5—St. Peter water

*Analyses shown in parts per million.

Table IX. Oil Field Brines of Muskegon Field.

OIL AND GAS DEVELOPMENT

The Muskegon field is now in the last stages of development. Drilling operations largely include deepening of old wells to the later discovered gas horizon in the Detroit River (Upper Monroe) formation. The productive horizons, in the order of their importance, are the "Dundee," Upper Traverse, Lower Traverse, and Upper Monroe porous members. These "pay" zones are entirely in limestones or dolomites, and most of the porosity probably has been formed by solution below surfaces of disconformity.

The limits of production in the field may be determined from Figure 29; which shows graphically the areas where oil and gas were obtained from the different horizons. The continuity of "Dundee" porosity evidently is much greater than that of the other "pay" zones. The Upper Traverse areas seem to be in small patches which strongly suggest that local factors determine the porous parts of the formation.

The field was extensively over-drilled because town-lot subdivision permitted unusually close spacing of the wells. The acre yield is comparatively small because of early loss of gas pressure and the rapid edge-water encroachment. On January 1, 1933, the Muskegon pool had produced 2,072 barrels per acre, and until accelerated late in 1932 by the use of acid, the yield was being increased at the rate of about 10 barrels per acre per month. Its yearly output was 1,928 barrels in 1927; 334,601 barrels in 1928; 3,157,668 barrels in 1929; 1,297,962 barrels in 1930; 531,147 barrels in 1931; and 478,728 barrels in 1932. The fluctuation of both oil and gas production is shown on the graph in Figure 30, and the decline curve of the "Dundee" rock pressure has been added for comparison. The monthly peak of gas production was reached in March, 1929, with

427,863,671 cubic feet, (measured on an 8 ounce basis), and the highest monthly output of oil was 557,140 barrels in August of the same year.

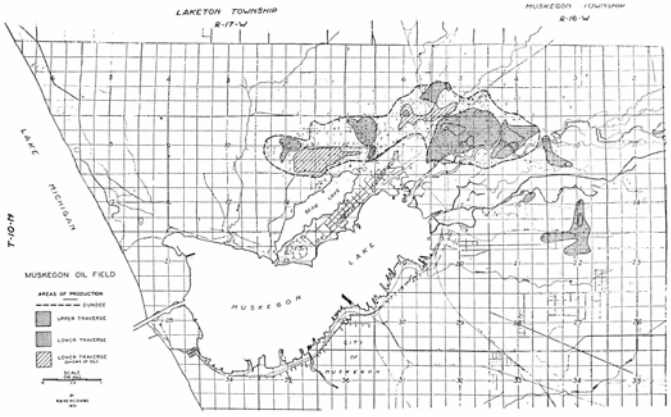

Figure 29. Map of Muskegon field showing approximate limits of areas of production from different producing horizons.

The gas withdrawals from the Muskegon field were somewhat uniform, considering the normal decline of the pool. The large percentage of industrial users probably contributed to this condition. However, the pipelines were not common carriers and due to the different capacities and individual demands of the lines, the various wells were not pulled regularly or uniformly. After the field was practically depleted, the percentage withdrawal of gas from individual wells was restricted by law, but this action came too late to stop the wasteful and uneconomical development of the area. The reserves of gas in the "Dundee" were calculated to be 3,760,000 cubic feet per acre, but because of careless operation, blowing of gas into the air, and waste of gas in the production of oil, the total actual recoveries for all pay horizons did not reach this figure. On the basis of 2,800 acres in the pool, only about 2,493,000 cubic feet of gas per acre for all horizons had been produced and sold up to January 1, 1933.

Four pipelines have transported gas out of the Muskegon field for use in the city. The Muskegon Gas Company line, consisting of 5.7 miles of 8, 6, and 4 inch pipe, delivered gas to domestic consumers in Muskegon for two and one-quarter years. The Continental Motors Corporation operated a 6 inch line during the boom period from the field to their plant on the southeast side of Muskegon Lake. The third line, built by the Muskegon Pipe Line Company, was made up of 6.9 miles of 10, 8, and 6 inch. The largest and longest line still in operation belongs to the West Michigan Consumers Company, whose distribution system includes, together with a treating and compressor plant, 10.7 miles of 12, 8, 6, and 4 inch pipe line. The pipeline transportation system for oil includes two principal lines built by the Stanolind Oil and Gas Company and the Simrall Pipeline Company. These lines lead from leases in the field to 30,000 and 55,000 barrel storage tanks near the Muskegon Sanitorium, thence to the Old Dutch Refinery on the east side of the city, and to loading docks on Muskegon Lake. The Simrall pipe line and storage has recently been taken over by the Old Dutch Construction Company.

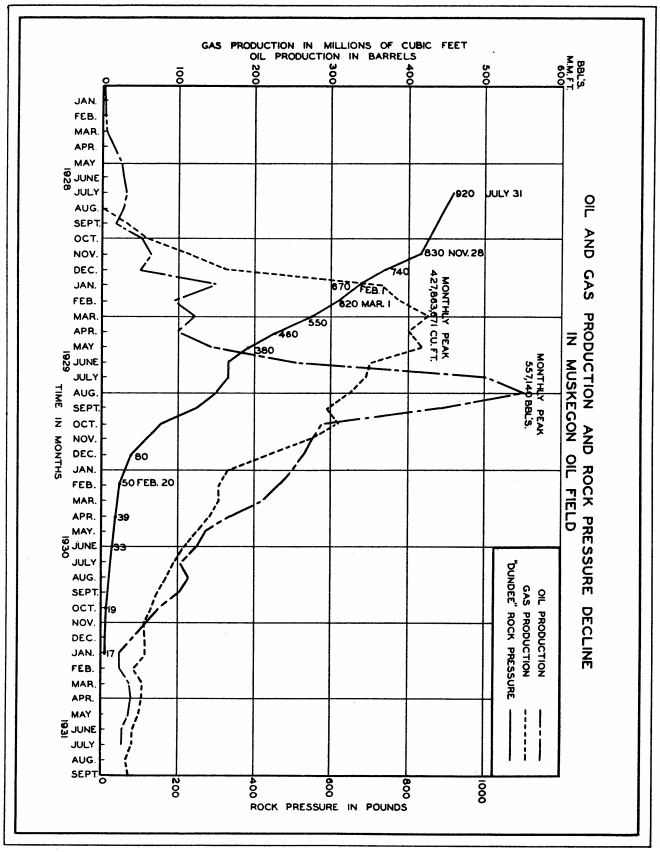

Figure 30. Graph showing fluctuations of oil and gas production and rate of rock pressure decline in Muskegon field.

Although several refineries were operated at Muskegon while the field was being actively developed, only two are now running. The Henry H. Cross Company erected a small topping plant of 1,000 barrels capacity which has become obsolete. The Michigan Central Refining Company of North Muskegon moved their equipment to Mount Pleasant and became the Roosevelt Refining Company. The Naph-Sol Refining Company refinery of about 2,000 barrels capacity in the middle of the field north of the Pere Marquette tracks, and the Old Dutch refinery of 2,500 barrels crude oil capacity are still operating and marketing naphthas, mineral solvents, kerosene, and fuel oil.

The crude oil from the Traverse has an average gravity of approximately 37° Be., and is a high-grade paraffine-base, sweet oil (sulfur 0.336 percent). The gasoline content ranges from 34 to 35 percent; the kerosene content is 14 percent; and the remainder is crackable residuum. The "Dundee" crude ranges from 37c to more than 39° Be. gravity, but it is a sour oil (sulfur, 0.98). The gasoline content varies from 26 to 29 percent; the kerosene, from 23 to 24 percent; the gas oil is 10 percent; the lubricating distillates, 16 percent; and the residuum, approximately 23 percent. The current prices paid for the Muskegon crude oils, except once when Dundee crude went to 50 cents a barrel, have been the

same as the Mid-Continent gravity scale and fluctuated accordingly.

The composition of the natural gases (see table X) shows considerable variation in the Muskegon field, partly because of the different stages

	1	2	3	4	5
Hydrogen sulfide	0.25	0.09	0.24	.....	.....
Carbon dioxide	0.27	0.21	Trace	.....	.....
Oxygen	1.07	0.19	1.29	.....	0.7
Methane	61.95	59.78	58.10	81.00	79.3
Ethane	22.04	23.22	21.13	10.40	19.6
Propane	.....	.....	.....	.....	.....
Butanes	.....	.....	.....	.....	.....
Unsaturated hydrocarbons	.....	.....	.....	.10	.....
Hydrogen	.....	.....	.....	.....	.....
Nitrogen	(Residue) 14.42	(Residue) 16.51	(Residue) 19.24	8.50	0.4
Total	100.00	100.00	100.00	100.00	100.00
Sulfur—Grains per 100 cubic feet	.....	.....	.....	3.05	.....
Moisture per 100 cubic feet	.....	.....	.....	1.296	.....
Sp. gravity—Air=1	.....	.....	.....	.....	.657
Heating value B. T. U.	1,016.00	1,015.00	912.00	1,005.3	1,153.00

1. Dixie Oil Co.—C. Reeths No. 1D, Muskegon County, Dundee gas.
2. Dixie Oil Co.—F. Figge No. 11D, Muskegon County, Dundee gas.
3. Joliet Morris—J. B. Nichols, No. 3, Muskegon County, Dundee gas.
4. Johnson Oil Refining Co., Smith No. 1, Muskegon County, Dundee gas.
5. Muskegon Oil Corp.—Daniloff No. 1, Muskegon County, Monroe gas.

Table X. Analyses of Natural Gas from Muskegon Field.

during the life of the field when samples were taken and partly because of the methods of analysis. The percentage of oxygen is from 0.19 to 1.29 percent, while nitrogen and other inert constituents range from 0.4 to 19.24 percent. Several analyses of the gas from Muskegon show helium from 0.19 to 0.24 percent, which is very small. The gases from the Traverse and Dundee horizons are nearly all sulfurous and analyses reveal from 1.54 to 3.05 grains per 100 cubic feet, but the Monroe gas is "sweet." Of the inflammable gas in the natural gas mixture, ethane ranges from 10.40 to 23.22 percent and methane from 58.10 to 81.0 percent. The heating value varies from 912 to 1,153 B.T.U., and the moisture content is usually small. The prices paid for gas at the well ranges between 7 and 12 cents per thousand cubic feet.

Natural gas is no longer used for domestic purposes at Muskegon and industrial gas which is still being burned under steam boilers and consumed in gas engines, core ovens, and dry kilns is diminishing in quantity. This may be eventually replenished with central Michigan gas if pipeline projects under consideration materialize. The increased gasoline content in the Muskegon gas has brought its heating value from approximately 1,000 to over 1,400 B.T.U. At the time when the supply of gas was large, about 1,750,000 cubic feet were handled daily by an absorption plant which had an output capacity of 5,000 gallons of natural gasoline per day. The gasoline recovery from this plant, which has now been moved to the Mount Pleasant area, was about one gallon per thousand cubic feet. The present gas withdrawal from the entire Muskegon field is less than a million cubic feet per day.

At the close of December, 1932, the area had produced 5,802,034 barrels of oil and close to 6,981,347,000 cubic feet of gas. On October 1, 1932, 466 wells had been completed in the field, of which 244 were still producing, 37 were idle, 184 abandoned and plugged, and one drilling. Of 214 producing oil wells, 149 were in the "Dundee," 43 in the Upper Traverse, and 22 in the Lower Traverse. The 30 gas wells included 13 in the Monroe, 11 in the "Dundee," four in the Lower Traverse, and two in the Upper Traverse. The daily gas production at that time was 783,188 cubic feet, including 581,086 cubic feet of casinghead gas and 202,102 cubic feet from dry gas wells. The daily oil production was 2,460 barrels, of which 1,996 barrels were from the "Dundee," 330 barrels from the Upper Traverse, and 134 barrels from the Lower Traverse. The average output per producing well was 11.5 barrels of oil and 20,740 cubic feet of casinghead gas. The 122 wells treated with acid were averaging 15.6 barrels of oil per well in comparison to 6.05 barrels per well from the 92 wells untreated, and approximately 90 per cent of the wells were making water with an average of 11.95 barrels per well.

[1]Rominger, Carl, Geology of the Lower Peninsula: Geol. Survey of Michigan, Vol. 3, Pt. 1, p. 84 (1876).

[2]Lane, A. C., Deep Wells and Prospects for Oil and Gas: Geol. Survey of Michigan, Ann. Rept. for 1901, p. 232 (1902).

[3]Op. cit., p. 84.

[4]Lane, A. C., Op. cit., pp. 232-34; The Geology of Lower Michigan with reference to Deep Borings; Geol. Survey of Michigan, Vol. V, Pt. 2, pp. 27, 71: Pl. 43 (1895).

[5]Lane, A. C., Deep Borings for Oil and Gas: Geol. Survey of Michigan. Ann. Rept. for 1903, pp. 275, 276 (1905).

[6]Smith, R. A., The Occurrence of Oil and Gas in Michigan: Michigan Geol. & Biol. Survey, Pub. 14, Geol. Series II, pp. 186-190 (1914).

[7]Newcombe, R. B., Oil and Gas Development in Michigan: Michigan Geol. Survey, Pub. 37, Pt. 3, Geol. Ser. 31, pp. 244-55 (1928).

[8]Newcombe, R. B., Middle Devonian Unconformity in Michigan: Bull., Geol. Soc. America, Vol. 41, pp. 732-33 (1930).

[9]Lane, A. C., personal communication.

[10]Harrison, Thomas S., Colorado-Utah Salt Domes: Bull., Am. Assoc. Pet. Geol., Vol. 11, No. 2, pp. 111-33 (February, 1927).

Prommel, H. W. C., and Crum, H. E., Salt Domes of Permian and Pennsylvanian Age in Southeastern Utah and their Influence on Oil Accumulation: Bull., Am. Assoc. Pet. Geol., Vol. 11, No. 4, pp. 373-93 (April, 1927).

[11]Nevm, C. M., written communication (1931).

Chapter III. CENTRAL MICHIGAN STRUCTURE

INTRODUCTION

The Central Michigan Area is treated as a single structural province, although it includes two distinct "highs" on which several distinct and separate structures have been partially outlined. These structures vary in shape, size, and depths at which the various producing horizons are found. Conditions of production also vary from field to field. Since these pools are in the vicinity of the lowest part of the "basin," they are grouped together.

Drilling and operating conditions in the different pools of the area are essentially the same, and the depths to the same formations do not vary more than two or three hundred feet.

Mount Pleasant is the center of the area, and it is about midway between the two separate lines of folding. The Mount Pleasant structure, as originally outlined, is in the approximate geographic center of the southern peninsula with about two-thirds in Isabella County and one-third in Midland County. In 1931, new production was found east of the original field and later drilling showed this to be on the same structure. The field as now defined is about one-fourth in Isabella County and three-fourths in Midland County.

Since the finding of oil on the Mount Pleasant structure, new discoveries have been made until the Central Michigan Area now includes 7 producing fields in Midland, Isabella, and Clare counties. These are called the Mount Pleasant, East Extension, Leaton, Vernon, and Porter pools, and Clare and Broomfield gas fields. The business and supply center of nearly all operations is Mount Pleasant, a city of over 5,000 people, and the county seat of Isabella County.

Mount Pleasant is not an industrial city, but living conditions are adequate to furnish accommodation for a large transient class of people. It is the trading center for a considerable area of good farming territory and the seat of the Central State Teacher's College and the United States Indian School. The city is served by the Ann Arbor railroad of the Wabash system, affording direct connections with Toledo and junction points to Detroit. A branch line of the Pere Marquette railroad goes to Coleman, where it joins with the main line to Saginaw and Bay City. A paved highway leads southward to Lansing, about 70 miles distant, and improved gravel and paved roads connect with Bay City and Saginaw. The side roads in some parts of the district are well maintained, but in the area of poor land east of Mount Pleasant, near the Isabella-Midland county line in which the original oil field is located, many of the roads are sandy and swampy.

Other towns in the vicinity of the Mount Pleasant field are Midland, Alma, St. Louis, and Clare. Midland is 27 miles east of Mount Pleasant and twelve miles east of the nearest producing oil well in the East Extension pool. The city is the center of a large mineral and chemical industry carried on by the Dow Chemical Company, who also operates a branch plant at Mount Pleasant. Many wells put down by this company for brine are located in parts of the area not included in the oil and gas fields.

Small refining plants which operate on Central Michigan crude have sprung up in Mount Pleasant, Midland, Big Rapids, and Saginaw. Large tank farms have been constructed by the Pure Oil Company in the field and at a terminal in Bay City. A six-inch oil pipe line built by the same company connects the field with water transportation facilities at Bay City. Gas lines have been laid to Midland, Mount Pleasant, Clare, and also connect with an older line from Midland to Zilwaukee near the city of Saginaw.

The Central Michigan Area is about 25 miles wide and 40 miles long. Although many dry holes have already been drilled and much of the district will be found barren of oil and gas, still several new pools along these "highs" are very probable. Prospecting to date has shown that the structural "lows" are unfavorable for commercial pools of oil or gas. Cross folds in different directions to the main trends and lenticular "sand" conditions seem to bring about the accumulation of natural gas in the shallow Mississippian formations at lower structural levels than have produced oil at greater depths. The area in which immediate future prospecting can be expected includes over 1,000 square miles.

PHYSIOGRAPHY

The surface features of the region are largely the result of Pleistocene glaciation, either from the melting of ice or the stages of glacial Lake Saginaw. Midland County and eastern Isabella County are covered by deposits of lake clay, sandy lake beds, and deltas formed by streams flowing into the glacial lakes which covered the district at different times during the retreat of the ice. The waters of glacial Lake Saginaw reached as far west as Mount Pleasant, and the shore features, of that lake are fairly well defined at an elevation of 780 feet extending northward and southeastward from the city. The soil of these lake deposits is usually poor in quality, land is comparatively flat with little relief, and swamps are frequently present. The surface elevations in the vicinity of the oil field vary from 670 to something over 740 feet above sea level. The ground surface is comparatively flat with occasional sandy crescentic bar or beach ridges and low sand dunes that rise a few feet above the surrounding country. Some of this lake bed country is underlain with clay, particularly in southern and northwestern Midland County, but much of the area is sandy. The vegetation consists of low bush, tamaracks, and scrub oak.

The land rises in a series of ridges to the west and northwest of Mount Pleasant in two pronounced rows of hills that attain elevations in excess of 1,060 feet. The first hills west of the city range between 860 and 890 feet high, and the Bundy Hills, between 4 and 7 miles farther west, rise from 950 to over 1,000 feet above sea level.

The glacial features besides the terminal moraine are till plain and outwash. The moraines are members of the West Branch-Gladwin group along the western edge of the Saginaw ice lobe. Southward from Clare County, where the West Branch morainic system is separated into several members, the relief of each ridge is less than 100 feet except in northwestern Isabella and eastern Mecosta counties, where it is 200 feet or more. In Gratiot, Montcalm, and central Isabella counties, the moraines are separated by broader strips of fertile till plain, which lie on the inner or eastern slopes of the moraines. The sandy and swampy areas of old glacial

drainage channels lie on the outer or western slopes. One prominent line of glacial drainage which gave rise to these swampy and sandy areas is continuous from southern Clare County southward across western Isabella County to the outlet of glacial Lake Saginaw, a distance of about seventy miles. It heads near Hatton and passes southwestward, leaving Farwell at its east border and enters the Chippewa Valley drainage in northwestern Gilmore township, Isabella County. This series of drainage channel, moraine, and till plain constantly repeats itself across the region west of Mount Pleasant.

The larger ridges of terminal moraine west of Mount Pleasant extend northwest-southeast and during the Ice Age, the position of the ice front at this point was apparently controlled in part by pre-glacial topography, a reflection of the structure of the underlying rocks. Near the western margin of Isabella County, the surface is extremely rough and the hills are high and steep. The moraines! are composed chiefly of boulder clay, with some sand and gravel. The land north and west of the city of Mount Pleasant is of much better quality than to the east, and the border between the two classes of soils Is more or less governed by the extent of the sandy glacial lake deposits.

The principal rivers of the region are the Pine, Chippewa, and Salt, tributaries of the Tittabawassee which empties into Saginaw River near the city of Saginaw. The Chippewa flows in a general eastward course across Isabella and Midland counties and is the most important stream of the oil field area. The divide which separates the eastward and westward flowing streams of the State crosses the northwestern corner of Isabella County and central Clare County in a northeast-southwest direction. The Muskegon River drainage is on the west side of this divide, and the tributaries of this river system serve the remainder of the district.

HISTORY

Drilling for brine in conjunction with the lumber and chemical Industries furnished structural data and led to the discovery of several Michigan oil fields. The first well belonging to the Dow Chemical Company, Midland, Michigan, was put down soon after the concern started operations in 1890. As the chemical plant grew, the company spread its drilling activity out into the surrounding territory. The new wells were scattered at irregular intervals along the Chippewa and Pine rivers, until the locations of holes put down for brine extended over several of the townships west of Midland. The more recent Dow brine wells have been spotted with greater regularity at approximately half mile intervals along the section lines.

For a long time, the records of most of the wells of the Dow Chemical Company were withheld, and since the rocks were deeply buried by glacial drift the anticlinal fold with its several individual domes was not recognized. Some of the holes drilled for brine found showings of oil and gas, and the drillers who worked at the wells and the people of the surrounding community remembered these. The Saginaw oil field was discovered in July, 1925, and with the influx of men trained and experienced in the petroleum industry, new interest was aroused in the oil and gas possibilities of the Central Michigan Area.

The Pure Oil Company obtained from the Dow Chemical Company the records of their many wells which had been previously held confidential. Close study of these well logs revealed a strong arching of the rocks in the same general locality where small quantities of oil and gas had been found years before. A deep well was drilled at a favorable place on the structure and this test hole, completed on February 8, 1928, was the discovery well of the Mount Pleasant oil field. The hole was situated on the Laura Boot farm, NE. ¼ of the SE. ¼ of sec. 18, T. 14 N., R. 2 W., Greendale township, Midland County, and W. A. Thomas, geologist for the Pure Oil Company, made the location.

The Boot well was not an unusual producer. It commenced at about 30 barrels and increased to about 100 barrels per day when later drilled a few feet deeper into the "sand" or pay horizon. This deepening of the hole definitely established that the water was at some distance below the "pay" and that the discovery had been made well up on the structure. Soon afterwards drilling became active, and other holes were put down which showed that the field would cover a wide area. The most sensational development occurred on May 8, 1931, when the so-called East Pool or the East Extension was discovered with the bringing in of the Kalamazoo Improvement Company, George Harnick No. 1, SW. ¼ of the NW. ¼ of the NW. ¼ of sec. 15, T. 14 N., R. 2 W., Greendale township, Midland County, good for 820 barrels initial production. In 1930, the Mount Pleasant district had become the leading oil producing area in Michigan, and the large output of the East Extension with several wells having over 3,000 barrels initial production brought the pool into national prominence. On June 1, 1932, it was believed that the original Mount Pleasant Pool, together with the East Extension, would include a potential productive area of approximately 9,000 acres.

STRATIGRAPHY

The general stratigraphy of the Mount Pleasant oil field is known in the structurally high places to a depth of 4,600 feet and in the lowest part of the district to 4,821 feet. The deepest wells have penetrated the Sylvania formation, but none have gone completely through it. The area as a whole shows considerable stratigraphic similarity, but several members change markedly from place to place. In most cases, these lithologic and thickness changes are related to unconformities. Bedrock does not crop out anywhere in the central part of the State, and the descriptions of the various formations are entirely from well logs, samples of cuttings, and cores. A well record from the northwest

part of the Mount Pleasant Pool on the Dixie Oil Company's N. Davis lease is shown as typical of the Central Michigan Area. (See table XI.)

Location: SE. ¼ of SE. ¼ of SW. ¼ sec. 2, T. 14 N., R. 3 W., Isabella County. 330 feet from north and 330 feet from east property line. Permit No. 816. Elevation: 716 feet above sea level. Record compiled by John D. Lamont and R. B. Newcombe from driller's log. Commenced: December 10, 1929. Completed: March 4, 1930. Initial production: 130 bbls. oil. Casing: 331 feet of 14; 810 feet of 10; 1,424 feet of 8¼; 3,208 feet of 6⅝-inch.

Formation.	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene:		
Sand	65	65
Sand; white clay, soft	55	120
Clay, white, soft	28	148
Sandstone, hard	7	155
Red rock, soft	27	182
Sandstone	30	212
Sandstone and gravel	38	250
"Permo-Carboniferous" (?):		
"Red Beds:"		
Red rock	2	252
Limestone shell, hard	2	254
Red rock	13	267
Ionia Sandstone (?):		
Sandstone, red	56	323
Pennsylvanian:		
Saginaw Formation:		
Sandstone, white, hard	129	452
Shale, black, soft	46	498
Clay, black, soft; shale	94	592
Limestone; "shell," hard	10	602
Clay, black, soft	118	720
Sandstone, white	34	754
Sandstone	27	781
Clay, blue, soft; shale	6	787
Sandstone, white, hard	3	790
Shale, gray	41	831
Parma Formation:		
Sandstone; (water)	11	842
Sandstone, white, hard	28	870
(Bayport apparently eroded)		
Mississippian:		
Michigan Formation:		
Shale, light, soft	72	942
"Shell," hard	5	947
Shale, dark, soft	23	970
Shale, dark, medium hard	45	1,015
Limestone, white, hard	10	1,025
Shale, dark	55	1,080
Limestone, white	10	1,090
Shale, dark	30	1,120
Sandstone, white	5	1,125
Shale, dark	17	1,142
Sandstone (show of oil 1,148-1,153)	39	1,181
Napoleon (Upper Marshall) Formation:		
Sandstone	131	1,312
Lower Marshall Formation:		
Sandstone, red	28	1,340
Red rock	44	1,384
Sandstone, red, medium hard	32	1,416
Coldwater Formation:		
Shale, white, hard	8	1,424
Shale, blue, soft	299	1,723
Shale, white, soft	682	2,405
Sunbury Formation:		
Shale, brown	15	2,420
Berea Formation:		
Sandstone, "grit"	40	2,460
Devonian:		
Antrim Formation:		
Shale, brown	440	2,900
Traverse Formation:		
Limestone	30	2,930
Limestone, hard	298	3,228
Limestone, hard, "broken" (steel line measurement 18 feet difference)	50	3,278
Bell Formation:		
Shale, white, medium hard	55	3,333
Shale, white, soft	182	3,515

Formation.	Thickness.	Depth.
	Feet.	*Feet.*
Dundee Formation:		
Limestone, dark, hard	3	3,518
Limestone, dark, hard	2	3,520
Limestone, gray, very hard	2	3,522
Limestone, gray, hard	11	3,533
Limestone, dark gray, hard	12	3,545
Limestone, gray, soft porous	3	3,548
Limestone, blue gray, hard	2	3,550
(show of oil-gas 3,546, hole filled 200 feet with oil at 3,548 feet)		
Limestone, gray, hard	5	3,555
Limestone, gray, soft	3	3,558
Limestone, gray, hard	2	3,560
Limestone, light gray, porous	3	3,563
Limestone, brown ("pay" from 3,560 to 3,564)	1	3,564
(well commenced to flow when drilled to 3,560 feet)		
Limestone, brown, soft	1	3,565
Limestone, brown, soft	½	3,565½
Limestone, gray, hard	5	3,570½
Limestone, dark, soft	½	3,571
Limestone, dark, medium hard	1	3,572
Limestone, light gray, hard	½	3,572½
Limestone, light gray, hard	1	3,573½
Limestone, gray, hard	1	3,574½
Limestone, gray, hard	1	3,575½
Limestone, gray, medium hard	3	3,578½
Limestone, gray, hard	2	3,580½
Limestone, dark gray, hard	1	3,581½
Limestone, brown, hard	2	3,583½
Limestone, gray, hard	4	3,587½
Limestone, light gray, hard	1	3,588½

Table XI. Log of Dixie Oil Company's (Stanolind Oil and Gas Company's) N. Davis No. 1.

PLEISTOCENE

The glacial drift materials of Pleistocene age are the surface deposits of the region. They consist of sand, gravel, and clay, either in beds or in heterogeneous, unevenly distributed deposits. The thickness of the drift is variable, but in the immediate vicinity of the Mount Pleasant Pool it averages 300 feet. In this part of the area, the materials are sand and lake clay. Some of the sand is cemented by infiltration of lime and in certain wells this cemented sand aggregate has caused much trouble in landing the drive pipe. The thickness increases, and the character of the drift changes to the north and northwest. In Isabella County, Denver township, it is 320 to 350 feet thick; Vernon township 415 to 430 feet; Broomfield township, 500 to 650 feet; and in the Clare gas field, Clare County, 450 to 540 feet. Some of this thicker morainic drift is sandy too, but much of it is of bouldery clay or till Artesian flows have been encountered from the drift in some parts of the Leaton Pool, Denver township.

"PERMO-CARBONIFEROUS" (?)

The "Red Beds" are not reported in all wells of the district but they are apparently very generally present. These beds, where thin, may be often logged with the glacial drift. It is evident from samples that the reworked red material is represented in some of the basal Pleistocene clays. The red sandstone which is usually found at the base of the series probably correlates with the Woodville (Ionia) member as shown in Figure 6, Part I, Chapter III.

PENNSYLVANIAN

The individual beds of the Saginaw formation cannot be easily correlated between wells over long distances. Sometimes dark shales coals or sandstone members are traceable from well to well if they are close enough together. The thickness of the formation depends on preglacial topography and the position of the drilling location in respect to regional and local structure. In the Central Michigan Area, there are usually from 300 to over 600 feet of Pennsylvanian rocks.

The Parma sandstone generally occurs at depths of about 800 feet throughout the Mount Pleasant field. It is not recognized in all the wells of the field and often has unusual physical characteristics. The typical milky to clear white sandstone carries water and is usually the first important water bearing stratum after bedrock is penetrated. Frequently, the sandstone is limy and interspersed with reworked Bayport, making it difficult to identify in well logs. The Parma, having been laid down on the uneven surface of the Grand Rapids group, may vary greatly in thickness from 20 to over 100 feet. It may rest on shale or sandstone but is more commonly found on the Bayport limestone, which is also extremely variable. The average amount of Parma is from 50 to 80 feet.

MISSISSIPPIAN

The Bayport limestone may be cut out by pre-Pennsylvanian erosion, and this is probably the explanation for its absence in the Davis No. 1 well. (See table XI). Where present, it is gray to buff limestone and usually sandy and impure in the upper part. The

recorded thickness ranges from 12 to over 100 feet but from 40 to 80 feet is most common.

The Michigan series is similar to the Saginaw formation in that the individual beds cannot be traced easily between wells, although sometimes correlation is possible in a limited area. The gray and black shales, the dolomitic bituminous limestones, the anhydrite and gypsum beds, and the lenticular sandstones characterize the formation. A rather persistent sandstone bed from a few feet to 30 or 40 feet above the base usually carries gas or heavy oil. This member, sometimes broken by shale partings, is similar in character to the Napoleon sandstone and seems to be a reworked phase of the Marshall formation. Northward and northwestward from Mount Pleasant the strata separating this horizon from the Napoleon sandstone frequently contain gypsum beds. Early records miscorrelated this sandstone as Marshall, but the gypsum layers between the upper sandstone and the typical Napoleon has made the present correlation more plausible. A thin, bituminous, brown limestone may overlie this upper sandstone, and a similar brown limestone nearly always overlies the thicker and more uniform Napoleon sandstone below. Therefore, unless a "wildcat" hole is drilled for some distance into the Marshall, it is difficult to know from the character and order of the beds whether the "stray" sandstone in the lower part of the Michigan series has been penetrated.

The Napoleon (Upper Marshall) sandstone is normally from 130.to 150 feet thick and present everywhere in the Mount Pleasant field. It is the principal horizon from which the Dow Chemical Company obtains the heavy brine for extraction of chemicals and the nature of this sandstone section is thoroughly known from the many scattered wells of this company. South and southeast of the oil field the Upper Marshall beds become thinner. In Jasper township, Midland County they are 105 to 115 feet thick; Porter township, Midland County, 75 to 125 feet; Mount Haley township, Midland County, 90 to 120 feet; and Bethany township, Gratiot County, 75 to 90 feet. East of the field in Lee township, Midland County, they are 90 to 115 feet thick; Homer township, Midland County, 85 to 125 feet; and Midland township, Midland County, 100 to 120 feet. North and northwest of Mount Pleasant, the Upper Marshall attains a thickness of from 160 to 170 feet. The formation generally consists of gray, white, yellowish, and light greenish sandstones with a few limy or gray shaly streaks and partings. The important unconformity at the top has caused local and regional changes in the character of the beds which are sometimes confusing. Among these changes are alternating red and gray sandstones in some of the top beds, a "broken" or shaly condition in some of the upper members, a red shale bed in the middle of the massive Napoleon sandstone, and a red sandstone at the base. The changes are localized as follows: the alternating red and gray top beds in the district north and northwest of Mount Pleasant; the "broken" or shaly upper members in the structurally high region along the southeast trend of the anticlinal fold in Jasper and Porter townships; the red shale in the middle of the Napoleon (Upper Marshall) in the region south of Midland and in the Leaton Pool; and the red sandstone at the base in scattered parts of the field. The red color in the Upper Marshall is probably related to the reworking of exposed red Lower Marshall rocks in Napoleon time and the reincorporation of this material with the coarser sand. These unusual Napoleon sandstone beds are generally pink instead of red, and much of the color is due to cementing matter as evinced by the way this color fades or disappears when the cuttings are thoroughly washed.

The Lower Marshall formation includes several beds of pink to red sandstone and red shale, aggregating from 80 to over 100 feet in thickness. The red color is darker than the Napoleon and the texture finer. It is micaceous, silty, and shaly, and more sharply differentiated from the Napoleon sandstone above than from the Cold water below.

The Coldwater shale is gray and light blue in color. Although the shale may be either soft or hard, it is for the most part uniform. In many wells, a series of dark beds have been found near the top of the formation. The thickness ranges from about 960 to 1,050 feet.

The Sunbury brown shale can usually be distinguished from cuttings, but many drillers do not recognize its dark color when the samples are wet. This shale contains pyrite and breaks up under the drill as large chips. It is an important marker at the base of the thick Coldwater shale section.

The Berea is not well represented as a definite sandstone and the beds are mostly sandy and limy shale. These sandy beds and the underlying gray Bedford shale are from 30 to 80 feet thick in the west part of the field and 30 to 125 feet in the east part. The Berea is better developed to the east and shows from 20 to 50 feet of "sand." The oil and gas in the formation increases eastward in the localities where rather favorable showings have been found.

DEVONIAN

The Antrim shale, as correlated in central Michigan, exceeds 400 feet in thickness and is largely brown to black shale. It contains abundant pyrite and *sporangites* (yellow-brown spore cases). The upper beds of this shale may represent a dark gray facies of the Ellsworth formation of western Michigan. The cause of the change in physical character and color of the beds in this part of the stratigraphic column between the western and the central counties of the State is not well understood. The abnormally thick section of dark colored shale is probably due to lateral variation in the Ellsworth beds. A series of gray and brownish limy beds occurs about 60 to 80 feet above the base of the Antrim. In some instances, these limestones are partly concretionary and usually from 5 to 25 feet thick. The basal beds of the Antrim may be transitionary with the upper gray shales of the Traverse, but the contact between the two formations is fairly sharp.

The Traverse group consists of gray to blue shales and gray, buff, and brown limestones and averages about 600 feet in thickness throughout the entire field. A porous zone that occurs from about 100 to 130 feet though usually about 120 feet below the top of the formation may contain oil, gas, or water. These porous strata are probably near the top of the Alpena limestone member. A basal shale series, which is usually about 60 feet thick, is correlated with the Bell shale. The lower beds of this shale are black and this indicates nearness to the top of the Dundee formation.

The Dundee limestone contains the important oil producing horizons of the Mount Pleasant field. The beds are buff to gray and often cherty or fossiliferous. The first porous layers are in horizons struck from 25 to 35 feet in the Dundee, and a certain degree of porosity is found for 25 or 30 feet. The beds then become more dense and, on the highest parts of the structure, water is not found until about 95 feet of Dundee has been penetrated. The productive part of the formation does not extend more than 70 feet beneath the top and drilling operations are generally stopped at that point.

The porosity of the Dundee beds is attributed to solution. Cores of the "pay" strata have cavities characteristic of those made by percolating water and many of these vugs contain recrystallized calcite. The porous beds are full of stylolites and many of the openings are adjacent to the stylolitic sutures. A stylolite is a small, short, columnar structure transverse to the bedding and commonly filled with a thin residual film of carbonaceous clayey material. If one is to accept the conclusion[1] that stylolites are caused by solution, then this relationship should serve as rather positive evidence that the openings originated by solution. Some have advanced the explanation that the unusual porosity in the East Extension is a result of the presence of coral reefs. Cores which have been examined show openings caused by the dissolving out of the internal structure of cup corals, but no reef forming corals were observed. Reefs have not been found in the Dundee where exposed; therefore, it would not seem plausible that they would be present in this area.

Only two wells in the Mount Pleasant Pool proper have gone through the Dundee limestone, so the data on the thickness of the formation are meager. One was on the top of the structure and the other was just off the southeast flank. The Dundee was 224 feet thick in the first well and 189 feet thick in the second. These figures seem to indicate a discomformable relief of over 35 feet on the top of the Dundee formation for the Mount Pleasant Pool proper, but the possible error due to the unconformity at the base must not be overlooked. A well west of Rosebush, Isabella County, showed 128 feet of Dundee, and a hole in the south part of sec. 9, Lee township, Midland County, also penetrated the entire formation. If the production in the Vernon Pool is coming from the Detroit River beds instead of the Dundee, then the topographic relief of the pre-Bell land surface for the entire Central Michigan Area is more than 224 feet.

The Detroit River series is abnormally thick, exceeding 1,050 feet in the central part of the State. The beds are largely dolomite and anhydrite, with a few thin salt seams. They are porous near the top of this series where the "black water" is encountered and the water horizon is about 5 feet in the formation. There are also several other water horizons which include zones 200 to 225 feet; 410 to 440 feet; and 500 to 550 feet from the top. In two wells, the deepest of these porous zones carried oil and the water below this "pay" zone contained sulfur. It is interesting to note that one of these wells was high on the structure and the other was low.

The Sylvania strata are the deepest rocks penetrated in the region. They are made up of fine grained sandstone and buff, cherty, sandy dolomite. The sand grains are more angular than those typical of the same formation in the southeastern corner of the State. The upper part of the Sylvania carries a heavy brine, which in one well was supersaturated. The approximate depth to the first Sylvania beds on the top of the Mount Pleasant anticline is about 4,700 feet.

STRUCTURE

The anticlinal fold which was discovered by drilling for brine and later outlined by wells put down for oil in the Mount Pleasant Pool has been traced across Midland and Isabella counties, and into Clare County. The position of the arch is much better known in some places along the general axis than in others. Contour maps drawn on two subsurface horizons indicating structural conditions, as of January, 1933, are shown in Plates IV and V. The contours are drawn on the top of the Lower Marshall (Red rock) of Mississippian age and on the Dundee limestone of Devonian age. The contour interval is 20 feet, and the elevations on the datum beds are below sea level. Dashed lines are used in most instances and indicate the uncertainty of the structure-as drawn. Future drilling may greatly change the local picture, but the regional aspects of the structure as represented are probably more certain.

Two important parallel "highs" are outlined on these maps. They are traced from Gratiot and Saginaw counties on the southeast into Clare and Osceola counties on the northwest. At somewhat regular intervals, they are interrupted by cross folding which changes their size, shape, and trend. These cross folds give rise to domes with sufficient closure to trap oil and gas in pools. There seems to be two series of these cross folds, one with an east-west and the other with a northeast-southwest direction. North-south folds with large dimensions seem infrequent. A third northwest-southeast "high" is suggested on the northeast as an extension to the northwest of the Saginaw structure. Further drilling is necessary to determine this.

These lines of folding have been termed in the field, the Mount Pleasant "high," and the Broomfield "high," but, as shown by the maps, the name given to the "high" east of Mount Pleasant is somewhat misleading. It is

suggested that discovery be made the basis for naming them and they be called in order from east to west, the Saginaw "high," the Greendale "high," and the Broomfield "high." The lows in between these trends of anticlinal folding could be called the Midland trough and the Mount Pleasant trough. The domes on these anticlines are from 1¼ to 2 miles across and the deepest part of the synclines 4 to 4½ miles wide. The maximum structural relief off the Greendale "high" into the Mount Pleasant trough is 270 to 280 feet and off the Broomfield "high" about 300 feet. The relief is essentially the same on both the Mississippian and Devonian rocks and in its major features the structure is largely conformable for both ages.

Several regional features of structure should be emphasized. The deepest part of the Michigan "basin" is in the Mount Pleasant trough west of the village of Rosebush and the two principal highs of the district are on each side of this deep trough. The troughs beyond on the outer side of these lines of folding are narrower and shallower than the central one. The comparatively steep dip like the west flank of the Greendale "high" does not seem to be present off the Broomfield "high" and the latter is more symmetrical in cross section than the former. This may be partly due to the lack of structural information on the Broomfield fold since wells are scarce in most of that region except in Broomfield township.

It may be observed on both maps (see pls. IV and V) that the structures seem to broaden out and the noses become less sharp up the regional dip to the southeast beyond a line between Alma and Saginaw. This is evident, particularly because the pitch of the Mount Pleasant trough flattens appreciably in northwestern Saginaw and northeastern Gratiot counties. A possible explanation for this seeming regional terracing is a deep syncline which parallels the long direction of Saginaw Bay. This transverse syncline (see pl. III) may be the result of a regional downwarp of sufficient magnitude to extend into the central part of the State and form terraces, gentle dips, and flattened structural noses.

The regional dip is difficult to determine in most of the Central Michigan Area, because it is interrupted by the local structures and is changed in short distances. The central trough and the major parallel highs affect the whole district. The axes of the Greendale "high" north of the Vernon Pool and of the Broomfield "high" north of Barryton seem to bend more to the north. This may possibly be due to a change in the trend of the axis of the basin itself, or to a local cross fold.

The individual structures along the trend of the Greendale "high" apparently have some characteristics in common. They are arcuate in shape and the closures are somewhat regularly spaced along the axis. The gas in the Mississippian rocks is more or less confined to the regions of northeast-southwest cross folds. The map on the Lower Marshall (see pl. IV) seems to indicate a similarity between the Leaton Pool structure and the southwest plunging nose in secs. 13, 23, and 24, Jasper township, Midland County. The arc concave to the northeast, which traces the axis of the Mount Pleasant Pool (Chippewa-Greendale townships), may possibly be duplicated again to the southeast but there is some evidence that the axis will swing to the south across Jasper township. Any similarity of structural pattern along the axis would be an invaluable aid to future prospecting.

MOUNT PLEASANT STRUCTURE

The Mount Pleasant anticline proper in Chippewa township, Isabella County, and Greendale township, Midland County, extends about 5 miles in a northwest-southeast direction. It is separated from the Leaton dome to the northwest by a saddle with a north-south axis which changes direction toward the northeast on the north side of the arch. The Mount Pleasant structure swings more to an east-west direction at the southeast end and joins with a subsidiary, more or less continuous structure, called the East Extension. This extends eastward into Lee township and is about 4 miles long. It is partially separated on the south from the northwest-southeast trending main fold by a small saddle coming in across section 20, 21, and 29, Greendale township. The Mount Pleasant anticline along its major direction is about 8½ miles long. The elongated dome is about 1½ miles across where widest and the steeply dipping flank is on the southwest, or basinward side of the arch. This steep dip varies from about 180 to 240 feet per mile, and the inclination of the beds on the gentle side of the fold does not greatly exceed 50 feet to the mile. The plunge of the fold to the northwest varies from 80 to 90 feet to the mile and from the nose of the structure, the north dip decreases eastward until on the north side of the East Extension it averages between 26 and 27 feet per mile.

The asymmetrical character of the fold compares very closely with the other known anticlines in Michigan. The East Extension of the Mount Pleasant Pool indicates an east-west direction of folding which, together with the arcuate (pistol-like) outline of the structure, is also characteristic of Muskegon. In a similar manner to the Muskegon field, the most productive area is found on this narrow east-west fold in sections 9, 10, 15, and 16, Greendale township. A somewhat gentle east-west syncline coming in from the east across the south part of sections 13, 14, and 15 seems to cut off production on the south side of the structure. The 560 foot contour suggests (see pl. IV) that in the southeastern corner of section 16, the Mount Pleasant anticline proper is joined by means of a saddle in the vicinity of Stearns to another anticline regionally higher to the southeast along the same trend.

The anticline has between 40 and 50 feet of closure on the northwest-southeast trending dome and between 20 and 25 feet of closure on the east-west trending dome. Oil occurs more than 10 feet below the level of the lowest closing contour on the west side and more than 20 feet below this level on the east side of the dome. The absence of normal edge water on the steeply

dipping side of the structure may possibly account in part for this. The wells on the steep side of the fold have generally shown a very slow, regular decline in production, and the disconformity at the top of the Dundee limestone may possibly explain these unusual characteristics. The variable thickness of the Dundee on and off structure and the nature of the porosity tend to support this conclusion.

The structure displays numerous minor irregularities, particularly on the south side. Several narrow saddles indent the crest at about right angles to the axis of the fold. Small local domes extending from a quarter of a mile to more than a mile are scattered along the crest and rise 20 to 30 feet. These, together with small depressions of like magnitude on top the structure, are seemingly due to the topography representing the erosion surface existent at the close of both Lower Marshall and Dundee times. The north side of the structure forms a broad nose northward and northeastward into western Geneva township. The nature of this nose and its relation to other nearby structures is difficult to explain, but it is significant that small quantities of free oil were found in the Dundee on this nose as far down the dip as sections 19 and 20, Geneva township. Possibly, there may be another parallel subsidiary structure on this side of the Greendale "high."

LEATON STRUCTURE

The Leaton structure is named from the small town of Leaton, Denver township, Isabella County. This dome is a much smaller structural feature than the Mount Pleasant anticline and, although the major axis seems to trend in a northeast-southwest direction, the contours on the Dundee show it to be nearly circular. Apparently, it is the result of the cross buckling which caused the saddle between the Chippewa and Vernon township parts of the fold. The east-west and north-south diameters of the dome are each about a mile and a quarter in length. The dip is very sharp on both the southern and western sides of the dome but it flattens out to the north and east. Westward, it is from 140 to 200 feet per mile and southward 50 to 60 feet per mile on top the Dundee.

Two small closures are indicated by the Lower Marshall map (see pl. IV), and the structure seems to be elongated in a northeast-southwest direction. The total amount of closure on these shallow beds is between 25 and 30 feet, but on the Dundee it is apparently greater, amounting to 35 or 40 feet. (See pl. V). The circular shape of the dome is more clearly defined on the Dundee beds, and there seems to be only one restricted closure in the vicinity of the section corner between sections 24 and 25, Isabella township, and sections 19 and 30; Denver township. The saddle joining the Leaton dome with the Mount Pleasant anticline crosses the middle of section 29, Denver township and, in this direction as well as down the gentler south dip of the dome, production is found from 10 to 15 feet lower than on the other sides. The depositional and structural importance of the northeast-southwest cross folding in the Mississippian rocks is indicated by the presence of large quantities of "Michigan Sand" gas on this dome. The uneven surface of the Lower Marshall is shown by the irregular contour lines and the small closures.

VERNON STRUCTURE

The Vernon structure is situated on the Greendale "high" in Vernon township, Isabella County, northeast of the Leaton dome, and about half way between Rosebush and Clare. Its developed area consists of two parts, outlined by the oil wells in sections 22, 26, and 27 and the "Michigan Sand" gas production in sections 26, 35, and 36. The limits and the characteristics of this structure are not well understood. The trend of the axis seems to be more northerly than in the other domes of the region, but there is a similar steep dip on the west side. Closures have not been well defined, but in section 22 a small dome 10 or 15 feet higher than the surrounding district is probably due to a cross fold trending (see pl. V) to the northeast. Apparently, the axis of the fold is west of the producing gas area and east of the producing oil wells. If this is true, then the oil wells in sections 26 and 27 may be located in a saddle joining larger structures to the north and south. The arcuate course of the Greendale "high" as contoured across Vernon township (see pls. IV & V) suggests such an interpretation.

The structure in Vernon and adjoining townships to the southeast is asymmetrical like the Mount Pleasant anticline proper. The basinward dip is generally from 100 to over 160 feet per mile on the various formations. The gentler dip to the east and northeast varies from 50 to 60 feet to the mile. The size of the individual anticlines is not known, but from present indications the closed structure extending southeast from section 22 is probably several miles long and from 1 to 1½ miles wide. However, the main axis seems to be interrupted by several important cross folds. One of these folds trends from the southwest corner of section 22, Vernon township toward section 7, Wise township; another has an east-west direction across the southern tier of sections in Vernon township.

Producing conditions in the Devonian "pay" horizons underneath the Bell shale are entirely different in the wells on this structure from those to the southeast. Judging from the nature and composition of these horizons, the Dundee beds have been eroded and the strata beneath the Bell shale are the Upper "Monroe" or Detroit River. The oil has some of the properties which are typical of "Monroe" crudes from Michigan, and the productive zones and water horizons underneath do not come at intervals which compare with the other pools of the region. Fitzgerald and Thomas[2] believe that the occurrence of fluorite in two wells in the Vernon Pool is further evidence of the pre-Traverse disconformity and the Upper "Monroe" age of the beds. The wells in the area are extremely erratic, both as to initial and

sustained production, and the secondary deposits of this mineral demonstrate clearly the importance of the break at the close of Dundee time. A clue to the directions of fracturing, jointing, and possibly faulting may be found by alining the wells in which fluorite occurs.

According to observers[3] in the field, the well in section 7, Wise township, showed normal Dundee beds instead of the Detroit River dolomites beneath the Bell shale. This would indicate that eastward from the present oil wells in Vernon township the typical Dundee limestone should again come in underneath the Bell shale. If these are the conditions present, it would be logical to expect more uniform porosity in the beds of the productive horizon. However, there may be abnormal conditions eastward in the township which are difficult to predict because of the possible faults in the region and the variations in the topography of the old post-Dundee land surface.

BROOMFIELD STRUCTURE

The most intensive development along the Broomfield "high" took place in the north part of Broomfield township where the shallow wells were put down for gas in the Michigan "sand." The wells have broadly outlined the local structure on the Mississippian formations. The regional importance of this feature is established, but the scarcity of control points makes it impossible to definitely extend the arch much beyond this small area of intensive drilling.

The closure on top of the fold has not been determined, but the level of the Michigan gas "sand" throughout the area of production in sections 3, 4, 5, 9, and 10 does not vary more than 15 feet. This area is 2 miles long and 1¼ mile wide. The dips off both the east and west flanks of the fold seem comparatively gentle, (see pl. IV) ranging between 30 and 50 feet per mile. On the east flank toward Weidman, the dip flattens to less than 15 feet per mile and there is evidently a cross fold extending in this direction that may be continuous with the Clare gas field structure.

The southeast prolongation of the Broomfield "high" beyond the gas field is similar in size to the Broomfield township district, and the fold may be sharper in Seville township, Gratiot County, where a deep well on its southwest flank had a substantial showing of oil in the "Dundee?." Southeast from Alma the "high" apparently broadens out and loses its sharpness. The northwest prolongation of the axis continues across northeastern Mecosta County and the well in section 14, Sheridan township may be on the arch but in the saddle beyond the nose where the gas was found in Broomfield township. The structure continues northwestward and, with a slight swerve to the north, crosses Osceola County, about 3 miles west of Evart.

Deep wells to the Devonian formations have not been put down on the Broomfield structure proper, but a well in section 14, Sheridan township, Mecosta County, showed a very small thickness of Dundee. A well in section 7, Deerfield township, Isabella County, was dry in the Dundee but had a good showing of gas in the Michigan "sand." Although the limits of the gas pool have not been determined, this well suggests that gas may be found for at least 5 miles along the structure.

CLARE STRUCTURE

The Clare structure includes the area northwest of Clare in the corner of Grant, Surrey, Lincoln, and Hatton townships where gas has been encountered in commercial quantities in the Michigan "sand." It is apparently related to the northwest extension of the Greendale "high" but on a strong cross fold or sharp, northeast plunging nose off the flank of that arch. This nose is a little over half a mile wide but may broaden out to the southwest. Its length is not known, but the axis seems to aline with a broad nose on the Broomfield "high" still farther southwest and suggests a regional structure of some importance (See pl. IV).

The structure of the Clare gas field is best known on the Mississippian formations, although three wells in the district have been drilled to the Dundee. The dip off the west flank is between 50 and 60 feet per mile and off the east flank about 45 feet per mile. The plunge of the nose northeastward is about 40 feet to the mile. A similar northeast plunging nose lies in the central part of Grant township southeast of the field.

The main arch of the Greendale "high" extends northwestward near Farwell, and probably turns more to the north in the northwest corner of Surrey township. More drilling will be necessary before the exact relation between the structure of the gas field and the Greendale "high" can be worked out. The regional rise of the formations out of the center of the "basin" in this district is to the northwest and this change may have a significant bearing on the minor structures of the area.

PORTER STRUCTURE

A southeastward extension of the Mount Pleasant anticline is indicated in southeast Greendale township, the extreme northeast corner of Jasper township, and parts of Porter township, Midland County (See pl. IV). The structure seems to cross Porter township diagonally from the northwest corner to the southeast corner. Possibly, two separate anticlines with arcuate shaped axes are present and separated by a saddle in the vicinity of Porter village. One small closure* is mapped from Dow Chemical Company wells in sections 34 and 35, Greendale township, and section 2, Jasper township. From structural indications, this area bears much future promise and the shallow Marshall brine wells are scattered thickly enough to more or less accurately outline the limits of the fold in the Mississippian rocks. Moreover, some of the brine wells in this district have shown significant quantities of oil and gas.

Late in 1931, a Dundee oil well was completed in the NW.¼ of the NW.¼ sec. 26, Porter township. The size of the anticline is not known, but there seems to be

some similarity between the north Porter structure and the Mount Pleasant structure. Less is known about the fold in south Porter township where the production was found, but the axis will probably bend to the east across northern Jonesfield township, Saginaw County. The characteristics of folding in this area are still undetermined.

Present evidence does not show the sharp west dip off the structure to be much more than 80 or 90 feet per mile, but further drilling may change these figures. The northeast dip is 25 to 35 feet per mile, except where the plunging noses due to cross folding increase the rate. Apparently, the intensity of folding along the axis of the Greendale "high" is not so great as it rises out of the basin along this southeast trend. The asymmetrical cross section and the arcuate or "pistol-like" trend of the axis seem to persist. The individual structures in Porter township are staggered to the east up the regional dip in a somewhat regular en echelon arrangement like the Mount Pleasant and Vernon structures to the northwest along the same "high."

*The Pure Oil Company—M. Yost et al No. 1. which was the discovery well on this structure, came in during December 1932 with an initial production of 1,127 barrels.

SCOPE OF THE FIELD

Before the discovery of the "East Pool," the producing limits of the Mount Pleasant field in 1931 had an estimated possible productive area of about 3,800 acres. This figure, when the whole field is included, has been more than doubled by recent discoveries. The potential producing acreage of the Mount Pleasant and East pools can be conservatively placed at 8,500 acres but it will probably exceed 9,000 acres. Since the two pools are continuous, an arbitrary separation based upon the low saddle coming across through section 16 places in the East Pool all of those wells east of the north-south center line of sections 9 and 16, Greendale township, Midland County. If the separation were based on production, the north-south center line of sections 8 and 17 would make a more logical division. On January 1, 1933, there were 176 producing wells in the Mount Pleasant Pool and 116 in the East Pool. Nearly all of the wells are producing from the Dundee "pay" horizons, although several have found commercial amounts of oil in the Traverse, and one of them is producing profitably from that formation. The Traverse oil is found at about 3,000 and the Dundee oil at about 3,500 feet depth. Exclusive of the dry wells off the Mount Pleasant structure, 14 holes have been plugged either because of light production at the time of completion or because the output became so small that it was unprofitable to operate. At the present time (January 1, 1933), 16 wells are either drilling or rigged up in the East Pool and 2 in the Mount Pleasant Pool.

The Leaton Pool in Denver and Isabella townships, Isabella County, is situated on a small dome northwest of the Mount Pleasant field proper. The producing horizons occur at slightly greater depths than in the original area, but general operating conditions are about the same. Gas is found in a horizon above the Marshall (Napoleon) sandstone but has not been commercially utilized. Early in the history of the pool, the flow of gas was drowned out by water because the casing in the wells was not set to shut the water off from the gas, "sand." The oil comes from the Dundee. The pool now has 25 completed wells, 8 of which have been abandoned because of small size, and the potential producing area is about 600 acres.

The Vernon Oil and Gas Pool has thus far been confined to Vernon township, Isabella County, northwest of the Leaton Pool. Drilling has been rather slow in this area because of the erratic nature of the wells and the unfavorable water conditions in the producing formation. The wells produce from the lower part of the Dundee or near the top of the Upper Monroe and are 3,720 to 3,770 feet deep. They range widely in initial production. There are 19 oil wells in the pool, 2 drilling wells, and 4 on the structure that were dry or small producers (January 1, 1933). The developed part of the gas pool is in sections 23, 26, 35, and 36, and the oil pool is in sections 22, 23, 26, and 27. The gas wells to date (January 1, 1933) are 8 in number, but one well was small and has been abandoned. These are in the Michigan "sand" at about 1,300 feet depth and several are closed in awaiting a market. The outlined potential gas area is approximately 1,500 acres. The limits of the oil pool have not been defined, but the oil wells seem to be on the west side of the pool.

The Broomfield gas field is the largest of the developed gas fields in the Michigan "sand" and its limits have not yet been determined. As outlined by the gas wells, it has a probable area of over 3,800 acres. The gas sand is found at 1,300 to 1,450 feet, depending on the surface elevation and there are 14 producing wells in the field. The only well drilled to the Dundee is in the SW.¼ SW.¼ sec. 7, Deer field township. It was a dry hole at 3,734 feet and somewhat off the structure. Excepting two locations, the wells are conservatively spaced in the center of 40 acre tracts. The size, shape, and real potentialities of this pool are still unexplored.

The Clare gas field is largely in section 6, Grant township, Clare County, although there is one well in the south part of section 31, Hatton township, and another in the southeast corner of section 1, Surrey township. The field is limited in every direction but southwest by 7 dry holes, 3 to the Dundee at 3,900 ± feet, and 4 to the Michigan gas "sand" at 1,400 to 1,430 feet. The 7 productive gas wells are shut in waiting pipe line facilities. The proved area of the field is estimated at about 500 acres.

The Porter Pool was discovered by a well in the NW.¼ NW.¼ sec. 27, Porter township, Midland County, where the Dundee was found at 3,382 feet. Several dry holes have been drilled in the vicinity of this producer but other wells are being put down. The Dundee test in section 8, Porter township, had a substantial showing of oil and gas. One hole of considerable promise is being drilled in

section 22, about one-half mile northwest of the discovery well.

PRODUCING CONDITIONS

The producing conditions vary in different parts of the area and the oil and gas horizons differ in thickness, porosity, and permeability. These "sand" factors, together with the relative amount of gas and size of hole, largely govern the initial output of wells in the field. While being "brought in," some of the wells spray oil, flow steadily (see pl. VI-A), or flow by heads; others flow by periodic agitation or must be swabbed or pumped. Gas wells usually "come in" with a more or less uniform flow but many increase gradually up to a maximum rate. (See pl. VI-B).

After the well has been completed and the production is under control, rate of decline and ultimate recovery are questions of chief concern. To determine these, much data and information covering the results of operation must be collected and compiled. Such data may be worked up either by wells, leases, or entire fields to estimate the rate of production and amount of recoverable oil and gas on a property. In the decline of an oil property, there are two stages, the "flush" and the "settled" production, which are not usually very sharply separated. The flush production stage is that period when the rate of decline is relatively rapid, the output large, and the well is usually flowing. The settled production stage is the period, when the rate of decline is slow, the output small and relatively uniform, and the well is usually being pumped. The period of settled production is much longer than the flush period and, therefore, the value of recoverable oil during the settled period is subject to fluctuating prices.

The oil horizons in the Central Michigan Area are in the Marshall, Traverse, Dundee, and "Upper Monroe" formations. They vary in depth from 1,100 to over 4,000 feet and except for the first named are porous, cavernous limestones and dolomites. Nearly all of the oil in the area comes from the Dundee and Monroe "pay" zones, with minor quantities from the Traverse.

MOUNT PLEASANT POOL AND EAST EXTENSION

The total thickness of the Dundee "pay" is not accurately known in all wells, but a general idea can be obtained from Figure 31 which shows an east-west section of the Dundee across the central part of the field. In some of the wells of the East Extension, three oil zones have been found but two are more common in the pool. The thickness of the zones is difficult to determine and, as may be inferred from the diagram, the lower limits of the "pay" are often unknown. The reported amounts of continuous oil bearing formation vary from 2 or 3 to 20 feet and the total thickness of strata containing "pay" streaks above the bottom and edgewater level is usually from 16 to 40 feet. The water level on the east side of the pool seems to encroach in both the second and third "pays," while on the west side it underlies practically all of the productive horizons in the field. It is interesting to note the different depths to which the wells along this line of section (see fig. 31) were drilled. The rough conformity of the top of the "pay" to the top of the formation is also obvious from the cross section, but it is difficult to explain whether the eastward thickening of the pay zones is a regional condition due to the thickening from unequal deposition of the Dundee, or the westward absence of some of the upper beds that may be cut out by the disconformity at the top of the formation. The latter hypothesis seems most plausible from a consideration of similar conditions in other parts of the area and the apparent absence of Dundee water horizons in many low wells.

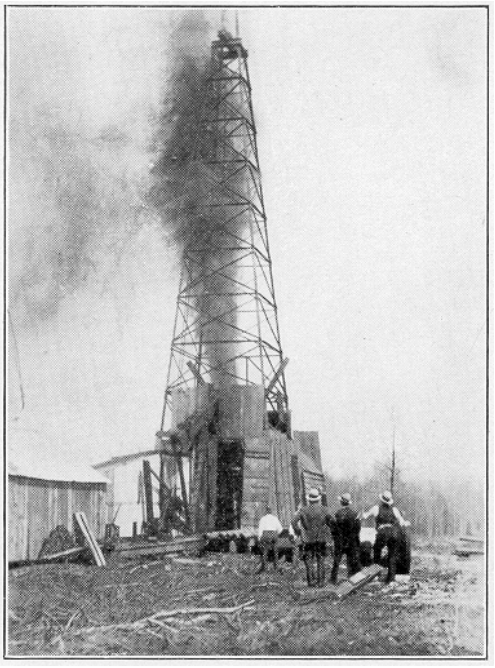

Plate VI. *A*. A large flowing well being “brought in” on State lease in East Extension of Mount Pleasant field. Its initial 24 hours’ production was 2,650 barrels.

Thus far, the wells with the largest initial production have been found in the East Extension where the "pay" zones are thickest and seem to have the greatest porosity. The rock as seen in cores and fragments is honeycombed. This is evidently due to solution. The porous beds are stylolitic and fossiliferous with many of the openings showing the shape and outline of cup corals and the molds of other fossils. The beds in some wells are so soft and porous that they drill up like a soupy, soft white mush. The irregular nature of the pore space makes porosity tests impracticable. The recovery of the oil is more closely related to connections between openings or *perviousness* that the perecentage of voids or *porosity*. Neither of these properties are uniform in most productive limestone horizons.

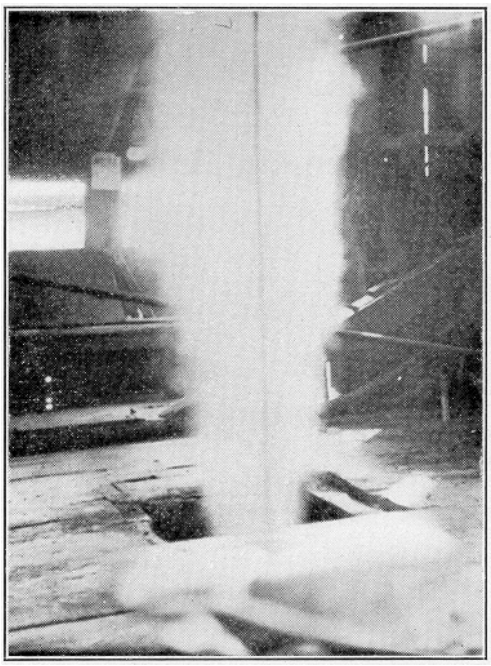

Plate VI. *B*. A large gas well in the Broomfield gas field being "brought in". (Note the drilling line coming out of the hole).

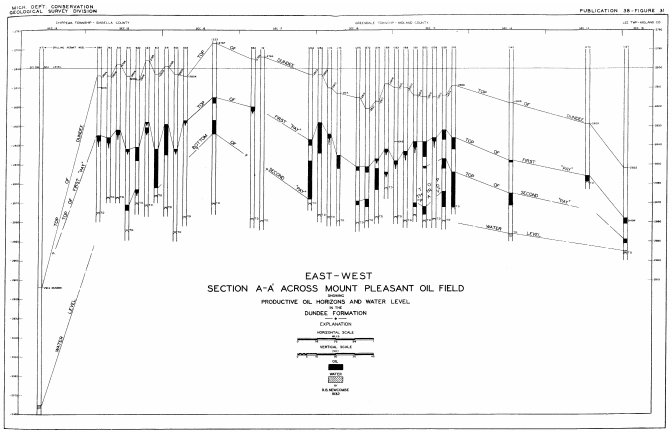

Figure 31. East-west section across central part of Mount Pleasant oil field showing productive oil horizons and water level in the Dundee formation.

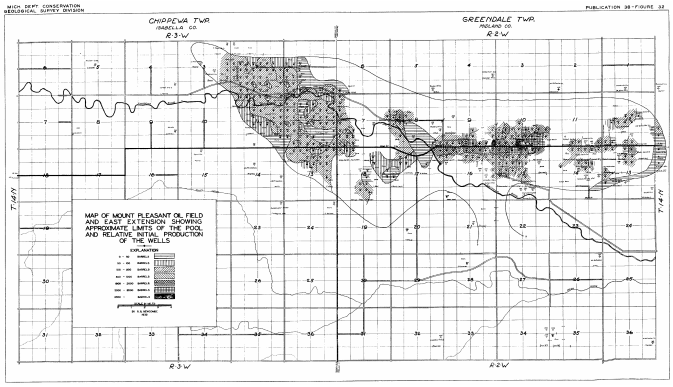

Figure 32. Map of Mount Pleasant oil field and East Extension showing approximate limits of the pool and relative initial production of the wells.

The initial production of wells in the Mount Pleasant field ranges from 10 or 15 barrels to 3,800 barrels per day, and four wells in the East Extension were rated at better than 3,000 barrels per day. Many of the wells in this part of the field have been produced wide open and the gas pressure has decreased so much that new wells are somewhat smaller. The approximate limits of the pool are indicated by Figure 32, which shows graphically by cross lining the relative initial production statistics for the field. A map of this kind does not take into account the order of completion, but it shows that there is not much relation between position on the structure and the size of the wells. The areas of light production and dry holes are roughly alined with the axis of the fold, but large wells have been found directly offsetting dry holes. Oftentimes, one or more "pays" are missing and a productive zone which may give a large flow in one well may be entirely absent in an adjoining well (See fig. 31). It is obvious that the porosity in the producing formation is not continuous. The Dundee formation has been cored in section 2, Chippewa township, Isabella County, and sections 9 and 18, Greendale township, Midland County. Characteristic features of the productive formation which have been observed in many wells are the calcareous, muddy streak near the bottom of the first "pay," the calcite and pyrite which has crystallized secondarily in many of the cavities, and the hard dense beds near the bottom of the last pay that usually drill up into angular flat chips and flakes.

The rate of decline and the ultimate production of the Mount Pleasant Pool and East Extension can now be fairly well determined from the first three years' history of the field. The decline of production on State leases shown in Figure 33 indicates that regardless of the rate at which leases are drilled, the flush period of production lasts about one year. The initial decline, however, is affected by the speed with which new wells are completed and the interference of one well on another. In the East Extension, some of the large wells decreased one half from their initial production in 15 to 20 days, but smaller wells in the Mount Pleasant Pool proper where drilling was not carried on so rapidly took as much as two or three months in declining this amount.

Production decline curves seem to indicate the economic life of the field to be about 7½ years. The use of acid may greatly increase this production. One lease in the Mount Pleasant Pool shows a decline to an economic limit of 7 barrels over a period of 50 months, and a few wells in the field have already been plugged. However, numerous factors, such as improved prices, new production methods, and the recently developed acid treatment, may act to increase the period of the field's productivity to even more than 7 years. The ultimate recovery of the field has been conservatively estimated at 4,000 to 4,500 barrels per acre, but several leases in the East Extension have already produced over twice this much. On the basis of 10 acres to the well, nine leases in this part of the field with 27 wells which had been in from 7 to 13 months had in June 1, 1932 produced between 6,800 and 16,600 barrels and averaged about 8,400 barrels per acre. Leases in the main part of the Mount Pleasant Pool have yielded from

less than 2,000 to over 6,000 barrels per acre. The pool with 300 wells has made a recovery to date (January 1, 1933) of 4,072 barrels per producing acre based on 10 acres per well. The curves of production are given in Figure 34.

The equipment and methods used in the Mount Pleasant Pool have practically set the standard for the other pools of the district. In most instances, the drilling has been carried on with standard rigs and until the fall of 1932 only about 6 wells had been put down with drilling machines. Nearly all the derricks are of steel, mostly "angle iron" Idecos and a few Moores. The operators in the field generally use concrete for derrick foundations, (see corner posts in pl. VII-B) but in the new East Extension some of the contractors set up their derricks on wood blocks. Pumping engines and some drilling engines are mounted on concrete. The drilling engines are generally from single cylinder to four or six cylinder types and Include Clark, Cyclone, Franklin, and Budda makes. The principal source of fuel and power is gas, but gasoline and steam are also used. The boilers are generally gas or oil fired. At most wells, the water for drilling Is procured from 2-Inch water wells that average about 25 feet depth. The two adjoining slush pits, dug to separate the sand and lime cuttings from mud, are approximately 40 by 40 feet and 10 by 15 feet and 3 feet deep.

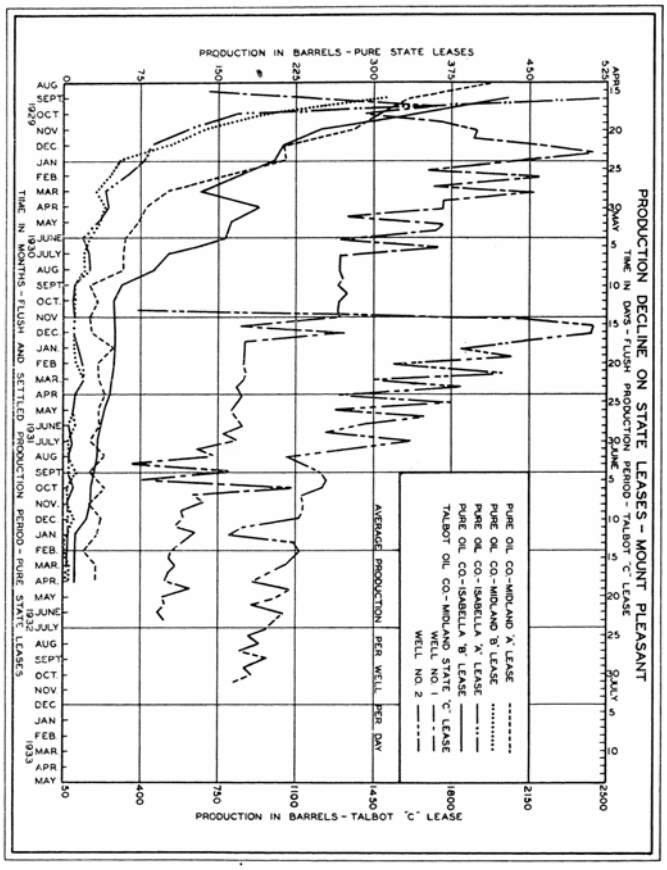

Figure 33. Production decline on State leases in the Mount Pleasant field and East Extension.

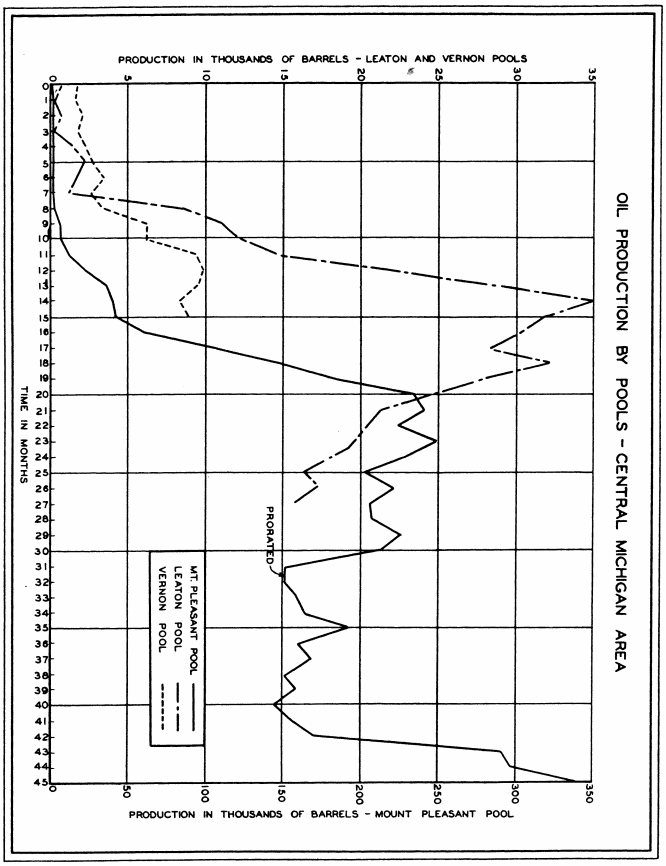

Figure 34. Graph showing fluctuation in monthly production by pools in the Central Michigan Area.

Because of the value of the Marshall brine, water shut-offs above and below this formation are of great Importance. During early operations in the field, the Marshall was sealed by means of packers or cement, but now mud has replaced cement. Wells were originally commenced with 14-inch drive pipe, but regular 10-inch has replaced this size. Usually from 250 to 300 feet of drive pipe is necessary. The 8-inch pipe is set at about 800 feet to shut off a cave that may occur near the Parma-Bayport contact and is placed wherever a suitable seat can be found below this contact. The 6⅝-inch string is mudded through the Marshall. A modification of the Haliburton method is generally used in mudding off this formation. When the casing is run, a metal disk with 1½ inch aperture is placed in the bottom joint of pipe. The pipe is raised off bottom, circulation established by means of the usual "mud hog" pumps, and then sufficiently fine uniform fire clay mud introduced to go behind the pipe well up over the Marshall formation. A single plug is run in on top the mud, and when this plug hits the disc, a pressure is built up which acts as a signal to lower the pipe on bottom. Savings of about one-half in setting the "Marshall string" have thus been made possible. A few operators seal off the Marshall brine horizon by means of packers. The "Marshall string" is from 1,400 to 1,450 feet of pipe, and the casing seat is most always in a dark gray shale formation directly beneath the Lower Marshall "Red rock." The "oil string" is generally of 5-3/16 inch casing and is set in lime formation from 1 to 10 feet below the

top of the Dundee or an average of 3 or 4 feet in the formation. In the main part of the field, this string is 3,500 to 3,530 feet long and is simply set on bottom with a steel shoe, but occasionally enough drilling mud is left in the hole to go behind the pipe and aid in preventing oil and gas from breaking out around the shoe.

The wells are rarely shot and then the charge is usually not more than 100 quarts (about ½ gelatin and ½ nitro-glycerin). The explosive is lowered in shells by the usual method and set off by means of a squib or "go devil." The work of shooting wells in the field is handled by one company. (See pl. VII A).

The locations are for the most part regular with four wells to a 40 acre tract, 330 feet by 330 feet in each corner of the property (See pl. VIII). The land is not divided into small parcels and since it is largely controlled by major operators there has not been any frenzied closely spaced drilling. Consequently, this spacing has become the established practice for the central Michigan district.

Costs have fluctuated greatly throughout the life of the field because of changing economic conditions. The drilling of a well on a "turnkey" basis originally cost about $25,000, later dropped to $22,500, and in June 1932, most contractors were willing to complete a regular Dundee well for $17,500 to $18,000. These prices include all costs up to the completion of the well with oil in the tanks, but tankage must be furnished by the operator. Prices have decreased sufficiently through 1932 so that at the beginning of 1933, some wells were being drilled for as little as $14,000. The price for drilling at the commencement of operations in the field was $3.00 per foot, but now the current price is $1.75 per foot, in addition to which the company must furnish rig, fuel, and gas lines for fuel purposes. Likewise drillers' wages were $10.00 per day for drillers and $9.00 for tool-dressers, but these are now down to $8.00 and $7.00 and lower. Working days are on the usual 12:00 o'clock to 12:00 o'clock or 12 hour "tour" (commonly pronounced tower) schedule.

The completion of wells in the prolific part of the Mount Pleasant Pool and East Extension is usually done with a 1,600 pound control head and oil saver. Master gates are seldom used. Plow lines to the separator and tanks either consist of a parallel hook-up of 2-inch pipe or a single 4-inch line. (See pl. VII). They may be hooked up so as to by-pass around the separator if necessary. The common types of separators are Smith or Ellis and from 40 to 60 pounds back pressure is ordinarily maintained upon them. The shut-in pressure on some wells in the East Extension (June 1932) runs up to 475 pounds.

The equipment in the field shows very little corrosion. This is possibly due to the comparative absence of sulfur and the effective shutting off of salt water. Water is far enough beneath the principal "pay" zones in the Dundee formation on top of the structure that there is very little "cut oil." Lifting costs per barrel over the present life of the field have not been computed, but the flowing life of most wells is about one year. Neither gas nor air lifts have been adopted. The flowing wells will average about one barrel of oil to a thousand cubic feet of gas, and on this basis the lifting costs through gas wastage can be fairly well estimated. The largest operator in the field tubes nearly all of its wells before they cease flowing.

Pumping is most commonly carried on by means of individual powers, the wells being pumped with the beam and wire line instead of jacks and rods. Savings are thus effected because deep wells of this type can be more cheaply cleaned out and valve cups replaced when the necessity for unscrewing and removing the rods is eliminated. The principal exceptions to this procedure are the three central power units in the field, by which the Stanolind pumps 8 wells on its N. Davis lease in section 2, Chippewa township, Isabella County; the Pure pumps 16 wells from the power on its State-Isabella "B" lease in the same section; and the Pure also pumps 16 wells from the power on its W. D. & H. Gibson lease in Section 12, Chippewa township. These powers are of modern design and, although the details will not be described here, it is interesting to note that Bessemer engines are used and in several instances two wells are hooked up in balance so that one pumps the other. Obviously, these wells on central powers are equipped with pumping rods and jacks. In the wells with individual powers, single cylinder gas engines are used and these are almost invariably mounted on a concrete base.

The paraffin difficulties are not due essentially to paraffin itself, but rather to a gummy mixture of sludge, salt, and paraffin. In the flowing wells, it cakes in the casing in the upper part of the hole, until only a very small opening is left for the passage of oil, thus providing a veritable “tapered tubing" condition. To be properly handled, wells of this type should be cleaned out once about every two months. The rate of production is probably checked more rapidly by "salting up" of the "sand" than any other factor, but the use of acid for treating the "pay" has notably increased the output of many wells.

This experimentation with acid which has been carried on in the field since December 1931, was initiated through the use of hydrochloric acid, manufactured by the Dow Chemical Company, on Pure Oil Company wells. The Dow Chemical Company has developed corrosion resistant inhibitors to protect the tubing and casing which, together with certain technique, are covered by patents. New methods are being evolved as the work progresses and, consequently, the present results are only preliminary. The use of acid for increasing production is not a new procedure, but it has been done very successfully in the Mount Pleasant field. It has also been introduced with considerable success in the Muskegon field. Several makes of acid for oil field use are now on the market.

The amount of acid used in a well may be from 500 to 1,000 gallons, but as small a charge as 60 gallons has been put in. At first, charges of 3 to 4 barrels were introduced into the wells and an alkaline reaction was obtained after a 24 hour period. It has now become

more common practice to put in the entire charge of 500 to 1,000 gallons. When wells under treatment are still flowing, usually a pressure is kept on the "Dundee sand" face with a high pressure pump. The acid is introduced first, then the hole is nearly filled with oil, and pressure fittings are placed on the well head. Since the acid weighs about 10 pounds to the gallon, there is no difficulty in keeping it on bottom, but sustained pressure is necessary to prevent gas from interrupting the early stages of the reaction of the acid with the lime formation and carrying it away from the pore spaces of the "pay" horizons. In the Muskegon field, it is common practice to introduce the acid into the hole through an oil column and then add enough oil to fill the hole to the top. Frequently, the reaction at the bottom of the hole creates a slight vacuum at the well head by oil forcing its way back into the newly opened pores and lowering the fluid level.

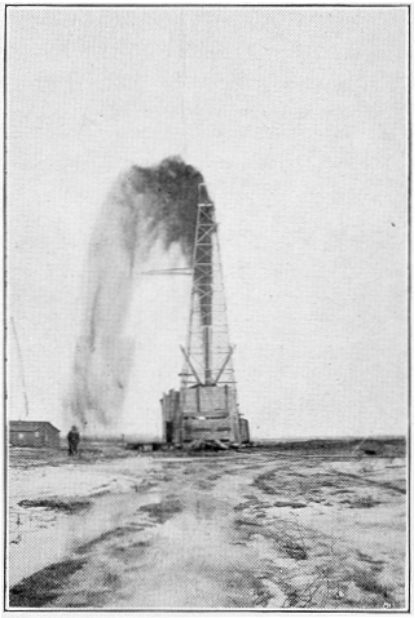

Plate VII. *A*. Well making a flow of oil after being “shot” with nitroglycerine.

Applications of acid have been used on new and old wells and flowing and pumping wells. The results have not been uniform but nearly all the wells treated have increased their output. Some of the wells on the beam have commenced to flow, thus indicating greater perviousness due to the opening of "sand" passages and a consequent increase in the amount of gas forcing its way to the face of the hole. The treatment has caused many wells to double and some to quadruple their output. A few have done even better than this. By July 1932, approximately 30 wells in the Mount Pleasant field had been treated, and some of the leases adjoining those where wells had been treated with acid showed a decrease in output. The use of acid increased in the last half of 1932 until on December 31, nearly all of the wells in the field had been treated once and some of them several times. The total increase in production from this was large.

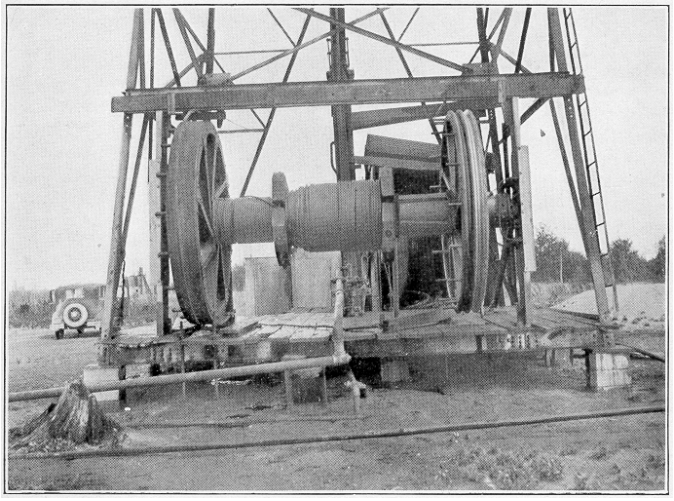

Plate VII. *B*. Floor of oil derrick set on concrete corner posts showing steel bull wheel, well head connections, flow line, and location of slush pits (to the right).

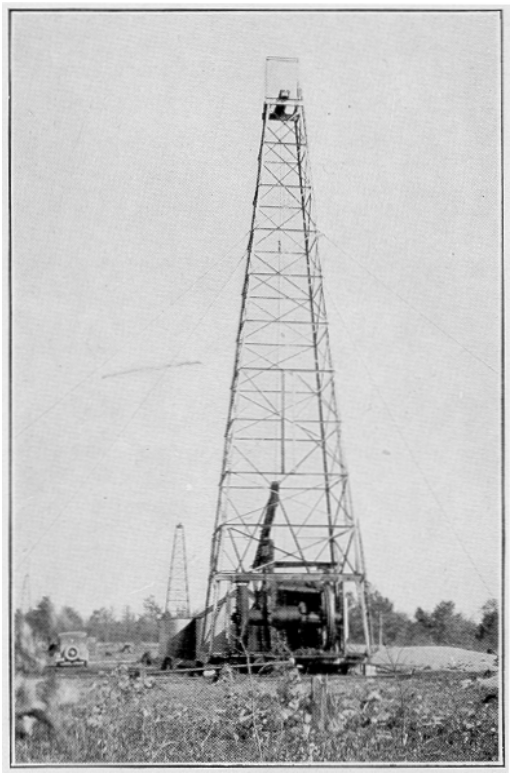

Plate VIII. Standard steel derrick with 4 guy wires (note the normal spacing of wells).

The presence of water in the productive formation has not greatly hampered operations in the Mount Pleasant Pool. When bottom water has been encountered in edge wells, it has usually been plugged off before much damage could be done. However, on one or two occasions when the hole was allowed to fill up, the water on the sand under the pressure of this column so displaced the oil in pores near the face of the producing formation within a single day's time that it was impossible to bring the production back after shutting off the water.

Although water conditions have not been considered serious, a number of wells have made from 20 to 50 barrels of salt water a day. This water trouble is increasing the lifting cost and making the area more expensive to operate. In addition to the increase in lifting cost, operators are having added expense in treating their oil. A number of methods are being used which are satisfactory for the present. Some operators are using their old boilers and are steaming the oil, while a few are using tretolite. The difficulties to be overcome are not only the presence of water in the oil, but also paraffin in the casing, tubing, and flow lines, and dissolved "salt" (calcium chloride, $CaCl_2$), which may cause refining trouble in high pressure stills.

LEATON POOL

The productive horizons are about the same in the Leaton Pool as in the Mount Pleasant field proper, except that the intervals between the tops of formation and "pays" vary a few feet. The Michigan "stray" and Marshall (?) gas horizons are present in most of the wells, and the principal flows of gas are found from 56 to 70 feet above the Napoleon sandstone. An unusual red horizon near the top of the Marshall is found in some of the wells in this pool, and gas and oil showings occur directly beneath this bed. In one well, gas was found beneath a thin shale break on top the Napoleon. Gas was also encountered beneath the Lower Marshall "Red rock."

The Traverse limestone contains several "pays," including the Saginaw "sand" at the top, a horizon from 65 to 80 feet in the formation, and the more prolific horizon of Central Michigan ranging from 105 to 188 feet below the top. There are no wells producing exclusively from the Traverse in the Leaton Pool, but several operators bradenhead the casing to save the Traverse oil. In about two-thirds of the wells, the first Dundee "pay" is from 40 to 47 feet from the top and in the rest of them not less than 35 feet from the top. The porous beds in the Dundee are found at intervals in about 20 to 24 feet of strata, but the "total pay," including the breaks of 3 to 7 feet between the porous horizons, probably does not exceed 12 feet. The first "pay" was recorded as 5^ feet thick in one well and 7 feet in another, and water was encountered beneath the oil in the third "pay."

The initial production in this pool was not large, the highest being 549 barrels. Seven wells made initially between 200 and 420 barrels, but many were under 100 barrels. The amount of gas with the oil in the Dundee ranged between 100,000 and 500,000 cubic feet. At the present time, 9 wells have been plugged and abandoned and all but 2 or 3 are on the pump, but acid is being used with considerable success. The curve of production in the pool is shown in Figure 34, and the yield per acre on the basis of 220 producing acres has been 3,081 barrels (January 1, 1933). Before the use of acid the ultimate recovery was computed at about 3,200 barrels per acre, but this probably will be materially increased.

The equipment used in the Leaton Pool is about the same as in the main field to the southeast. Most of the larger wells flowed for approximately 18 months and about half a dozen of them have been tubed. The pumping wells are on individual powers and, as in the Mount Pleasant Pool, wire lines take the place of rods because of the greater ease in cleaning out and replacing valve cups.

VERNON POOL

Producing conditions are unusual in the Vernon Pool, in that the Dundee seems to be largely absent and "pay" horizons are very close underneath the Bell shale. The interval from the Bell shale to the first "pay" varies from 0 to 10 feet, but in most of the wells it is under 7 feet. Recently, several wells have been deepened from about 10 to 30 feet into new "pays." Two unusual wells in the pool, situated in the SW.¼ SE.¼ NE.¼ sec. 27, and NW.¼ NW.¼ SW.¼ sec. 26, Vernon township, Isabella County, found the "pay" at 40 and 50 feet in the formation. These anomalous conditions, together with the erratic water horizons, absence of Dundee, and occurrence of fluorite, suggest that the productive formation is locally faulted.

Two "pays" have been found in the Upper Monroe of the Vernon Pool. The first is from 1 to 6 feet thick but usually contains only 1 or 2 feet of porous formation. The second, which is separated by a break of 4 to 7 feet of tight, dense lime, is from 2 to 5 feet thick and generally carries water in the bottom. Water has been found with the oil in the first "pay" in some wells. The total thickness of productive beds averages a little over 4 feet but is not over 9 feet. These porous zones are found throughout 8 to 14 feet of dolomite strata. Further proof of the stratigraphic position of these "pays" has been obtained in a well off structure in Section 12, Gilmore township, Isabella County, where important showings of dead oil were found beneath the first water at the base of the Dundee.

The Michigan "stray sand" occurs in the Vernon Pool from 55 to 70 feet above the Marshall and contains both gas in the top and a residue of heavy oil near the bottom of the "broken up" sand. The Traverse has several porous members and showings have been found from 30 to 510 feet in the formation. These seem to occur with little consistency between wells.

Despite the many oil wells in this district that have either made appreciable amounts of or have gone entirely to water, most of them are holding up satisfactorily. The largest initial production of any one well was 2,500 barrels and 6 wells had an initial output of over 500 barrels each. The others came in at rates varying from 10 to 390 barrels. The pool is nearly three years old and up to January 1, 1933 produced 589,136 barrels of oil. It is reported that the largest well in the field has made over 80,000 barrels of this total and on the basis of 190 producing acres the Vernon Pool has already shown a recovery of 3,101 barrels per acre. Development has

been slow because of the erratic nature of the production.

Except for the greater depth, the equipment and methods are much the same as in the other pools of the Central Michigan Area. The water problem has been handled in several different ways. At first, large settling ponds were built, but these did not prove adequate to take care of all of the brine produced with the oil. Rains washed some of the dikes away, the earthen reservoir became too full, slopped over, and it was necessary to adopt some new type of disposal. Efforts to put the brine back in the wells between the six and eight inch have been successful, and most of the excess salt water with the oil is now being taken care of in this manner. In two wells, however, the Parma sandstone would not absorb the water put back in the hole between the casings and earthen reservoirs had to be used.

Contrary to expectations, only a small quantity of "cut oil" has been produced in Vernon township. The largest amount reported is 1½ per cent and this is now reduced by back pressures on the wells. The oil from this pool brings the same price as other crudes from the central district.

PORTER POOL

The discovery well is the only producer in the Porter Pool, but several other holes found small showings in the same township. The Berea had oil in section 32 and a substantial "pay" of uncommercial size was penetrated at 19 feet in the Dundee in section 8. The well in the northwest corner of section 26 is producing from the Dundee formation. Gas was first encountered at 34 feet from the top, oil about a foot deeper, and small increases in the next 26 feet. The exact thickness of the porous horizons was not determined. The north offset to this well, which was at about the same structural elevation on the Dundee, encountered a show in the same "pay," but the formation was tight and water was tapped at 90 feet from the top. The discovery well in section 26 also had a showing of oil and gas at about 125 feet in the Traverse or about the same as the Traverse "pay" of the Mount Pleasant field. Two other showings were found in the Traverse at 328 and 370 feet from the top of the formation. This well had an initial production of 118 barrels but did not flow regularly. The output has been stimulated by using acid.

PROPERTIES OF THE OIL

The properties of Dundee crude from Central Michigan are interesting from a refining standpoint and from the regional relations which some of these properties seem to have to the location of the different pools. Although the Devonian oils from the district are high gravity, paraffin base crudes, until very recently they have been unable to compete in the lake port refinery markets with light crude oils from the Southwestern States. The reason for this is apparently related to the low anti-knock rating of the straightrun gasolines, as shown in Table XIV. These oils when cracked give a satisfactory motor fuel, but certain plant adjustments are necessary which result in costly interruptions in operations if a steady supply of Michigan crude is not available. Until recently, many of the larger refineries avoided Central Michigan crudes, and the flush production of 1931 and 1932 brought on local supply in excess of demand, thus depressing prices. The price of Mount Pleasant crude has fluctuated between a minimum of $.37, and a maximum of $1.70, but it has almost always been below the Mid-Continent gravity scale. Even in the fall of 1932, with demand increasing, Mount Pleasant oil which brought $.85 should have been worth $1.00 a barrel on the basis of the Mid-Continent prices. Still later in the year, however, in the face of a sharp drop in the prices of Mid-Continent oil, the price for Central Michigan crude was advanced to $.95 per barrel.

The Dundee and Upper Monroe crudes from the different pools of Central Michigan seem to have similar properties, but there is a slight variation from pool to pool toward the center of the Basin. Whether this is due to distance of migration, change in the source and reservoir beds, or combination of these factors is uncertain. However, the increase in gravity, sulfur content, and gasoline recovery toward the center of the Basin is well shown in Table XII. These analyses were on samples taken from different wells at the same time and under similar conditions. The gas oil ratios in the wells at the time the samples were taken, however, were not determined. It is very probable that there was considerable variation among these; hence, the results of the analyses would vary accordingly. The ones which show properties apparently most out of line are those of small output and possibly in the pumping stage. These include the samples with relatively low gravity and gasoline recovery in the Mount Pleasant Pool and the high sulfur in the Porter Pool. Otherwise, gravity, sulfur content, and gasoline recovery increase progressively down the regional dip.

Location		A.P.I. Gravity	Flash O. C. °F.	B. S. & W. %	Sulphur (H) %	Pourpoint °F	Gasoline Recovery %
Porter Pool		40.4	below 60	trace	0.18	below 0	33.0
East Extension	Lee Township	41.8	below 60	trace	0.13	below 0	33.5
	Greendale Township Section 14	41.8	below 60	trace	0.12	below 0	32.5
	Greendale Township Section 10	42.0	below 60	trace	0.11	below 0	33.5
		42.7	below 60	trace	0.12	below 0	33.5
Mount Pleasant Pool		41.8	below 60	trace	0.11	below 0	32.5
Leaton Pool		43.0	below 60	.05	0.15	below 0	35.0
Vernon Pool		44.5	below 60	trace	0.24	below 0	36.0

Table XII. Properties of the Central Michigan Dundee crudes.

The more detailed analyses of oils from the Mount Pleasant field indicate some of the refining difficulties to be encountered in the manufacture of finished petroleum products. The properties of the Marshall, Traverse, and Dundee crudes, and the topped product from the Dundee oil are summarized in Table XIII. The Marshall production is not large enough to be of commercial importance, but a heavy oil of this type in the Mississippian rocks of an eastern State is rather unusual. Traverse oil is produced in minor quantities in the field. The analyses of Dundee crudes and topped products are from the work of Egloff, Nelson, and Truesdell[4] and the Kansas City Testing Laboratory.

Although the exact sources of these oils are not known, they are probably from the older part of the Mount Pleasant field in Chippewa township, Isabella County.

SUMMARY OF PROPERTIES

Sample No.	1. (Marshall)	2. (Traverse)	3. (Dundee)	4. (Dundee)	5. (Dundee)	6. (Dundee)	7. (Topped Crude)
Gravity	17.9	42.7	43.4	41.2	42.3	42.7	34.5
Color	Black	S. R. Green			Green	Green	
Pourpoint °F.	35	Below 0			0	Below 0	20
B. S. & W., Percent		0.3			0.05	Trace	0.4
Water, Percent					Trace	Nil	
Sulfur, Percent		.22	.62	.19	.137	.306	.21
Visc. at 100° F. (Sec.)	712	38 at 70° F. 36	S. U. 39 at 70° F.				11 at 77° F.
Initial	406 (for the distillate)	124	90	134	110		325
Flash °F.	295	R. T.					(Pensky-Martens) 130
Fire	335						(Cleveland open cup) 160
Base	Asphalt	Paraffin	Paraffin	Paraffin	Paraffin	Paraffin	Paraffin

A.S.T.M. 100 c.c. DISTILLATION TEMPERATURE °F.

Percent Distilled Over	On the 36° Gravity Distillate						
10	467	207	229	228	219		396
20	487	294	310	298	300		434
30	503	372	384	366	374		
40	515	436	450	444	443		
50	532	490	530	506	506		593
60	549	545	Steam	582	578		
70	565	592			618		
80	592	636			665		
90	631	Steam			729		731
E. P.	697	636+			764		760 +
Percent Distilled Over		89.5					97.5
Percent Coke		10					2.6
Percent at 410° F.							13.5
Percent at 437° F.							21.5
Percent at 572° F.							47.5

SUMMARY OF YIELDS

Gasoline, Percent		38.85	35.0	40.7	41.5	38.5	
Kerosene, Percent		4.5	25.0			8.0	
Gas oil, Percent		23.68	10.0			21.8	
Lub. Dist., Percent			15.0				
Wax. Dist., Percent		14.15	Residuum, 15.0			13.7	
Cylinder stock, Percent						15.0	
Topped crude, Percent					57.4		
Total distillate, Percent	26.5						
Loss, Percent	0.5	8.22			1.1	3.0	
Fuel oil, Percent.....	73.0	10		30.6	33.8	28	Flashed Residue from cracking
Gravity	14.3	19.4		11.0	12.3	10.0	
Percent B. S. & W.				0.4	0.6	0.3	
Visc. at 122° F.	240 at 210 S. U.	192 at 210 S. U.		27	20	36	
Flash C.O.C.	450 F.	550		190	180	195	

SUMMARY OF YIELDS—Continued

Sample No.	1. (Marshall)	2. (Traverse)	3. (Dundee)	4. (Dundee)	5. (Dundee)	6. (Dundee)	7. (Topped Crude)
Fire C.O.C.	485	615		280	270	285	
Flash point Pensky-Martens				165	155	175	
Cold Test	65 F.	35		Below 0	Below 0	Below 0	
Initial				412	414	395	
Over 572°				18.5	24.0	17.0	
Sulfur	0.63						

Table XIII. Analyses of crudes from Central Michigan Area.

According to these authors, a gasoline of high antiknock value can be manufactured from Michigan oil:

"(1) By cracking the *topped crude* to make a product of such high knock rating that blending it with the straight run gasoline will give a motor fuel meeting acceptable knock rating standards.

(2) By cracking the *straightrun*, badly knocking gasoline itself.

(3) By cracking the crude oil."

The properties of six Dundee straightrun gasolines, with different end-points, and one Traverse straightrun gasoline are shown in Table XIV, in which it may be observed that the highest knock rating is an octane number of 52. The three gasolines which were cracked from the topped crude have an octane rating of 67 and 68, and the recovery was between 62.3 percent and 63.6 percent. The motor tests to determine knock ratings were carried on with the Ethyl Gasoline Corporation new "Series 30" motor, and the motor fuel used as a base for expressing benzol equivalents was a Pennsylvania straightrun gasoline to which pure benzol was added on a volume basis in amounts to match the unknown fuel in the motor. The high knock ratings of the straightrun gasolines from Mount Pleasant crude have given rise to a demand for this oil as a source of naphthas and cleaning solvents, and two refineries at Muskegon are using this oil to manufacture such products. As indicated under the summary of yields in Table XIII, the flashed residue from the cracking of the topped crude gives an excellent fuel oil with gravity from 10° to 12.3° Be. A.P.I. The kerosene distillate from Central Michigan crude has a gravity of 44.5 Be. and the boiling range is 420° to 493°P. with the flash point at 197°Tag. The gas oil has a gravity of 37.6° Be., with a flash point of 260 and fire point of 290°F.

Straightrun Gasolines (No.).....	1.	2.	3.	4.	5.	6.	7. (From Traverse Crude)
Gravity	73.1	67.1	62.8	61.9	60.4	59.3	58.4
Initial °F.	91	111	111	113	121	128	133
Endpoint °F.	298	348	398	407	426	435	426
Per cent of crude.....	14.4	23.0	32.3	34.7	38.2	40.7	38.85
Knock ratings: Per cent benzol equivalent	38	25	—10		—20	—26	
Octane number	52	41	23		18	15	
Percent over—	A. S. T. M. 100 c.c. DISTILLATION Temperature.						
5	120	145	151	155	160	162	
10	131	161	173	177	179	181	186
20	147	181	202	207	216	217	210
30	160	197	225	231	243	245	232
40	172	210	245	253	267	281	255
50	182	223	265	275	289	306	279
60	193	237	284	293	314	330	303
70	205	251	305	320	337	353	328
80	218	267	327	340	357	375	355
90	239	289	353	366	383	402	384
95	262	312	380	391	401	431	406
E. P.	298	348	398	407	426	435	426
Percent over	96.5	96.5	97.0	97.0	98.0	95.0	97.5
Percent bottoms	1.0	1.5	1.5	1.5	1.5	2.5	1.4
Percent loss	2.5	2.0	1.5	1.5	0.5	0.5	1.1

Cracked Gasolines from Topped Crude of Sample No. 6— Table XIII.....	Sample No. Topped Crude. 1.	2.	3.
Gasoline recovery (percent of topped crude).....	62.3	63.6	62.5
Residuum (percent of topped crude).....	30.6	33.8	28.0
Coke, gas and loss (percent of topped crude)	8.2	3.9	12.2
Gas (Cu. ft. per bbl. of charge)	391	458	437
Gravity	60.9	61.2	60.5
Initial °	94	86	94
Percent over—	Temperature F°		
20	192	172	184
50	284	269	272
90	400	367	373
Endpoint °F.	404	388	389
Knock ratings:			
Percent benzol equivalent	54	54	53
Octane number	68	68	67
Gas Oil:			
Gravity	37.6		
Flash point	260		
Fire point	290		

Table XIV. Properties of gasoline from Central Michigan crudes.

MARKETS

The marketing of the crudes from the Mount Pleasant Area has largely been outside the State, although local refineries in Michigan are gradually taking up more and more of the crude. Unlike the Muskegon field, where most of the shipments were to Chicago refining centers, the Central Michigan oil is largely being shipped by rail or pipeline and boat to points on the lower Great Lakes. Principal among these market outlets are refineries at

Sarnia, Ontario, Canada; Trenton, Michigan; Toledo, Ohio; Cleveland, Ohio; Toronto and Montreal, Canada. These plants are operated by the Imperial Oil Co., Ltd.; White Star Refining Co.; Pure Oil Company; Sun Oil Company; Standard Oil Company of Ohio; McColl-Frontenac Oil Co., Ltd., and several other Canadian concerns. The movement of oil to all of them has not been continuous, the marketing arrangment being either by single commitments, exchange of crude in other refining centers, or long term contracts. However, the total aggregate movement at any one time has been comparatively steady and has taken most of the production from Central Michigan.

Several small refineries in the State are in active operation, some are shut down, and others are under construction. Mount Pleasant crude is being used in the manufacture of naphthas by the Old Dutch Refining Company and Naph-Sol Refining Company at Muskegon, Michigan. The Peerless Oil Company of Big Rapids is operating small topping plants at Big Rapids and Saginaw, producing chiefly gasoline and fuel oil. This concern also operates a plant of about 2,000 barrels capacity in Chicago, Illinois. In Mount Pleasant, the Roosevelt Refining Company has expanded its plant until now it can furnish lubricating stock as well as gasoline, kerosene, gas oil, and fuel oil. The refinery built by the Standard Oil Company of Indiana at Zilwaukee, near Saginaw, is shut down, but a new plant constructed by the Pure Oil Company at Midland is now in operation. Some of these refineries obtain oil by pipe line, but most of them are being supplied by tank car or truck. The refined products, particularly motor fuels, are being largely distributed within the State through the smaller retail organizations.

The sale of crude oil as fuel and for gas oil purposes has been widespread. The Consumers Power Company, Detroit City Gas Company, and other large artificial gas concerns have been the principal buyers. The Dow Chemical Company is now purchasing crude oil for fuel, but with the completion of the new refinery at Midland, this company will probably use fuel oil exclusively. Numerous small shipments of crude oil for fuel are made to beet sugar plants and other industrial concerns in various parts of the State, and some farmers have even used the unrefined oil in tractors and gas or oil engines,

PIPE LINES AND STORAGE

The Pure Oil Pipe Line Company has the most extensive gathering and trunk pipe line system serving the field. The total capacity of all its lines is about 15,000 barrels daily. The largest is a six inch joint-welded line 38.7 miles long and extends from the Purtell station and tank farm in section 15, Greendale township, Midland County, to the Bay City Terminal on the Saginaw River near Saginaw Bay. The original capacity of this line was rated at 9,000 barrels daily with a working pressure of 600 pounds, but this has been stepped up somewhat. In addition to the main line, there are 16 miles of 3 and 4 inch to the Leaton and Vernon pools and a 10 mile branch line to the Mount Pleasant loading rack. Four field pump stations and two terminal stations are necessary for the operation of this system.

Besides lease storage owned by the various operators, the Purtell Tank Farm of the Pure Oil Company includes 7 standard type 55,000 barrel tanks for storing oil in the field. (See pl. IX). The Bay City Terminal has eight 55,000 barrel tanks which are of lesser diameter and 45 feet high. Other storage facilities are available at the Roosevelt Refinery in Mount Pleasant and on the Adams lease of the Talbot Oil Company in section 10, Greendale township. The Talbot Oil Company tank is of 80,000 barrels capacity.

The Simrall Pipe Line Company has a 4 inch line into Mount Pleasant which serves the Roosevelt Refining Company and also brings some oil for rail shipment from the refinery siding where loading racks are situated. It is about 14 miles long, and although the capacity is 8,000 barrels daily, approximately 3,000 barrels were being run in July 1932. The Old Dutch Construction Company maintains a gathering system in the Leaton district. The Wellman Oil Company also operates a line with loading racks at Leaton, which consists of 5 miles of 3 inch and 23 miles of 2 inch. This pipe line has a capacity of 1,000 barrels and about 350 barrels daily are now being run. The Peerless Oil Company operates 17 miles of pipe line from the East Pool to St. Louis, Michigan. This line goes from the Harnick lease to Oil City, and then straight south. It is 17 miles long, consisting of 12½ miles of 3 inch and 4½ miles of 4 inch pipe. There are loading racks at St. Louis for 14 cars and in the middle of August 1932, the line was running about 3,000 barrels per day, most of which was being shipped to Chicago. A new 3 and 4 inch line has been recently completed from the East Extension to a loading rack at North Bradley on the Pere Marquette Railroad. This pipe line, which is owned by the Producers Pipe Line Company, is approximately 8.1 miles long and has a capacity of 5,000 to 6,000 barrels daily. The amount being run in July, 1932 was 1,000 barrels per day. It will probably transport most of the oil for shipment to Muskegon.

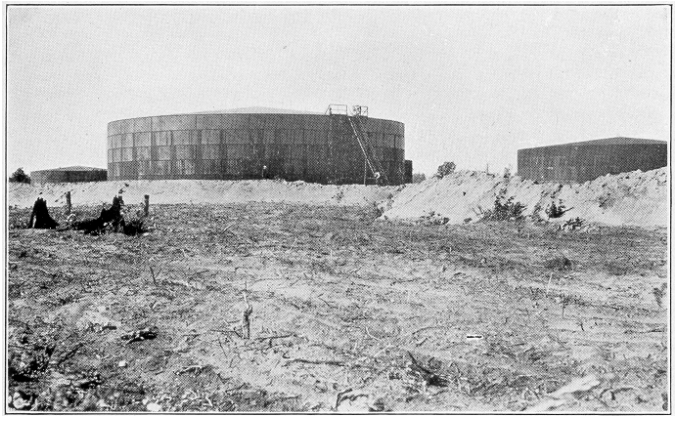

Plate IX. Storage tanks (55,000 barrels capacity) on Purtell Tank Farm of the Pure Oil Company. (Note the earthen dikes thrown up around the tanks for fire protection.)

WATER CONDITIONS

The oil field waters of Central Michigan are more concentrated than the brines from most other eastern districts and show many important relationships between chemical composition and structure, both regionally and locally. The chemical properties of the various brines from this area are indicated in Table XV. The analyses are given in the percentage of the principal salts as calculated in hypothetical combinations by the Dow Chemical Company and also in the accurate determinations of ions in parts per million as reported by the laboratory of the State Department of Health. The high concentration is shown in Table XV by the percentage of total solids which ranges between 265,000 and 404,000 parts per million and is usually over 300,000 parts per million. The brines are also characterized by the exceedingly small amounts of sulfate and carbonate, and traces of iodine. They are very high in primary salinity, the Dundee brines from the entire State ranging from 60 to nearly 80 percent, and secondary salinity varying from 20 to over 30 percent. Chloride salinity is usually over 99 percent and primary alkalinity is almost lacking, being normally less than one percent. The quantity of bromides and calcium-magnesium chlorides seems to increase with both depth and the nearness to the structural center of the "basin."

The Traverse, Dundee, and Monroe brines usually contain small amounts of dissolved hydrogen sulfide and are often blue or black in color. The "black water" in the upper part of the Detroit River is so strikingly different in physical properties from other brines in the Dundee above that it is usually easily identified by drillers in the field. It is very black in color and has a strong sulfur odor. The composition of the brines indicates that they are connate waters which have been reconcentrated by leaching and modified by chemical interchange of radicals. Supersaturated brine was found in one porous Monroe horizon at Saginaw, and the percentage of salts characteristic of mother liquors or bitterns is large in most instances.

Table XV indicates certain progressive changes in composition with depth and, although these changes are not regular in all analyses, definite trends seem fairly well established. The increase in specific gravity with depth is also notable. The first group of analyses shows an increase in the amount of calcium chloride ($CaCl_2$), potassium chloride (KCl), and bromine (Br_2) in the deeper horizons, but sodium chloride (NaCl), which varies over a wide range, decreases with depth. The percent of magnesium chloride ($MgCl_2$), except in the Parma and the shallow Marshall, ranges between 2 and 4 percent, and there seems to be no very definite relation between these changes and depth.

The Traverse brines are apparently distinguishable from the Dundee, because they have higher specific gravity, and percentages of calcium chloride ($CaCl_2$) and bromine (Br_2). The Monroe has more calcium chloride ($CaCl_2$) than either the Traverse or Dundee, and the amount of bromine (Br_2) in the Monroe brines is very high. The analyses show over twice the Dundee percentages of bromine (Br_2) in the Monroe.

Dow Method—Hypothetical Combinations—Percentage of Principal Salts.

Formation.	Depth.	Location of Well.	Sp. Gr.	$CaCl_2$.	$MgCl_2$.	NaCl	KCl.	Br_2.
Parma	845	Sec. 14, T. 15 N., R. 9 W.	1.169	4.44	1.64	16.50		.0751
Parma	1,025	Sec. 31, T. 16 N., R. 4 W.	1.207	4.05	1.75	19.31		.0689
Marshall	710	Sec. 16, T. 9 N., R. 1 W.	1.096	2.21	.87	7.92		.040
Marshall	1,238	Sec. 23, T. 14 N., R. 3 W.	1.236	12.50	2.77	10.50	0.76	.1777
Marshall	1,509	Sec. 26, T. 14 N., R. 8 W.	1.208	9.71	3.45	10.98		.1493
Berea	1,837	Sec. 14, T. 12 N., R. 4 E.	1.229	8.3	2.53	11.85		.1217
Traverse	2,249	Sec. 5, T. 7 N., R. 2 E.	1.223	8.11	2.47	15.59		.1134
Traverse	2,491	Sec. 16, T. 9 N., R. 1 W.	1.252	12.73	3.10	10.32		.156
Traverse	2,600	Sec. 9, T. 9 N., R. 1 W.	1.231	12.25	3.52	10.67		.15
Traverse	3,027	Sec. 16, T. 14 N., R. 2 W.	1.241	13.94	3.07	9.66	0.78	.1906
Traverse	3,150	Sec. 14, T. 15 N., R. 9 W	1.202	9.96	2.52	10.25		.1467
Dundee	3,470	Sec. 23, T. 13 N., R. 1 W.	1.207	8.56	2.57	12.47	0.41	.1329
Dundee	3,592	Sec. 16, T. 14 N., R. 2 W.	1.216	8.93	2.34	14.30		.1322
Dundee	3,606	Sec. 18, T. 14 N., R. 2 W.	1.223	8.44	2.14	15.74		.1311
Dundee	3,643	Sec. 12, T. 14 N., R. 2 W.	1.222	8.94	2.02	14.84	0.61	.1247
Dundee	3,665	Sec. 14, T. 15 N., R. 9 W.	1.230	11.10	2.70	12.50		.1375
Dundee	3,693	Sec. 19, T. 15 N., R. 3 W.	1.212	8.78	2.37	13.10	0.52	.1315
Dundee	3,806	Sec. 27, T. 16 N., R. 4 W.	1.212	7.90	2.08	14.15	0.44	.116
Detroit River	3,560	Sec. 14, T. 12 N., R. 4 E.	1.287	19.46	4.20	4.99	2.89	.2835
Detroit River	3,692 (Black Water)	Sec. 12, T. 14 N., R. 2 W.	1.227	8.64	2.17	15.3	0.48	.1192
Detroit River	3,841	Sec. 12, T. 14 N., R. 2 W.	1.222	8.49	2.09	14.90	.50	.1254
Detroit River	4,200	Sec. 12, T. 14 N., R. 2 W.	1.296	21.23	3.60	4.58	1.57	.2919
Detroit River	4,242	Sec. 12, T. 14 N., R. 2 W.	1.282	19.9	3.4	4.93	2.34	.2770
Detroit River	4,257	Sec. 12, T. 14 N., R. 2 W.	1.293	22.05	3.78	3.39	2.63	.3037
Detroit River	4,329	Sec. 16, T. 14 N., R. 2 W.	1.294	21.40	2.96	3.32	2.67	.2958
Detroit River	4,348	Sec. 12, T. 14 N., R. 2 W.	1.298	21.7	3.9	3.35	2.06	.2993
Detroit River	4,371	Sec. 12, T. 14 N., R. 2 W.	1.274	19.06	3.33	5.46	2.2	.2644
Detroit River	4,385	Sec. 12, T. 14 N., R. 2 W.	1.303	22.05	4.06	3.05	2.62	.3113
Detroit River	4,425	Sec. 12, T. 14 N., R. 2 W.	1.295	21.25	3.68	3.87	2.44	.2974
Detroit River	4,433	Sec. 12, T. 14 N., R. 2 W.	1.293	20.9	3.61	4.11	2.42	.2952
Detroit River	4,470	Sec. 12, T. 14 N., R. 2 W.	1.295	21.3	3.64	3.82	2.46	.2978
Detroit River	4,510	Sec. 12, T. 14 N., R. 2 W.	1.291	20.9	3.66	3.95	2.42	.2969
Detroit River	4,646	Sec. 12, T. 14 N., R. 2 W.	1.269	19.0	3.49	5.38	2.18	.2621
Sylvania	4,697	Sec. 16, T. 14 N., R. 2 W.	1.285	20.0	3.50	2.41	2.11	.2751
Sylvania	4,808	Sec. 12, T. 14 N., R. 2 W.	1.282	20.1	3.64	5.00	1.09	.2540

Analyses in Parts per Million.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Total Solids	328,000	331,400	265,000	340,000	308,000	320,000	345,400		324,000	404,000
Specific Gravity	1.223	1.205	1.175	1.214	1.218	1.216	1.214	1.213	1.217	1.288
SiO_2		600								
Fe_2O_3		1,000								
Ca	51,000	40,750	32,500	43,000	37,500	43,500	42,000	43,125	37,500	99,000
Mg	12,880	10,750	8,560	8,720	7,424	8,080	7,480	7,650	6,960	11,440
Na+K	53,370	56,300	53,743	65,280	66,878	63,951	65,848		73,618	28,315
Cl	210,000	189,750	160,500	202,000	191,000	199,000	197,500	200,000	200,000	252,000
SO_4	144	657	437	195.8	165	191	200.7		204	65
HCO_3	12		64	58	66	50	32		88	272
CO_3										
Bromine	2,223	1,958	1,265	1,685	1,600	1,695	1,637		1,525	3,451
Iodine	trace	trace	trace	16	14.6	10	23.4		11	25

1. Marshall brine—section 7, T. 14 N., R. 2 W.—Depth 1,140.
2. Marshall brine—section 26, T. 14 N., R. 8 W.—Depth 1,509.
3. Marshall brine—section 33, T. 18 N., R. 6 W.—Depth 1,642.
4. Dundee brine—section 1, T. 10 N., R. 1 W.—Depth 3,140.
5. Dundee brine—section 25, T. 12 N., R. 4 W.—Depth 3,334.
6. Dundee brine—section 32, T. 13 N., R. 1 W.—Depth 3,555.
7. Dundee brine—section 9, T. 14 N., R. 3 W.—Depth 3,773.
8. Detroit River brine—section 1, T. 10 N., R. 3 W.—Depth 3,273.
9. Detroit River brine—section 27, T. 16 N., R. 4 W.—Depth 3,733.
10. Sylvania brine—section 16, T. 14 N., R. 2 W.—Depth 4,693.

Table XV. Analyses of Central Michigan brines.

Because of its commercial significance as the original source of nearly all the chemicals manufactured by the Dow Chemical Company, the Marshall brines are the most thoroughly studied of all central Michigan waters. Chemically, they show marked increases in concentration toward the center of the basin and these are seemingly related to both structure and depth. The progressive increase takes place in total solids, specific gravity, calcium, magnesium, chlorine, and bromine as the Marshall is encountered at greater depths. The percentage of sodium and potassium is more or less constant. In the deeper wells, there is an apparent decrease in sulfate and carbonate, but this does not take place regularly.

The Dow Chemical Company makes use particularly of the calcium chloride, magnesium chloride, and bromine, and manufactures in all something over 150 chemicals and chemical combinations. These products include ethyl fluid, insecticides, commercial calcium chloride, aspirin, epsom salts, bromine, chlorine, metallic magnesium and magnesium alloys, dyes, and salt as a byproduct. The brine is obtained from 125 wells scattered over Midland, Isabella, and Gratiot counties and there are approximately 110 wells operating at a

time. The total output of these wells ranges from 28,000 to 35,000 barrels of brine daily. Brine has been pumped from the district for more than thirty-five years.

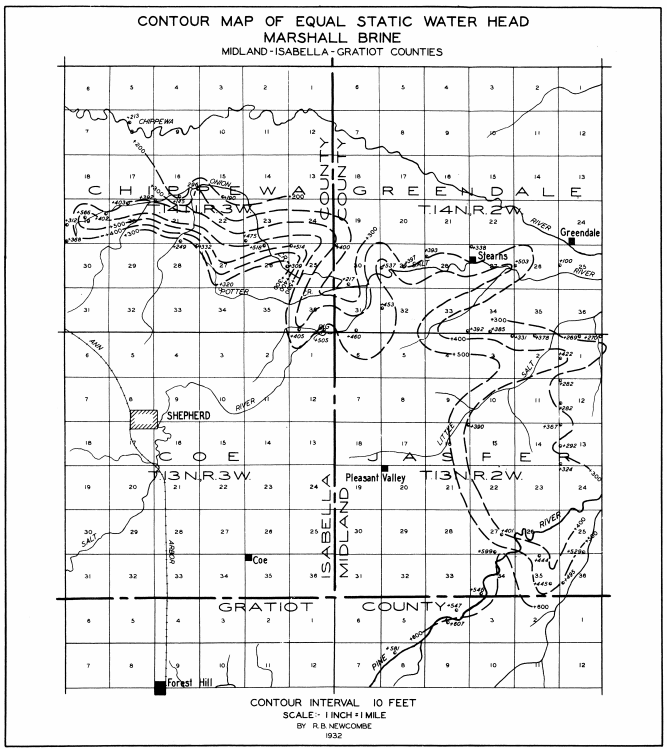

Figure 35. Contour map of equal static water head for the Marshall brine. Contour interval 10 feet.

During 1930 and 1931, many new wells were drilled to the Marshall brine horizon, and in most of these the static water head was determined rather accurately. There seemed to be rather close correspondence between the variation in static water head and the position of the well with respect to the local structure. This relationship is shown in Figure 35 where contours of equal static head conform closely to the steep west dip of the Greendale "high" in Jasper, Greendale, and Chippewa townships. In this part of the field, the static head varies between 190 and over 600 feet above sea level. The brine comes up in some wells to within 100 to 200 feet of the top but in most of them it is from 300 to 600 feet down. According to Thomas[5], "The constant drain on the Marshall water has lowered its static head, so that the wells on structure have a head of only 300 feet, but those off the axis have about 800 to 1,200 feet (of water), with an occasional flowing well. There is also a very, noticeable demarcation in the sandstones in wells where the static head is low; the upper portion of the sand from which the brine has been exhausted shows considerable oxidation, though the lower 20 feet of the sand has the characteristic white of the Napoleon without any apparent change in color. The bromine content of wells on structure is much less than that of wells drilled in the synclines, as shown by the following table:

	Percentage of Bromine
Laura Root Number 1, Section 18, Greendale, Midland (T.14N., R.2W.)	0.0059
G. West Number 1, Section 25, Isabella, Isabella (T.15N., R.4W.)	0.0425
Shepherd Number 1, Section 23, Chippewa, Isabella (T.14N., R.3W.)	0.1777
Buck Number 1, Section 19, Geneva, Midland (T.15N., R.2W.)	0.1349
Isabella State Bank Number 1, Section 8, Denver, Isabella (T.15N., R.3W.)	0.1536

"The Root Number 1 and West Number 1 are on structure, the others are off."

These differences in static water head, the oxidizing effects on the formation of lowering the head, and the variation of bromine content in the Marshall brine from the synclines and the anticlines indicate how changes in concentration and pressure take place due to structural causes. The principle is about the same as that of oil and gas accumulation and the knowledge of structure in the region has made possible the location of wells for maximum recovery of both the brine and the contained chemicals.

The Traverse has several water horizons, the most important of which is the one that occurs at about 120 feet in the formation. Extensive studies of this brine have not been made, since it is shut off in drilling by the "oil string." Very little water is found in the Traverse in the wells structurally high and this is often easily exhausted when encountered. The Traverse brines seem to have rather definite chemical characteristics which distinguish them from the Dundee and Monroe waters below.

The conditions under which the Dundee brine is found have been closely studied in connection with edgewater encroachment and the producing limits of the field. For this purpose, it has been necessary to determine the relation of the Dundee water level to structure and whether or not it is uniform. The absence of edgewater on the west side of the Mount Pleasant Pool and the varying intervals at which low wells have encountered the water in the Dundee has aroused much conjecture as to how the Dundee water level is related to the disconformity at the top of the formation. This problem is further complicated by the position of the water level in the Vernon Pool, where it occurs close under the oil and high up in the producing formation. The Dundee brine is also apparently lacking above the black water of the Upper Monroe in many wells off structure, and many of these anomalous water phenomena seem due to the uneven erosion surface at the base of the Bell shale.

The static head of the Dundee water has not been closely observed in all wells, but the hole usually fills with 1,200 to 2,000 feet of brine. Some Wells on structure have filled up nearly as much as those structurally low, and the lack of continuity in the water horizon probably accounts for this.

The level at which Dundee water was first encountered on the steep west side of the Mount Pleasant structure varied widely between 2,949 and 2,976 feet below sea

level, and on the top it was between 2,904 and 2,912 feet. Along the axis where the nose of the structure plunges into the saddle between the Mount Pleasant and Vernon pools, the Dundee Water was found at about 2,850 feet below sea level; but farther down the regional dip in this same saddle the level ranged between 2,920 and 2,934 feet. Both north and south of the East Extension, the original edgewater level was 2,896 and 2,897 feet below sea level. However, in several wells "on structure" in this part of the area, water was found from 2,883 to 2,889 feet below sea level and in section 12, Greendale township, channeling or the upward intermingling of water from the third into the second "pay" brought the level up to 2,872 and 2,878 feet.

The first edge well on the extreme east tip of this structure had water at 2,894 feet below sea level. In general, the Dundee water in the East Pool stands at between 2,872 and 2,897 feet below sea level, and the edgewater is usually found in the third "pay" zone of the producing horizon. (See fig. 31).

At first, the normal Dundee water level in the Leaton Pool was 2,934 feet below sea level, but with the decline in production it rose to between 2,903 and 2,921 feet. Similarly, the original water level in the Vernon Pool was 2,937 to 2,938 feet below sea level, but the flowing of several wells brought this level up in some wells to between 2,912 and 2,926 feet. It is interesting to note that even though these wells in the Vernon Pool are regionally lower, from 30 to 60 feet on the base of the Bell shale, than in the Leaton Pool, the water levels are very nearly the same. This is probably in some way related to the disconformity at the top of the Dundee and the unevenness of the land surface and associated water table in post-Dundee time prior to the deposition of the Bell shale beds.

The Dundee water level in the Porter Pool is 2,791 to 2,794 feet below sea level in wells structually high. North of this pool in the syncline between the East Extension structure and the main axis of the Greendale "high", the water level is 2,840 feet below sea level, or about 50 feet lower than the Porter structure. Regionally, in this part of the field, the water level conforms more closely to structure and the disconformity does not seem to exert such an important controlling effect as north of Mount Pleasant. However, the upper porous streaks of the Mount Pleasant field Dundee "pays" have not been consistently present in the Porter district; therefore, the upper 30 to 60 feet of the Dundee beds farther north in Greendale township may have been entirely eroded away.

The fact that the position of the water in the Dundee is not only related to structure but also to the disconformity at the top of the formation can be used to show at least partially the extent of erosion and the amount of relief on the pre-Bell land surface. The water table in limestone regions does not usually conform so closely to the land topography as in other types of surface materials. It conforms instead to some particular stratum that is more susceptible to solution than the beds above or below. This is frequently seen in areas of limestone surface rocks, where contacts of certain beds when traced along stream valleys can almost invariably be recognized because they are the water carriers of the region. In view of this common relationship, it is believed that the interval between the top of the Dundee and the first water in the formation shows approximately the relief of the land prior to the deposition of the Bell shale. If this is essentially correct, a contour map showing such an interval will be not only helpful in determining where the first water horizon will be found in the Dundee but also in calculating the amount of possible porous Dundee to be expected, and in pointing out the close relation between post-Dundee topography and structure.

A map of this type is shown in Figure 36, and from a comparison with the structural contour maps of the Central Michigan Area (see pls. IV and V) this relationship seems obvious. The territory in which the interval between the top of the Dundee and the water horizon is greatest conforms closely to the axis of the Greendale "high," not only along the main flexure but the cross folds as well. The structural high is apparently also a topographic one. It is of particular interest to note the apparent Dundee ridge extending northeast into Geneva township, Midland County, because in this part of the field sizable showings of oil were found in wells regionally low. There may be some relation between these showings and local porosity caused by the post-Dundee disconformity, or possibly they mark an important line of cross folding reflected in the post-Dundee topography.

Some geologists consider that the variation in interval to the Dundee water is because water is trapped in the synclinal and off-structure wells in the upper porous zones of the formation instead of the lower zones where it is found higher up on structure. In other words, they believe that the water horizon crosses the beds to higher porous layers in the synclines and the interval from the base of the Bell shale to the water does not express a consistent stratigraphic relationship over the whole district. However, this does not explain the absence of Dundee water in many low wells where the first brine is encountered over 100 feet in the formation. In these wells it seems to be the Monroe "black water" instead of the Dundee brine. The conclusion would follow that the upper part of the Dundee is missing in these low wells and, therefore, the water horizon elsewhere almost invariably present in the formation has been cut out entirely. The wells in which no Dundee water was encountered are indicated on the map (see fig. 36) by large circles surrounding the well symbol and the data from these wells were not used in contouring the thickness of Dundee beds above the first water horizon.

It is usually comparatively easy to recognize the Monroe "black water" when encountered in a well. Aside from the chemical differences, the black color, the rank odor, and the occurrence in dolomitic rocks are generally sufficiently convincing evidence.

Some of the other Monroe brines are also strongly sulfurous, but they are not usually so black in color. The Sylvania water has been found in only three wells in the central part of the Michigan Basin and is characterized by high concentration and relatively large amounts of calcium chloride, potassium chloride, bromine, and iodine. The Detroit River brines are also high in these substances and some of them contain even more (see table XV) than the Sylvania.

GAS PRODUCTION

Natural gas in the Central Michigan Area is of two types, that associated with the Dundee oil and that of the more or less dry gas in the shallower Mississippian beds of the Michigan "stray" and Marshall. The gas with the oil has been principally utilized for lifting purposes and field fuel, although some has been treated in a small absorption plant for the extraction of natural gasoline. The dry gas found in wells outside the Mount Pleasant Pool proper has been mostly capped and saved and some of it already is entering active markets in Mount Pleasant, Midland, and smaller towns of the district.

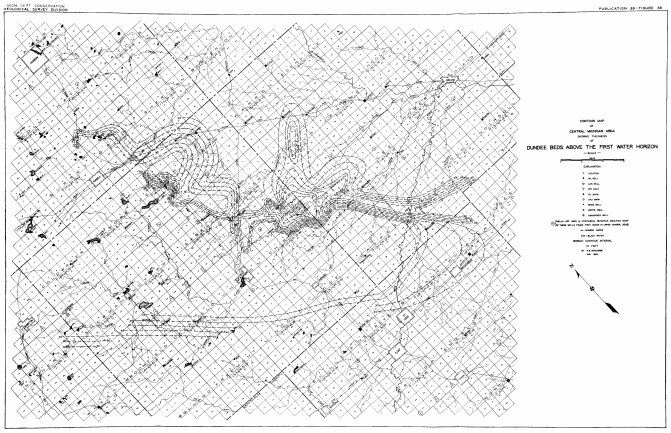

Figure 36. Contour map of the Central Michigan Area showing thickness of Dundee beds above the first water horizon below the Bell shale. Isopach (thickness) contour interval 10 feet.

The amount of gas in the first Dundee wells of the field was not large, ranging from 100,000 to 500,000 cubic feet, or about enough to nicely flow the oil. Larger gas flows accompanied the oil in the East Pool and the Bell Gasoline plant was installed. This is now hooked on to 28 wells on 9 leases. The capacity of the plant is about 15 million cubic feet per day, but in July 1932, they had run only as high as 8 million, and the average was about 5 million. The gathering line pressure for the casinghead gas is approximately 40 pounds. The recovery of gasoline is reported at from .5 to .7 gallon per 1,000 cubic feet, and the residue gas has a heating value of about 1,400 B.T.U.

The gas from the Dundee wells of the East Extension ranged to 4 million cubic feet open flow and several wells came in for 1½ million to 2½ million cubic feet. The average gas-oil ratio was about 1,000 cubic feet to the barrel for newly completed wells. The shut-in pressure has been gauged on several wells at about 475 pounds and potential gas being wasted in the East Pool has been estimated up to 20 million cubic feet 4 daily (July 1932). There is approximately 5½ million in the older part of the field that is not being commercially used.

The "Marshall" gas in the Mount Pleasant and Leaton pools also has been largely wasted. When one of the wells at Leaton gauged 6,500,000 cubic feet in this "sand," attempts were made to bradenhead the well and save the gas between the 8¼ and 6⅝ inch casings. These were unsuccessful because casing procedure in other wells had not satisfactorily shut off water horizons and the water slowly drowned out the gas. However, in the Clare, Broomfield, and Vernon gas fields the gas was found in sufficient quantities in the first wells so that they were immediately shut in to await market developments. A list of the completed gas wells in these fields as of July 1, 1932, is given in Table XVI.

The productive sandstone members comprising the Michigan "stray sand" are sometimes called Marshall because of the similarity in physical appearance. They are made up of fine to medium irregular quartz sand grains with minor amounts of pyrite and clay minerals. The Michigan "sand" is somewhat lenticular and changes character by overlap northwestward up the regional dip. According to the records, (see table XVI), this "pay" horizon contains from 2 to 29 feet of "sand" which is often separated by one or more thin shale beds, and the average thickness is about 12 feet. The distribution of the Michigan "sand" on and off local' structures is not well understood because of the limited extent of drilling operations, but apparently it is thicker in the Broomfield area than in the wells farther down the regional dip to the east. The interval between the gas sand and the Marshall thickens off structure, as well as regionally, and the sand seems better developed on structure than off structure. This condition is probably explainable by deposition along with folding and the greater distance of the structurally low places from the source of supply.

Some layers of the productive horizon are more tightly cemented than others so that average porosity is difficult to determine, but samples from one well in the Broomfield area showed 18 percent porosity and one well in the Vernon area showed 19.55 percent from the upper part of the sand where the big "pay" was encountered. In nearly every well in the Vernon area, a hard, tight zone has been found at the base of the productive gas "sand" and sometimes a dark, heavy oil occurs beneath this zone. The reservoir cap rock consists of black to brown bituminous dolomite and its average thickness is about 10 feet.

The gas in the Michigan "sand" occurs farther down the flanks of the structures than the oil in the deeper porous limestones of the Traverse and Dundee. In fact, minor cross folds which are structurally lower than the major folds of the district contain large quantities of gas in this horizon. (See pls. IV and V.) As shown by Table XVI, the sand varies in thickness and position in the section,

but is usually present in some form or other except in a very few wells. The initial open flow output of different wells ranging from 250,000 to over 10 million cubic feet per day depends almost entirely upon variations in porosity and perviousness. Oil is commonly present in the sand beneath the gas reservoir, although occasionally small quantities of heavy oil have been found above the gas. There seems to be only local regularity in the segregation of oil beneath gas, and oil is present in minor amounts. The gas "sand" may be absent in some wells that are structurally low, but this is not always the case. Water has been found in a few structurally low wells where the gas "sand" is present and also beneath the gas in "high" wells. In the latter case it may possibly be due to the penetration of the Napoleon brine horizon instead of bottom water in the gas "sand."

Name of Company.	Name of Well.	Elevation.	Gas Sand.	Gas.	Total Depth.	Sand Thickness.	Marshall.	Shut-in Pressure (Rock Pressure)	Open Flow.	Porosity.	Drive Pipe.
		Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Pounds.	Cu. Ft.	Percent.	Feet.
BROOMFIELD AREA											
Isabella Oil Development Co.	Mitchell-Keeler No. 1	916	1,319	1,324	1,333	14		575	8,330,000	18.00	528
Isabella Oil Development Co.	Mitchell-Keeler No. 2	922	1,324	1,328	1,335	11		580	2,284,000		582
Isabella Oil Development Co.	Mitchell-Keeler No. 3	948	1,363	1,363	1,381	2½			1,065,000		573
Isabella Oil Development Co.	Bartlett-McClintic No. 1	902	1,299	1,307	1,321	22		580	6,500,000		533
Isabella Oil Development Co.	Bartlett-McClintic No. 2	892	1,295	1,298	1,313	18		347	4,300,000		522
Rockford Oil and Gas Co.	Weidman No. 1	993	1,400	1,409	1,423	23		580	2,125,000		625
†Geneva Oil Co.	Nicholson No. 1	946	1,356	1,366			1,370		1,000,000		590
Wittmer Oil & Gas Properties	McArthur No. 1	952	1,353	1,373	1,377	24		580	1,074,000		578
†Benedum-Trees Oil Co.	Brand No. 1	1,049	1,425–1,436				1,500		No Gas		681
†Benedum-Trees Oil Co.	Grove No. 1	1,021	1,387	1,389			1,472		2,000,000		686
The Pure Oil Co.	Wille No. 1	923	1,322	1,332	1,342	20		580	7,890,000		599
The Pure Oil Co.	Wille No. 2	920	1,330	1,331	1,351	21		580	1,530,000		556
The Pure Oil Co.	Wille No. 3	979	1,373	1,396	1,402	29		580	2,700,000		620
The Pure Oil Co.	Wille No. 4	997	1,383	1,399	1,406	23		535 (24 hrs.)	3,700,000		630
F. M. Stilgenbauer, Tr.	Skerritt No. 1	993	1,398	1,399	1,413	13		580	6,800,000		608
Gas Producers, Inc.	Edmore State Bank No. 1	1,047	1,448	1,452	1,470	22			4,150,000		660
G. G. Hanners	Keeler-Mitchell No. 1	960	1,375	1,376	1,387	7			7,400,000		640
VERNON AREA											
Gibson-Johnson (Old Dutch Oil and Gas Co.)	Scott No. 1	795	1,306	1,307	1,310	4		600	4,400,000	19.55	415
Gibson, Johnson & Borden, Inc. (Old Dutch Oil and Gas Co.)	McGuire No. 1	784	1,296	1,297	1,304	8		600	2,700,000		404
†General Petroleum Corp.	Regan No. 1	787	1,300	1,300			1,360(?)		1,500,000		381
Chartiers Oil Co.	Hodson No. 1	784	1,296	1,296	1,300	4		595	3,700,000		405
Mellon-Pollock Oil Co., et al	Lynch No. 1	824	1,310	1,310	1,324	14		540	1,000,000		409
Mellon-Pollock Oil Co., et al	Battle No. 1	826	1,319	1,320	1,321	2		540	1,150,000		402
†Uhl-Sarver-Raymer	McManaman No. 1	852	1,504	1,504			1,560		600,000		490
E. Brown Development Co., et al	Campbell No. 1	789	1,293	1,302	1,306	13			500,000		410
T. K. Buzard	Sheahan No. 1	795	1,307	1,308	1,312	5		560	2,272,000		380
CLARE COUNTY AREA											
J. A. McKay	McKay No. 1	964	1,408	1,408	1,409	1		600	3,500,000		508
†J. A. McKay	McKay No. 2	971	1,430	1,430			1,495	600	250,000		444
J. A. McKay	McKay No. 4	962	1,424	1,427	1,435	11		585	350,000		531
E. G. Palmer	Citizen's State Bank No. 1	962	1,413	1,414	1,422	9			400,000		434
Peninsular Oil Co.	Smith No. 1	945	1,403	1,418	1,421	18		590	600,000		512
John A. Mercier	Bicknell No. 1	954	1,402	1,402	1,406	4		590	3,135,000		446
J. A. McKay	Bicknell No. 2	961	1,405	1,405	1,408	3			9,050,000		550
W. J. Sovereign	Pere Marquette R. R. No. 1	961	1,407	1,407	1,413	6			11,700,000		

*Exclusive of the Ashley shallow gas pool.
†Not completed as gas wells.

Table XVI. Summary of wells in Central Michigan gas fields.

Of the three gas fields in the Central Michigan Area, the Broomfield Pool has shown the largest initial production and potential area. This district with 14 completed wells (as of January 1, 1933) and an aggregate initial open flow of 59,948,000 cubic feet already seems to include proved territory exceeding 3,800 acres. The field was discovered on October 1, 1929. The tentative estimates of reserves range between 8,500,000,000 and 12,000,000,000 cubic feet, with the lower figure predominating, and of the ultimate yield per acre between slightly less than 3,000,000 to 3,500,000 cubic feet. The relation of pressure to the depths of the wells shows that the initial rock pressure of the fields depends largely on hydrostatic head, but the small amounts of gas withdrawn from the pool make computation of reserves from pressure drops rather unsatisfactory. Preliminary tests were, however, undertaken to determine reserves by this method. The Consumers Power Company in 1931 constructed an 8-inch pipeline, 43 miles long, from Broomfield into Midland. This company in July 1932, withdrew gas from 4 wells in the Broomfield Pool in making tests of its potentialities. A hook-up was made with the line from the field into Midland and the old artificial gas line from Saginaw to Midland, so that the natural gas from Broomfield was transported to their central power plant at Zilwaukee, between Saginaw and Bay City. Since May 16, 1932, approximately 3 million cubic feet of gas per day was burned under one boiler at the Zilwaukee plant, and from six months' observation of the effect of this steady pull on the wells of the field, the Consumers Power Company endeavored to determine more accurately the available reserves. Although a test of this type has a practical value, still it must be emphasized that the geological evidence shows that the Michigan "sand" is a series of lenticular, overlapping sand bodies, and this lack of continuity in the producing formation may raise some question as to the accuracy of the reserve figures determined by this method from so few wells.

The capacity of the line at 300 pounds pressure is about 15 million cubic feet, but soon after its completion in September 1931, only 50,000 to 70,000 per day or about 1,500,000 cubic feet per month was being run. At that time, the working pressure at the wells was 560 pounds and the line pressure from 30 to 35 pounds. On July 15, 1932, when between 3 and 4 million cubic feet of gas daily was being run through the line, the working pressures at the well heads varied roughly between 400 and 500 pounds, and the reported line pressure was about 225 pounds. Besides the gas sent to the Zilwaukee plant, the pipe line served domestic consumers in Midland. During the winter of 1931-32, some gas from this line was sold for heating purposes in Mount Pleasant, but this seasonal demand is no longer active since increasing the size of Vernon pipe line.

The Vernon township gas pool, discovered on August 8, 1930, has 7 wells with an aggregate potential open flow of 14,972,000 cubic feet and the initial production varies from 500,000 to 4,400,000 cubic feet per well. The gas is from a stray "sand" in the Michigan series, almost equivalent to the productive horizon in Broomfield township. The size of the pool has not been determined, but the estimated reserves on a partly proved area of 1,500 acres amounts to about 3,500,000,000 cubic feet. The line to the field is operated by the Gas Corporation of Michigan and supplies Mount Pleasant, Rosebush, and Clare. Originally, it was a 2-inch line and transported about 140,000 cubic feet per day with a working pressure at the wells of about 575 pounds and a line pressure of 50 pounds. This has been replaced by a 4-inch line which is now connected to three wells.

The Clare gas field, which was discovered on February 14, 1930, comprises about 500 acres of proved gas area. It is in the corner of Grant, Surrey, Hatton, and Lincoln townships and 7 of the 8 completed wells that produced gas are now shut in awaiting pipe line facilities. The size of the wells ranges from 250,000 to over 10 million cubic feet and the total potential open flow has been gauged at 29,035,000 cubic feet. The initial rock pressure varies from 585 to 600 pounds and the estimates of the reserves vary from 600,000,000 to 1,500,000,000 cubic feet. The gas from the pool has been used only for drilling purposes.

The only other gas pool in the Central Michigan Area is the shallow field in the "Parma sand", possibly Upper Michigan series, discovered in 1927 by the Sun Oil Company near Ashley, Gratiot County. This pool now

has 5 wells which came in with open flows varying from 400,000 to 2,400,000 cubic feet and a total initial production of 7,691,000 cubic feet. The closed-in rock pressure in 1927 was 213 pounds, but since then some gas has been used for drilling, and the pressure has declined to 195 pounds or less. Water is appearing in these wells and careful operation will be necessary to prevent drowning out the gas. The area underlain by gas seems to be confined to a narrow belt less than a quarter of a mile wide, which has been proved for about a mile north and south. There is no pipe line outlet from the field.

These four gas fields include 33 wells, with an aggregate estimated original daily open flow of 111,646,000 cubic feet. The Broomfield gas analyzes 81.2 percent methane, 14.5 percent ethane, 4.3 percent nitrogen, and has a heating value of 1,076 B.T.U. The proved acreage has been conservatively placed at 5,800 acres but this is probably too small. Estimates of reserves in the spring of 1932 varied between 12,900,000,000 and 15,000,000,000 cubic feet, but recent discoveries have so expanded the area that the reserves of dry gas in July 1932, were estimated in excess of 21,000,000,000 cubic feet.

Because of thick glacial drift in two of the fields, the same heavy equipment has been used as for for deep wells and this has made them cost from $6,000 to $10,000. The holes are started with either 14 or 10-inch drive pipe, usually completed with 5-3/16-inch casing, and most of them are shut in with 3-inch perforated tubing and packer. The 8¼-inch string is generally run through the Parma sandstone. Cable tools are used almost exclusively, although a small rotary has been used successfully to set the drive pipe in several wells, but this method is still in the experimental stage. After the hole has been drilled, the cost of completing a gas well in the Vernon township pool, including 3-inch tubing, packer, and well-head control equipment, is between $1,700 and $1,800. Thus far, meter houses and regulators have been installed at nearly all the individual wells which are connected into the line.

The present pipe line law in Michigan (Act No. 9, Public Acts of 1929) restricts the withdrawal of gas to 25 percent of the open flow capacity and the strict enforcement of this restriction should tend toward efficient recovery of gas. Additional precautions have been made against waste by the prudent operators who locate their gas wells in the middle of each 40 acre tract.

PRODUCTION TOTALS

The production of the Central Michigan Area has been gradually mounting since 1928, and during the past year (1932), it reached a total of 6,382,827 barrels, which is greater than the entire output of the State in any one year up to the present. This district has been increasing in prominence since 1929, until the wells with large flush production in 1931 stamped it as[6] "One of the most successful and important producing districts opened in the East in ten years." The total production of oil in the area to January 1, 1933, was 13,512,101 barrels, which is: over two-thirds of the production of Michigan since it became one of the important eastern oil producing states in 1925. The yearly growth of production for the different pools and the State are shown in Table XVII.

Oil Production (in barrels).

	1928.	1929.	1930.	1931.	1932.	Total.
Mount Pleasant and East Extension	27,019	1,367,836	2,378,775	2,647,879	5,795,860	12,217,369
Leaton	.....	1,948	138,470	299,621	237,870	677,909
Vernon	.....	.....	22,616	244,166	322,354	589,136
Porter	.....	.....	.....	944	26,743	27,687
Total	27,019	1,369,784	2,539,861	3,192,610	6,382,827	13,512,101
Total production of entire State [b]	Prior, 1929 1,126,448	4,641,239	3,928,229	3,785,633	6,925,665	20,407,214

Gas Production (in thousand cubic feet)

	1928.	1929.	1930.	1931.	1932.	Total.
Ashley	.....	.....	.....	.....	.....	.....
Broomfield	.....	.....	.....	183,126	454,681	637,807
Clare	.....	.....	.....	.....	.....	.....
Mount Pleasant and East Extension	.....	161,100		46,335	576,912	784,347
Vernon	.....	.....	.....	25,765	86,079	111,844
Total	.....	161,100		255,226	1,117,672	1,533,998
Total production of entire State [b]	379,992	4,248,581	1,848,521	757,168	1,405,880	8,640,142

Summary of Operations (January 1, 1933)

	Oil Wells.	Gas Wells.	Abandoned Oil Wells.	Abandoned Gas Wells.	Dry Holes.	New Locations.
Mount Pleasant:						
Chippewa township	136	0	12	0	9	3
Greendale township	152	0	2	0	14	18
Lee township	5	0	0	0	4	0
Geneva township	0	0	1	0	4	0
Leaton:						
Denver township	12	0	8	0	13	2
Isabella township	3	0	1	0	4	0
Vernon:						
Gilmore township	0	0	0	0	1	0
Vernon township	19	6	1	1	7	2
Porter	1	0	0	0	4	1
Ashley	0	5	0	0	13	0
Broomfield	0	14	0	0	1	2
Clare	0	7	0	0	7	0
Total	328	32	24	1	82	28

(*a*) Michigan State Tax Commission figures.
(*b*) Compiled figures.

Table XVII. Annual Oil and Gas Production in Central Michigan Area.

Gas production has been increasing slowly, but only a few of the smaller cities have changed to natural gas, and consumption is not keeping pace with the increase in available supply. Several new pipeline projects and pending negotiations between the Consumers Power Company and the cities of Saginaw and Bay City will probably result m larger markets. In 1929 and 1930, the only gas used from the field was casinghead gas for power in drilling and pumping. This was taken largely from the Mount Pleasant field in Chippewa Township, Isabella County, and Greendale township, Midland County. However in 1930 the construction of a pipeline by the Gas Corporation of Michigan from the Vernon gas field to Mount Pleasant and the Consumers Power Company line from the Broomfield gas field to Midland marked the beginning of domestic and commercial utilization of natural gas from central Michigan.

According to the compiled figures, (see table XVII), up to January 1, 1933, Michigan has produced 8,640+ million cubic feet of natural gas. About 1,534 million cubic feet of this has been taken from the Central Michigan Area, where many wells are still to be connected with

pipelines. The Clare and Ashley fields are without pipeline outlet and only a few wells in the Broomfield and Vernon fields are turned into the line. The gas production from the area was 161,100,000 cubic feet in 1929-1930; 255,226,000 in 1931; and 1,117,672,000 in 1932.

The summary of operations in Table XVII shows that at the end of 1932 there were 328 producing oil wells and 32 gas wells in the Central Michigan Area. The total number of completions was 467, of which 82 or 17.5 per cent were dry holes. The new locations where drilling was in progress totaled 28 wells and about two-thirds of these were in the eastern part of the Mount Pleasant field in Greendale township. The old part of the field in Chippewa township, Isabella County, has 136 oil wells, and Greendale township, Midland County, 152 wells. There are 15 wells in the Leaton and 19 in the Vernon township pools, Isabella County. The locations of the wells in the different pools are shown in Plates IV and V.

FUTURE PROSPECTS OF THE AREA

Four oil pools and three gas fields have been found thus far in the Central Michigan Area. Two of these pools are largely developed, the one including approximately 9,000 acres and the other about 600 acres. The other two are being developed slowly because of depressed economic conditions and spotty production. The new discovery well in section 35, Greendale township has probably opened a new pool.

The gas fields are developing slowly because the gas pipe lines leading from the district are inadequate. Pipeline projects which will probably materialize in 1933 ought to foster more widespread drilling for gas. This new drilling should result in further discoveries of both oil and gas.

Much is yet to be learned about the geology of the district. The two well defined "highs" crossing the area have not been thoroughly prospected and are almost certain to include additional pools. These pools should ultimately lead to further exploration and the discovery of other structures.

Central Michigan oil has actively entered the refinery markets along the Great Lakes, and an enlarged demand is gradually building up through improved refining technique and recognition of the potential supply. If the increase in production keeps up the steady pace of the past few years, the State bids fair to assume a leading position among eastern producers of oil and gas.

[1]Stockdale, Paris B., Stylolites, Their Nature and Origin: Indiana Univ. Studies, Vol. IX, pp. 1-97 (1922).

_____, The Stratigraphic Significance of Solution in Rocks: Jour. Geol., Vol. 34, No. 5, pp. 399-414 (1926).

[2]Fitzgerald, P. E., and Thomas, W. A., The Occurrence of Fluorite in the Monroe Formation of the Mount Pleasant Oil Pool: Papers, Michigan Acad. Sci., Arts & Letters, Vol. XVI, p. 416 (1931).

[3]Thomas, W. A., Personal communication.

[4]Egloff, Gustav, Nelson, E. F., and Truesdell, Paul, Paraffin Crude Oils for Antiknock: Oil and Gas Journal, pp. 16, 73 (July 2, 1931).

[5]Thomas, W. A., A Study of the Marshall Formation in Michigan: Papers, Michigan Acad. of Science, Arts and Letters, Vol. XIV, p. 495 (1930).

[6]Gulley, M. G., Petroleum Development in Michigan and the "Trenton Rock" Fields of Northwestern Ohio and Northern Indiana, 1931: Trans., Am. Inst. Mining and Metallurgical Engineers, Pet. Dev. and Technology, p. 213 (1932).

Chapter IV. HOWELL STRUCTURE

INTRODUCTION

The Howell structure of southeastern Michigan is in central Livingston County between Lansing and Detroit. The subsurface structure of most of the county has been mapped (see fig. 38) from a limited number of wells, but the structure has been worked out in detail in only a small part of the area. The contours as drawn for some parts of the district are very uncertain and suggest only the general form and direction of the anticline.

There has been much prospecting in the region, but commercial quantities of oil and gas have not been found. The structure of the area is sufficiently well known to indicate that the most favorable territory is still unexplored. Much of this lies directly under the city of Howell which is 33 miles from Lansing and 40 miles from Detroit. Railway lines through Howell cross the county in several directions. Howell is a junction point on the Ann Arbor and Pere Marquette, thus affording connections! with Grand Rapids, Toledo, and Detroit. A branch line of the Grand Trunk crosses the southern part of the county. A concrete highway between Grand Rapids and Detroit nearly parallels the general direction of the structural trend. The side roads are mostly of gravel and well maintained.

Howell is the county seat of Livingston County and has the best type of social and housing accommodations. Churches, schools, and the McPherson Hospital are high grade, and merchandising concerns are well equipped to serve the needs of a growing population.

PHYSIOGRAPHY

The topography is largely morainic and the surface relief varies from about 900 to nearly 1,100 feet above sea level. Drainage is northward to the Shiawassee River, emptying into the Saginaw River, southward to the Huron River, and westward to the Grand River. The divide where the headwaters of these streams rise crosses Livingston County near the southeast corner in a northeast-southwest direction.

Livingston County is extensively farmed although much of the south and southeast parts is underlain by sandy and gravelly soils derived from outwash material. In these southern townships lakes are abundant, and resort development has reached an advanced stage.

HISTORY

The abnormal geological conditions in the vicinity of Howell have been recognized for many years. As early as 1834 probable surface indications of oil and gas about two miles northwest of the city were observed by Elisha H. Smith, an early settler and historian. In 1893, Lane[1] mentioned the discovery of significant amounts of gas in the eastern part of the city of Howell. Since that time, frequent showings of oil and gas have been reported in water wells between Howell and Fowlerville. Smith[2] referred to the possibility of "a very pronounced arching of strata in the vicinity of Fowlerville," and at the same time discussed general structural conditions in northwestern Livingston County. In 1928, Newcombe[3] designated the structure as the Howell-Owosso anticline and a generalized subsurface map of southeastern Michigan accompanied the report.

New drilling since 1928 has added more information by which this structure may be interpreted, but the relationship between the Howell anticline and the folding in the vicinity of Owosso is not clear. These two structural features seem to be joined by a north-south "high," trending a little west of north across western Shiawassee County. Whether this line of folding is a part of the major structure or simply a cross fold joining two separate trends is uncertain from the present evidence. An extension of the Howell anticline is indicated across Clinton County (see pl. III), and if this is correct the two structures are separate and not directly related to each other. The solution of this problem cannot be certain until more drilling has taken place along the northwest trend of the Howell anticline.

A complete list of deep wells in Livingston County in order of their completion is shown in Table XVIII.

All of the wells located upon the structure that penetrated the Berea or deeper had some showings of oil and gas, but no extensive drilling has been carried on below the Dundee formation. A few of the later holes have been put down to the Sylvania sandstone. The only well in the county which reached a depth of over 3,500 feet was completed in the Lower Salina beds at 8,640 feet.

The detailed structural geology has been recently checked by test well drilling, but the information obtained is not available. A large number of water wells which penetrated rock have furnished clues to structural conditions and have been used as points of control. These wells have been useful in determining the surface configuration of the bedrock.

Several types of geophysical work have been carried on over the area by different major oil companies. Special preliminary studies in earth resistivity measurements were sponsored by the Michigan Geological Survey in cooperation with the Physics Department of Michigan State College. The results of this work added support to previous deductions about the subsurface structure.

STRATIGRAPHY

PLEISTOCENE

The details of stratigraphy in Livingston County have not been worked out accurately because the bedrock is buried and all studies of strata must be made on logs, well cuttings, and cores. The cover of glacial drift varying from 50 to over 150 feet thick consists of sand, gravel, and boulder clay. The beds directly beneath the drift material range upward from the Berea sandstone of Mississippian age to the Saginaw formation of Pennsylvanian age, but there may be a small patch of Mississippian and Devonian Antrim shale in the extreme southeast corner of the county. The general areal geology of the region is shown in Plate II.

Date.	Permit.	Company.	Farm.	Location.	Total Depth
					Feet.
		Jason-Shumway...	Grill.....	Center SE. ¼ section 8, T. 4 N., R. 3 E.....	970
1915	.....	.....	F. C. Burkhart....	NW. ¼ of SW. ¼ section 33, T. 4 N., R. 4 E....	506
1917	.....	.....	Howell Municipal Well No. 4.	SW. ¼ of SW. ¼ section 36, T. 3 N., R. 4 E....	324
			Fowlerville Village Well.	Near waterworks, T. 3 N., R. 3 E.....	303
1926	.....	Norris-Montgomery.	J. M. Bradley.....	Center of section 21, T. 2 N., R. 3 E.....	625
1927	.....	Norris & Smith....	John Finlan.....	SW. ¼ of SW. ¼ section 9, T. 4 N., R. 3 E.....	696
1927	.....	Norris & Smith....	J. E. Raymer.....	SW. ¼ of SE. ¼ section 16, T. 4 N., R. 3 E....	777
1928	17	Hannahs & Andrus	C. L. Johnston....	NE. ¼ of NE. ¼ section 15, T. 4 N., R. 5 E....	845
1928	41	Norris & Smith....	Ross Robb.....	SE. ¼ of SE. ¼ section 26, T. 4 N., R. 3 E....	3,640
1930	873	P. A. Myers, et al..	T. F. Crandall....	NW. ¼ of NW. ¼ section 14, T. 3 N., R. 4 E....	1,332
1930	1,020	Crude Oil of Mich.	J. Tooly.....	SE. ¼ of NW. ¼ section 28, T. 3 N., R. 4 E....	1,603
1930	1,010	A. S. Storm.....	L. W. Latson.....	NW. ¼ of SE. ¼ section 8, T. 2 N., R. 5 E.....	1,082
1930	967	Hilmur Oil Co.....	Geo. Cicarlon.....	SE. ¼ of SW. ¼ section 28, T. 4 N., R. 3 E....	1,850
1930	958	Glennbrook Oil Co.	C. L. Glenn.....	SW. ¼ of SW. ¼ section 32, T. 1 N., R. 4 E....	2,295
1930	1,064	Crude Oil—Empire	G. A. Wilkinson...	NE. ¼ of SW. ¼ section 22, T. 3 N., R. 4 E....	1,715
1930	1,112	Crude Oil—Smith Petroleum Co.	E. & A. Smith....	SE. ¼ of NW. ¼ section 26, T. 3 N., R. 4 E....	1,483
1931	1,128	A. R. Nelson.....	Wm. F. Zeeb.....	NE. ¼ of SE. ¼ section 33, T. 2 N., R. 5 E....	1,965
1931	1,120	Kehlet & Craft....	A. Killinger.....	NW. ¼ of NE. ¼ section 15, T. 4 N., R. 3 E....	1,548
1932	1,254	B. A. Browne, et al.	Albert Smith.....	SE. ¼ of SW. ¼ section 31, T. 3 N., R. 5 E....	1,152
1932	1,280	F. W. Kehlet.....	P. J. O'Connor....	NW. ¼ of SE. ¼ section 31, T. 3 N., R. 5 E....	S. D. 1,743
1932	1,308	White Star Refining Co.	Francis Shields....	NW. ¼ of SW. ¼ section 6, T. 2 N., R. 5 E.....	1,700
1932	1,344	H. Snell, et al.....	Wm. F. Zeeb.....	NW. ¼ of SW. ¼ section 34, T. 2 N., R. 5 E....	3,450 Drilling

Corrected to February 18, 1933.

Table XVIII. Deep Wells in Livingston County.

PENNSYLVANIAN

The Saginaw formation consists of white to gray sandstone, gray shale, and some red shale near the base. The amount of the formation penetrated in wells has not exceeded 176 feet.

The Parma sandstone is usually white to gray in color and dolomitic or limy in the lower part. The thickness varies greatly because of the pronounced disconformity at the base. In the Cicarlon well, 60 feet of Parma was found.

MISSISSIPPIAN

The Bayport limestone is brown, buff, and gray in color and often contains much chert, partings of sandstone, and dolomitic beds. The thickness varies from 40 to 50 feet in northeastern Livingston County.

The Michigan formation is made up of blue to gray and greenish gray shale, sandy shale, and brown dolomitic

limestone. Some of the lower beds are locally micaceous. The series, which is from 80 to 120 feet thick, contains numerous layers, nodules, veins, and stringers of gypsum.

The Napoleon sandstone or Upper Marshall is white to greenish gray and carries water in abundant quantities. If low structurally, some of the beds may be red. The thickness varies from 120 to 150 feet.

The Lower Marshall formation contains beds of gray micaceous sandstone and sandy shale. The red color is prevalent in wells low structurally and nearly absent in wells high on the structure. The Lower Marshall is from 200 to 340 feet thick.

The Coldwater formation consists of gray to blue shale, sandstone, and sandy shale. The Coldwater beds are the first encountered by wells "on structure" in northwest Livingston County and "off structure" they are 740 to 770 feet thick.

The Sunbury black shale is 15 to 26 feet thick and indicates nearness to the top of the Berea. The Berea formation is gray to brown pyritous sandstone, sandy gray shale, and limy sandstone. Beds of gray shale near the base are assigned to the Bedford formation. The total thickness varies from 150 to 174 feet.

DEVONIAN

The Antrim formation includes from 220 to 230 feet of black and brown shale. A dolomitic zone about 50 feet above the base probably contains the large concretions, common to this part of the formation.

The Traverse formation is shaly and cherty in the upper members, and wells on top the structure show about 280 feet of the strata. The limestone beds are gray and buff in color. The Bell formation when not included with the Traverse varies from 35 to over 50 feet in thickness.

The Dundee formation is made up of buff to brown limestone, which is sandy and argillaceous in the lower part. These sandy beds may be equivalent to the Oriskany sandstone of the eastern states. There is no sharp break at the base between the Dundee and the Monroe, and the transition dolomitic beds are difficult to correlate. The Dundee appears to be from 175 to 200 feet thick.

The Monroe series has been penetrated by only a few wells in Livingston County. The Detroit River formation, including beds of brown to gray dolomite and blue anhydrite, is about 600 feet thick. The Sylvania formation is composed of sandy and gray dolomite and white sandstone and is about 190 feet thick. Some of the lower beds are cherty.

SILURIAN

The Bass Island formation of brown to gray dolomite and sandy dolomite is 470 feet thick in the Ross Robb well.

About 1,100 feet of Salina was penetrated in the same well, but the base of the formation was not reached. The entire Salina formation is probably not much thicker than this. It is made up of salt, gypsum and anhydrite, shale, bituminous limestone, and dolomite.

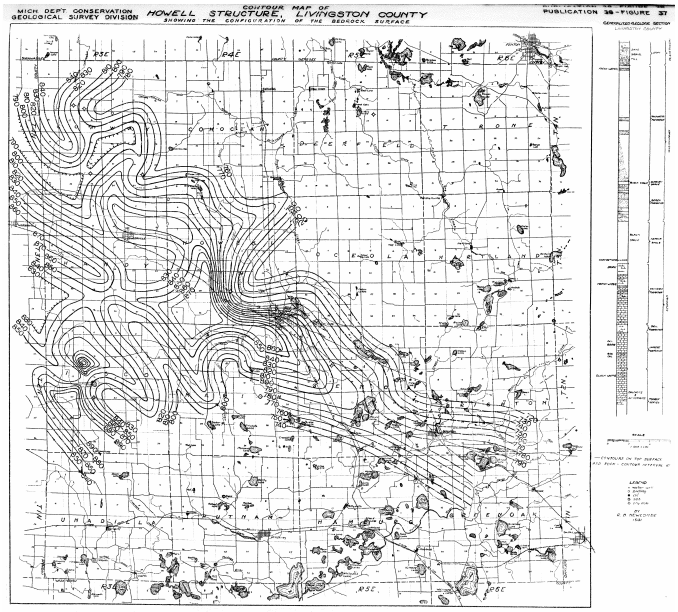

Figure 37. Contour map of Livingston County showing the configuration of the bedrock surface.

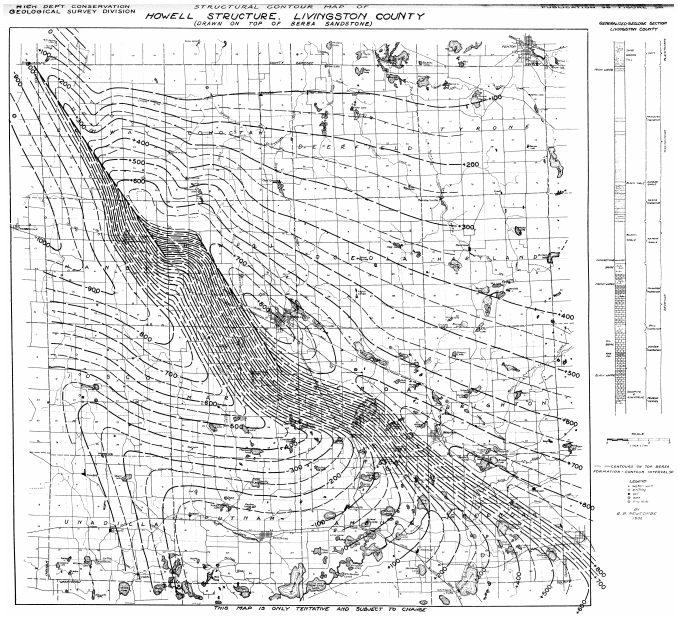

Figure 38. Structural contour map of the Howell structure, Livingston County, drawn on top of Berea sandstone.

STRUCTURE

The normal regional strike of the rocks in Livingston County is N.26°E., and the general regional dip is northwest with younger beds continually appearing in that direction. A pronounced "high" crosses the county from the southeast corner to the northwest corner, but the axis seems to follow a sinuous course. About 150 feet of closure is suggested near where the townships of

Howell, Oceola, Marion, and Genoa corner in the southeast part of the city of Howell.

The top of the Berea formation and the surface of the bedrock have been contoured to show the relation between the structure (see fig. 38) and the pre-glacial topography (see fig. 37). The trend of the ridge of bedrock and the axis of the arch are nearly parallel. The position of the ridge conforms to the steeply dipping flank and the deep syncline on the southwest side of the arch. The striking similarity of the two contour maps indicates the control which the structure of the rocks apparently has exercised upon pre-glacial and glacial erosion. The fold is a northwest plunging asymmetrical anticline with dips on the northeast flank averaging from 100 to 120 feet per mile and on the southwest flank from 300 to 560 feet per mile. The southwest side of the structure is apparently faulted.

That the steeply dipping zone along the west flank of the structure is faulted can only be shown by fragmentary subsurface evidence, and obviously the nature of the faulting and the exact traces of the individual faults are hypothetical. The total vertical displacement (throw) may have amounted to as much as 1,000 feet. The field relationships of the rocks suggest a series of small faults with a considerable amount of drag folding. The surface trends of the fault zones are mapped en echelon or staggered to each other. Kirk and Weirich[4] mention a number of other structural irregularities which might be mistaken for faults and show how under some conditions the subsurface expression of a disconformity might easily be misinterpreted as a fault. However, the evidence for the faulted west flank of the Howell structure seems rather convincing.

Salt water was struck in many of the wells north and east of Fowlerville, but in others a short distance away fresh water was found at a similar depth. These shallow wells containing salt water line up strikingly with the trend of the structure where it dips steeply. A line drawn on a map through the locations of these salt water wells is also somewhat parallel to the indicated zone of faulting. Fissures in the rock were reported in a water well In the north part of section 29, Conway township. Another well in the SE¼ sec. 2, Handy township, was drilled to 412 feet without striking water and, instead, the water used in drilling absorbed salt from the hole.

Lane[5] has recently observed that the radioactivity of various waters obtained from the region seem to support the conclusion that faulting has taken place.

The extremely steep west dip of the Howell structure was found when the Cicarlon well in section 28, Conway township was drilled. The average west dip from the Robb well in section 26, Conway township to the Cicarlon well is over 6°. All indications are that this dip takes place in a much shorter distance than that between the two wells. If this is true, then the dip would be even steeper.

In the Latson well in section 8, Genoa township, many showings of oil and gas were found in the drift. This would suggest that much seepage had resulted from faulting. In the Tooly well in section 28, Howell township, the Traverse formation was from 80 to over 100 feet thinner than in any of the other holes on the structure. Pieces of recemented breccia bailed from a cave in the Traverse at a depth of about 957 feet indicate that the beds are much fractured and movement has taken place. Samples of this breccia were secured at the well and saved by Mr. J. Tooly and Mr. John Wesley Kinsler, who kindly furnished them for observation and study. These samples are shown in Plate VI. The grooved and striated surfaces, the angular cemented fragments, and the secondary calcite making up the cementing material shows that movement along a fault has probably caused the brecciation.

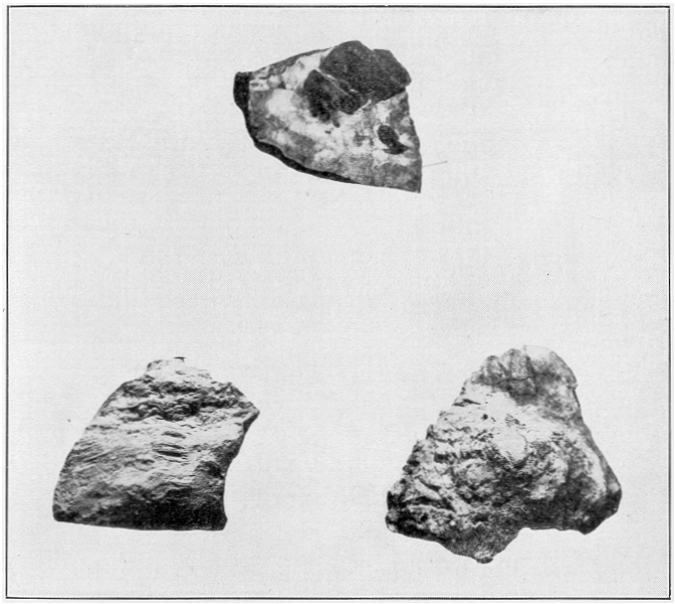

Plate X. Samples of fault breccia taken from the Tooly well, section 28, Howell township, Livingston County. Specimens show the grooved and striated surfaces, the angular recemented fragments, and the calcite cementing material. (These samples furnished by Mr. J. Tooly and Mr. John Wesley Kinsler of Howell, Michigan).

A comparison of the logs of the Tooly well (see table XIX) and the Wilkinson well (see table XX) in section 22 of the same township shows that the Traverse section is 88 feet thinner in the former hole than in the latter. This fact, together with the breccia, seems sufficient proof that the Tooly well went through a fault. If this thinning of the Traverse had been due to the disconformities at either the top or the base of the formation, the broken-up crushed zone should be found where the disconformities occur rather than half way between. The simplest explanation of conditions seems to be that the Tooly well went through a normal fault about 110 feet in the Traverse on the downthrown side and found the base of the Traverse on the upthrown side.

The detailed records of the two wells follow in tables XIX and XX.

OIL AND GAS SHOWINGS AND FUTURE POSSIBILITIES.

Location: SE. ¼ of NE. ¼ sec. 28, T. 3 N., R. 4 E., Livingston County. 320 feet from north and 320 feet from west line of quarter section. Permit No. 1020. Elevation: 957 feet above sea level. Drilling contractor: Crude Oil Company. Record compiled by O. F. Poindexter from driller's log and samples. Commenced: July 8, 1930. Completed to Detroit River (Upper Monroe) formation: August 5, 1930. Plugged and abandoned: August 10, 1930. Casing: 151 feet of 14; 358 feet of 10; 976 feet of 8¼ inch.

Formation	Thickness	Depth
	Feet	*Feet*
Pleistocene:		
Drift; no samples	130	130
No samples	21	151
Sand and gravel	4	155
Mississippian:		
Coldwater Formation:		
Shale, gray, sandy; with drift cavings	47	202
Shale, gray, sandy, and micaceous; a few drift cavings	55	257
Shale, gray, and gray sandy	35	292
Shale, gray, sandy	99	391
Shale, gray, and sandy gray	45	436
Sunbury Formation:		
Shale, black, with a little greenish gray shale and gray shale cavings	13	449
Berea Formation:		
Sandstone, brown, fine grained, micaceous, with black shale; cavings	7	456
Sandstone, brown, and gray fine grained, micaceous, with black shale cavings (small show of oil 469-483)	59	515
Sandstone, gray and brown, fine grained, micaceous	40	555
Sandstone, gray, micaceous, fine grained; and gray shale	63	618
Devonian:		
Antrim Formation:		
Shale, dark brown to black	110	728
Shale, greenish gray and brown; some cavings	39	767
Shale, greenish gray and brown	33	800
Shale, dark brown to black pyritiferous with some gray shale and brown dolomite	35	835
Limestone, brown magnesian (concretions?)	11	846
Traverse Formation:		
Shale, gray limy, with a little brown magnesian limestone; cavings	13	859
Limestone, gray shaly and cherty	18	877
Limestone, gray and buff gray, cherty	20	897
Limestone, buff and brown, cherty	28	925
Limestone, gray and brown, fossiliferous (cave at 957)	32	957
Limestone, gray, fossiliferous, shaly	19	976
Limestone, gray, shaly, with cavings	5	981
Shale, gray	11	992
Limestone, gray, shaly, with limy shale	51	1,043
Bell Formation:		
Shale, gray limy, and gray, fossiliferous limestone	38	1,081
Dundee Formation:		
Limestone, buff, with gray limy shale and gray shaly limestone	12	1,093
Limestone, buff, with gray shale and limestone cavings	12	1,105
Limestone, buff, (show of oil at 1,130)	62	1,167
Limestone, buff, and light gray buff	26	1,193
Limestone, light gray buff to buff	37	1,230
Limestone, light buff	18	1,248
Limestone, buff and brown, magnesian	13	1,261
Limestone, buff, crystalline, magnesian	16	1,277
Limestone, brownish buff, crystalline, magnesian	6	1,283
Limestone, buff, magnesian	25	1,308
Limestone, brownish buff, magnesian	13	1,321
Limestone, buff and brown, magnesian	18	1,339
Limestone, buff, magnesian	20	1,359
Detroit River (Upper Monroe) Formation:		
Dolomite, buff and gray, limy	32	1,391
Dolomite, buff and gray, limy; with a little anhydrite	11	1,402
Dolomite, buff and brown	16	1,418
Dolomite, light gray and buff	40	1,458
Dolomite, buff and gray	6	1,464
Dolomite, light buff	5	1,469
Dolomite, brown and dark brown	12	1,481
Dolomite, brown	7	1,488
Dolomite, light buff to brown; with a little anhydrite	19	1,507
Dolomite, brown; with a little anhydrite	12	1,519
Dolomite, light brown	5	1,524
Dolomite, light brown; with a little anhydrite	7	1,531
Dolomite, light brown and gray	14	1,545
Dolomite, light yellow buff	13	1,558
Dolomite, light buff	7	1,565
Dolomite, buff to brown	12	1,577
Dolomite, buff; with fine angular clear sand grains (Sylvania?)	16	1,593
Dolomite, buff	9	1,602
TOTAL DEPTH		1,602

Table XIX. Log of Crude Oil Company and Empire Oil and Refining Company's J. Tooly No. 1. (Permit NO. 1020).

Important showings of oil and gas are found in nearly all wells favorably located on the Howell structure. In the northwest part of the county in the John Finlan well, section 9, Conway township, gas was struck in a stray sand in the Coldwater formation about 250 feet above the Berea. Three possible "pay" horizons are encountered in the Berea from 7 to 10 feet, 20 to 28 feet, and about 100 feet below the top of the formation. Showings of oil and gas in the Traverse thus far are rare. The "pays" in the Dundee are at 0 to 16, 43 to 52 feet, and about 100 feet from the top. Other showings of oil and gas occur at the base of the Dundee, in the middle of the Detroit River formation, and near the top of the Sylvania.

The area within the highest closing contour has not yet been tested and, with one exception, other parts of the structure have been drilled only to the Sylvania. The highest contour (+800) on the Berea includes most of section 35, the SW.¼ sec. 36, the NE.¼ sec. 34, the SE.¼ sec. 27, the SW.¼ SW.¼ sec. 26, Howell township; the NW.¼ sec. 1 and the NE¼ sec. 2, Marion township. Since the structure seems highly faulted on the west flank, much of the oil and gas in the shallow rocks must have escaped to the surface, and deep drilling will be necessary to thoroughly test its possibilities for commercial production.

On the top of the structure, the Trenton formation should be found within the area of the +800 foot contour at depths between 4,325 and 4,350 feet. Other oil and gas formations which have been only slightly tested include the Sylvania at depths ranging from 1,500 to 1,525 feet; the Lower Salina from 3,330 to 3,360 feet; and the Engadine (Niagaran) from 3,460 to 3,500 feet.

Location: NE. ¼ of SW. ¼ sec. 22, T. 3 N., R. 4 E., Livingston County. 250 feet from north and 330 feet from east line of quarter section. Permit No. 1064. Elevation: 893 feet above sea level. Drilling contractor: Crude Oil Company. Record compiled by O. F. Poindexter from driller's log and samples. Commenced: September 11, 1930. Completed to Sylvania formation: October 31, 1930. Plugged and abandoned: November 21, 1930. Casing: 98 feet of 14; 130 feet of 10; 647 feet of 8¼; 754 feet of 6⅝; 1,614 feet of 5 3-16 inch.

Formation.	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene:		
Drift	92	92
Mississippian:		
Coldwater Formation:		
Sandstone, fine grained, gray, silty, micaceous; a little gray shale; dolomite, and chert	16	108
Sandstone, fine grained, gray, silty, micaceous; gray shale and greenish gray glauconitic (?) dolomite	15	123
Sunbury Formation:		
Shale, black, pyritiferous; sandstone and dolomite cavings	5	128
Berea Formation:		
Sandstone, gray and brown, pyritiferous, cherty, gray; shale, black, and drift cavings	3	131
Sandstone, gray and brown fine grained, micaceous, pyritiferous, cherty; drift cavings	10	141
Sandstone, brown, fine grained, micaceous, pyritiferous	28	169
No sample	3	172
Sandstone, brown and gray, fine grained, micaceous, pyritiferous; shale, gray	17	189
Sandstone, gray and brown, fine grained, micaceous, pyritiferous	15	204
Sandstone, brown and gray, fine grained, micaceous, pyritiferous	35	239
Sandstone, gray and brown, fine grained, micaceous, pyritiferous; a little brown dolomite	12	251
Sandstone, gray; fine grained shale, gray, micaceous	59	310
Devonian:		
Antrim Formation:		
Shale, dark brown to black with gray shale and sandstone cavings	88	398
Shale, dark brown to black	49	447
Dolomite, gray shaly; shale, gray, dark gray and black, pyritiferous	8	455
Shale, black	7	462
Dolomite, gray, shaly; shale, gray, dark gray to black, pyritiferous	26	488
Shale, black, pyritiferous; some gray shale	22	510
Shale, brown to black, pyritiferous; dolomite, brown	12	522
Dolomite, brown	16	538
No sample	9	547
Dolomite, brown	6	553
Traverse Formation:		
Shale, gray	6	559
Limestone, gray, dolomitic, cherty; shale, gray	30	589
Limestone, gray and brownish (6-7 bbls. water per hour 600-605)	13	602
Limestone, gray brownish, white and buff, cherty	6	608
Limestone, buff, white and gray, cherty	13	621
Limestone, buff, cherty	10	631
Limestone, brownish gray and buff, cherty	6	637
Limestone, brownish gray, slightly cherty	24	661
Limestone, light buff, cherty	6	667
Limestone, light buff and gray, cherty	13	680
Limestone, grayish brown, granular	7	687
Limestone, gray and grayish brown, variegated	12	699
Limestone, gray, variegated, fossiliferous, pyritiferous; a little gray shale	7	706
Limestone, gray, argillaceous, fossiliferous	47	753
Bell Formation:		
Shale, gray, limy; limestone, gray	5	758
Shale, gray, limy; limestone, gray	8	766
Shale, gray, limy	6	772
Shale, gray, limy; limestone, gray, argillaceous, fossiliferous	8	780
Limestone, gray, shaly, fossiliferous; shale, gray, limy	44	824
Shale, gray, limy; limestone, gray, shaly, fossiliferous	43	867
Shale, gray, limy; limestone, gray and brownish buff, variegated	19	886
Dundee Formation:		
Limestone, brownish buff with gray limestone and shale cavings	20	906
Limestone, brownish buff (show of oil 925-930, small)	19	925
Limestone, light brown	25	950
Limestone, buff	20	970
Limestone, buff to brown	7	977
Limestone, buff to brown; considerable white calcite	25	1,002
Limestone, brown, buff and light gray (small show of oil 1,005-1,008)	11	1,013
Limestone, brownish buff	7	1,020

Formation	Thickness	Depth
	Feet	*Feet*
Limestone, buff to brownish buff (fluorite?)	21	1,041
Limestone, brown, crystalline (Anderdon limestone?)	6	1,047
Limestone, brown and light gray	7	1,054
Limestone, light brown and light gray	5	1,059
Limestone, buff	5	1,064
Limestone, light brown (black water—1,075)	9	1,073
Limestone, buff	7	1,080
Limestone, light buff and light gray	14	1,094
Limestone, light buff, dolomitic	13	1,107
Limestone, brown dolomitic, cherty	8	1,115
Limestone, light brown, dolomitic, cherty	35	1,150
Limestone, buff, dolomitic, cherty	6	1,156
Detroit River (Upper Monroe) Formation:		
Dolomite, buff; anhydrite	7	1,163
Dolomite, buff	6	1,169
No samples	14	1,183
Dolomite, buff, brown and brownish gray; anhydrite	27	1,210
Dolomite, buff to brown	19	1,229
Dolomite, buff; anhydrite	12	1,241
Dolomite, yellow buff and gray, anhydrite	17	1,258
Dolomite, gray and buff; anhydrite	8	1,276
Dolomite, yellow buff and gray; anhydrite	10	1,286
Dolomite, brown to dark brown	8	1,294
Dolomite, brown, limy	10	1,304
Dolomite, buff to brown, anhydrite	12	1,316
Dolomite, brownish buff; anhydrite	13	1,329
Dolomite, brownish buff	14	1,343
Dolomite, brownish buff; anhydrite	10	1,353
Anhydrite and dolomite, brownish buff	23	1,376
Dolomite, brownish buff to brown	13	1,389
Dolomite, brownish buff; anhydrite	9	1,398
Dolomite, brownish buff, a little anhydrite	22	1,420
Dolomite, tan white; anhydrite (no samples to 1,575) (slight show of oil 1,425–1,430)	5	1,425
Dolomite, light buff	7	1,432
Dolomite, light buff; anhydrite	15	1,447
Dolomitic limestone, gray white	10	1,457
Dolomite, white and light gray; anhydrite	8	1,465
Dolomite, white and tan white	18	1,483
Dolomite, light gray	7	1,490
Dolomite, light tan; anhydrite	12	1,502
Dolomite, light tan and buff; anhydrite	5	1,507
Dolomite, light buff	10	1,517
Dolomite, buff (slight show of oil 1,520)	6	1,523
Dolomite, tan white, siliceous	12	1,535
Dolomite, white; anhydrite, little	8	1,543
Dolomite, white, siliceous	7	1,550
Dolomite, light buff, siliceous	5	1,555
Dolomite, gray buff, sandy; anhydrite	7	1,562
Dolomite, gray buff, siliceous; little anhydrite	8	1,570
Dolomite, buff, sandy	5	1,575
Dolomite, brownish buff to brown and gray	5	1,580
Dolomite, gray and brownish buff	13	1,593
Dolomite, buff and gray	9	1,602
Limestone and dolomite, brown, black and buff, sandy	7	1,609
Limestone, brown and black dolomitic, very sandy (about 50% sand; small show of oil 1,610?, in Sylvania?)	5	1,614
Limestone, light brown, dolomitic, sandy	5	1,619
Dolomite, brown, limy	5	1,624
Dolomite, light brown, limy, slightly cherty	3	1,627
Dolomite, grayish brown	5	1,632
Dolomite, brown	10	1,642
Dolomite, grayish brown, limy	7	1,649
Dolomite, brown, limy	4	1,653
Dolomite, grayish brown, limy	4	1,657
Dolomite, brown, limy	11	1,668
No sample	6	1,674
Dolomite, grayish brown, limy	5	1,679
Dolomite, brown, limy	6	1,685
Dolomite, grayish brown, limy	6	1,691
Dolomite, brown, limy	7	1,698
Sylvania Formation:		
Dolomite, gray buff, cherty (1,300 feet water 1,695-1,710)	7	1,705
Dolomite, buff gray, cherty	6	1,711
Dolomite, gray buff and buff gray crystalline, cherty	12	1,723

Table XX. Log of Crude Oil Company and Empire Oil and Refining Company's G. A. Wilkinson No. 1 (Permit NO. 1064).

[1]Lane, A. C., The Geology of Lower Michigan with Reference to Deep Borings: Geological Survey of Michigan, Vol. V, Pt. 2, p. 62 (1895).

[2]Smith, R. A., The Occurrence of Oil and Gas in Michigan: Michigan Geol. & Biol. Survey, Pub. 14, Geol. Ser. 11, p. 164 (1912).

[3]Newcombe, R. B., Oil and Gas Development in Michigan: Michigan Geol. & Biol. Survey, Pub. 37. Pt. 3, p. 215 (1928).

[4]Kirk, C. T., and Weirich, T. E., Steep Subsurface Folds versus Faults: Geol. Soc. America, Bull., Vol. 38, No. 4, pp. 577-589 (1927); also Pan American Geologist, Vol. 47, No. 2, pp. 153-154 (1927).

[5]Lane. A. C., Personal communication.

Chapter V. UNDEVELOPED STRUCTURES

The discovery and proving of the well known structures in Saginaw, Muskegon, Midland, Isabella, and Livingston counties, brought on widespread but scattered "wildcat" drilling. This showed the continuation of known anticlinal folds into adjoining districts. Some of these highs had been indicated by wells drilled prior to 1925, and showings of oil and gas in them led to new explorations after the development of the Saginaw, Muskegon and Mount Pleasant pools. The size and extent of undeveloped structures found in this way are still unknown. The projected trends of important folds are shown on the regional contour map of the southern peninsula in Plate III.

Since 1928, there have been significant discoveries of small amounts of oil and gas in many counties outside the areas of the principal pools. These discoveries have varied from small showings to wells that produced oil for several weeks, months, or even years. Some of them are still producing, but the size and life of the wells do not always bear a direct relation to the magnitude of the structures that caused the accumulations. Wildcat development in the vicinity of these discoveries may possibly reveal new pools, but some of the showings have been in regions that are structurally low.

The explorations in counties where small quantities of oil and gas have been found are summarized below:

ALLEGAN COUNTY

The first oil wells near the city of Allegan were drilled in the early years of the present century. One of them yielded several barrels of oil per day for a few weeks. Two more wells were drilled at Allegan in 1912. One was dry and the other produced about a barrel per day. The production was thought at that time to be coming from the Dundee, but studies of new wells indicate that it was probably from the Traverse.

The details of structure in the county are not understood, but apparently there is a series of northeast plunging noses which curve more northward in the northern and eastern parts. A nose and a broad terrace are shown (see pl. III) in the vicinity of Allegan where most of the oil has been found. The general flattening of dips in the west part of the county may be due to east-west trending structures that have not been definitely worked out by drilling. Closed anticlines are still unknown in Allegan County from the evidence of deep wells, but core drilling carried on by private concerns may have determined domes yet untested.

From 1928 to 1932, fourteen deep wells were commenced in Allegan County, and all but two of them were drilled to the Traverse or deeper. Six of these wells yielded more or less important quantities of oil and gas in either the Traverse or Dundee formations. All but two have been plugged and abandoned. One well in the city of Allegan is still making some oil and a considerable amount of water.

The East Shore Oil Company put down a well on the S. Dewitt farm in the SE.¼ NW.¼ sec. 11, T.4N., R.16W., Laketon township, to a depth of 2,056 feet (Elev. 661 feet). The well penetrated the Coldwater red rock at 613 feet, the Traverse at 1,425, water at 1,463 and 1,707, and was full of water at 2,056 feet. No showings of oil and gas were recorded.

The Pure Oil Company drilled on the H. K. Hoeve farm in the NE.¼ SE.¼ sec. 2, T.4N., R.14W., Overisel township, to a depth of 2,600 feet (Elev. 679 feet).

In Salem township, Allegan County, NE.¼ sec. 9, T.4N., R.13W., the National Petroleum Corporation drilled on the John Commissaris property (Elev. 711 feet). Red rock was penetrated at 940 feet, top of the Traverse at 1,555, Traverse limestone at 1,605, and the Dundee at 1,825. Oil and water were encountered at 1,614, but the test was abandoned as a dry hole at 1,968 feet.

The Puritan Oil Corporation of Muskegon completed a test on the O. W. Gere farm in the NW.¼ NW.¼ sec. 13, T.3N., R.12W., Hopkins township, in March, 1930 (Elev. 732 feet). Red rock of the lower Coldwater was found at 1,135 feet, Traverse formation at 1,728, Traverse limestone at 1,745, and the Dundee at 1,927. A show of oil was reported in the Dundee, but the hole was plugged and abandoned at 2,108 feet.

H. P. Manion and W. M. Thomas started a well about half a mile north of Allegan, but trouble was encountered in the hole, and it was abandoned in June, 1930, at 359 feet. A second well on the same tract was drilled by H. P. Manion in 1931 (Elev. 739 feet). The Coldwater red rock was found at 720 feet, top of the Traverse at 1,377, and the Dundee at 1,570. Oil was reported at 1,519 feet, oil and water at 1,570, gas at 1,583, and operations are now shut down at 1,635 feet.

In the city of Allegan, Guy Carlton Irvine put down a well in Pingree Park, in sec. 28, Allegan township (Elev. 631 feet). The red rock was found in this well at 558 feet, Traverse formation at 1,174, Traverse limestone at 1,234, and oil at 1,238 and 1,327 feet. The well was shot from 1,330 to 1,335 feet with 150 to 300 feet of oil and water in the hole. After tubing was run, the well pumped 16 barrels of oil in two days, and for several days thereafter it averaged between 7 and 8 barrels daily. Operations were suspended during most of 1932, and the hole stood at a depth of 1,367 feet.

The East Shore Oil Company drilled on the Dick Nyland farm in the NE.¼ sec. 26, T.2N., R.11W., Martin township, Allegan County, to 2,000 feet, at which depth the well was plugged and abandoned (Elev. 734 feet). Red rock was penetrated at 969 feet, the Traverse at 1,600, Traverse limestone at 1,660, and water at 1,990.

During the summer of 1929, G. F. Kimmell and G. H. Schrack, completed a "wildcat" test on the F. L. Hamilton farm in the NE.¼ SW.¼ sec. 15, Hamilton township (Elev. 684.5 feet). Red rock was struck at 627 feet, the Traverse at 1,205, the Dundee at 1,435, and the Sylvania at 1,673. Brine was found at 1,290, 1,450, 1,575, 1,685, and 1,773 feet. The test was completed as a dry hole in the Sylvania at 1,800 feet.

The Johnson Oil Refining Company drilled two deep wells and one red rock test in Trowbridge township, Allegan County. In the M. H. Holland No. 1 in the SW.¼ SW.¼ sec. 26, T.1N., R.13W., red rock was found at 731 feet (Elev. 755 feet). The finding of oil and gas in the Traverse near the top of the lime at 1,348 to 1,352 feet in the Frank T. Forster No. 1 in the NE.¼ NW.¼ sec. 32 (elev. 770 feet) caused some excitement. The red rock was encountered at 670 feet and the Traverse at 1,300. The well pumped 20 barrels of oil the first day and about 5 barrels of oil and 200 barrels of water daily until drilled deeper to 1,557 feet, where it was plugged and abandoned. The third well on the E. L. Gilson farm in the SE.¼ SW.¼ sec. 28 was a dry hole (Elev. 750 feet). The red rock was struck at 698 feet and the Traverse at 1,305, and the hole bottomed at 1,350 feet.

Two tests were put down by the Wiser Oil Company in Gun Plains township, T.1N., R.11W., where small showings were found. The first of these wells was drilled in the NE.¼ NW.¼ sec. 21 (elev. 728 feet), to a total depth of 2,011 feet, penetrating the red rock at 845 feet, the Traverse at 1,375, the Dundee at 1,602, and the Detroit River at 1,697. Shows of oil were reported at 397 and 1,730 feet. The second well, which was in the NE.¼ NE.¼ sec. 33 (elev. 733 feet), encountered the red rock at 876 feet, the Traverse at 1,405, the Dundee at 1,685, and was abandoned as a dry hole in February, 1930. Oil and water were encountered in the Traverse at 1,457 and 1,660 feet, and brine, which nearly filled the hole, at 1,700 feet.

BAY COUNTY

The discovery of a small amount of oil in a water well at Pinconning and the results of core drilling in the northern part of Bay County have led to some "wildcatting" in this district. Although only three new wells have been drilled, they indicate that the county has possibilities and that important folding is actually present in the northern part. The nature of this folding is uncertain.

A northwest-southeast trending "high" probably extends across Pinconning, Gibson, and the northeast corner of Mount Forest townships. The axis of this fold seems to be in the vicinity of Pinconning. Another anticlinal axis may cross the southwestern part of the county and join by a low saddle on to the prolongation of the Saginaw anticline. The structural depression north of Saginaw, which has been defined by wells in Bay City, probably has a northeast-southwest trend and connects with the trough east of the Mount Pleasant structure in Midland County. It may also continue southwestward beyond the Midland trough, but there are not enough wells to determine its exact position. Another "low" separates the Pinconning anticline in the northern part of the county from the "high" crossing the southern townships.

A group of Pinconning business men formed the Pinconning Oil Company and in the summer of 1930 started a well on the property of Eugene Clements et al in the NW.¼ NE.¼ sec. 23, T.17N., R.4E., Pinconning township, Bay County (Elev. 609 feet). The Marshall was found at 295 feet, the Berea at 1,522, the Traverse at 2,023, and the Dundee at 2,808. A showing of oil and water was reported at 2,033 and oil at 2,865 feet. Operations at the well have now been shut down for nearly two years at a depth of 3,050 feet.

The Eureka Oil Corporation put down a test in the SW.¼ SW.¼ sec. 9, T.16N., R.4E., Eraser township, Bay County, on the W. J. Lambert farm (Elev. 620 feet). They

struck the Lower Marshall red rock at 815, the Berea at 1,720, the Traverse at 2,341, and the Dundee at 3,002 feet. The black water was encountered at 3,112, and the hole was plugged and abandoned at 3,117 feet.

A well was drilled in the name of Dr. Miles S. Reinhart in the SW.¼ NE.¼ sec. 21, T.18N., R.3E., Gibson township, Bay County, on the H. H. Lewis tract (Elev. 711 feet). The formations were penetrated at the following depths: the Marshall at 440, the Berea at 1,608, the Traverse at 2,151, and the Dundee at 2,956 feet. Water was found in the Berea at 1,608-84, in the Traverse at 2,575, and in the Dundee at 3,102, 3,115, and 3,130 feet. The hole was plugged and abandoned at 3,131 feet.

CASS COUNTY

Prospecting for oil and gas in northern Cass County followed the discovery of small amounts of oil in the Traverse formation just north of the county line near Decatur, Van Buren County. Since 1928, eight wells have been put down in the county and one is now drilling. A small quantity of oil is produced from the wells of Blair and Miller in the vicinity of Union, Porter township.

According to the regional subsurface map (see pl. III), two broad folds cross the county in a northeast-southwest direction. The most prominent of these folds extends from near the southwest corner of the county to about the middle of the north county line. The other "high" seems to trend across some of the townships in the southeast corner of the county. The folding is apparently not sharp but more in the nature of broad warpings several miles wide. No production has been found in formations deeper than the Traverse.

After the discovery of oil in the Traverse on the A. D. Vought property in southern Van Buren County, a well was drilled in 1928-29 by Frank Reed and Fred Springsteen (Dowagiac Development Company) on the Rick Norton farm in the NW.¼ NE.¼ sec. 2, T. 5 S., R. 15 W., Wayne township, Cass County (Elev. 755 feet). They encountered the Coldwater red rock at 393, the Traverse at 850, Traverse limestone at 922, the Sylvania at 1,265, the Lower Monroe at 1,309, and the Niagaran at 1,757 feet. The hole was deepened from 1,688½ feet to a depth of 1,788 feet by R. H. Kersey and J. R. Baker of South Bend, Indiana. Showings of oil were found at 948 and 1,238 feet and gas at 1,668 and 1,768 feet. A large flow of artesian water was struck in the drift at 160-180 feet and brine, which filled the hole, was encountered at 1,580 feet.

Walter McLaren drilled a well to the Trenton on the W. W. Wright farm in the SE.¼ SE.¼ sec. 18, T. 5 S., R. 14 W., Volinia township, Cass County (Elev. 899 feet). In this well, red rock was struck at 530 feet, the Traverse at 1,015, Traverse limestone at 1,060, the Sylvania (?) at 1,400, the Niagaran at 1,625, the Trenton at 2,552, and the hole bottomed at 2,728 feet. Water was reported at 1,220, 2,590, and 2,725, and a show of oil at 2,582 feet.

A well was put down by the Berrien Petroleum Syndicate on the Fred C. Franz tract in the SE.¼ SE.¼ sec 3, T. 7 S., R. 16 W., Howard township, Cass County (Elev. 761 feet). This hole penetrated the Traverse at 635 feet, the Dundee at 804, and the Niagaran at 1,003. It was drilled to 1,201 feet, and water was found at 180, 335, 920, and 989, and a small showing of oil at 683½ feet. The Antrim black shale in this well was shot between the depths of 575 and 624 feet with 100 quarts of nitro-glycerin in 3½ inch shells. Sixty-eight feet of water was put on top for a tamp. About 5,000 cubic feet of sweet gas resulted from the shot, but salt water drowned it out.

Another Trenton test was drilled by C. A. Daniels on the Charles Clute farm in the NW.¼ NE.¼ sec. 2, T. 7 S., R. 13 W., Porter township, Cass County (Elev. 928 feet). This well struck the Coldwater red rock at 503, the Traverse at 942, the Dundee at 1,075, the Detroit River at 1,160, the Sylvania at 1,280, the Niagaran at 1,694, Manitoulin lime at 2,033, and the Trenton at 2,439 feet. The water horizons were at 920, 1,006, 1,125, 1,190, 1,400, 2,562, and 2,660, with sulfur water at 1,160 feet. Showings of gas were reported at 707, 1,013, and 1,264 feet with oil at 1,580 to 1,631 feet.

The first well put down by Blair and Miller was on the Charles Stutsman property in the NE.¼ NW.¼ sec. 32, T. 7 S., R. 13 W., Porter township (Elev. 794 feet). The Traverse was found at 657 feet, the Detroit River at 891, the Sylvania (?) at 950, and the well was finished at 1,130 feet. A good show of oil was found at 708 feet and brackish water from 711 to 720 feet. The well was plugged and abandoned because of drilling difficulties.

The second well on the Stutsman farm, NE.¼ NW.¼ sec. 32, 780 feet from the north and 1,858 feet from the west line of the quarter section (elev. 803 feet), is still producing oil from the Traverse formation. In this hole, completed in the spring of 1930 to a depth of 708½ feet, the top of the Traverse was found at 657 feet and the "pay" at 706. It was drilled to a depth of 708½ feet and pumped from 8 to 15 barrels daily when first completed.

A Trenton well was drilled by Blair and Miller on the Frank Knowlton tract in the SW.¼ SW.¼ sec. 2, T. 8 S., R. 16 W., Milton township (Elev. 850 feet). The Traverse was penetrated at 657 feet, the Monroe at 826, the Niagaran at 1,154, Manitoulin limestone at 1,525, and the Trenton at 1,945 feet. Water was encountered at 735, 1,122, 1,131, 1,448, 1,462, 1.950, and 2,014 feet, and the hole was abandoned in the Trenton at 2,029 feet. A small showing of gas was reported in the Traverse at 687 feet.

The same operators drilled a dry hole into the Trenton near the Stutsman location on the F. A. Shippy farm, SE.¼ NE.¼ NW.¼ sec. 32, North Porter township (Elev. 795 feet). In this well, the Coldwater red rock was penetrated directly below the glacial drift at 248 feet, the Traverse at 653, the Detroit River at 850, the Sylvania (?) at 943, the Niagaran at 1,188, the Manitoulin at 1,678, the Trenton at 2,089, and bottomed at 2,382 feet.

Another well now drilling on the Wright farm in the SE.¼ SE.¼ sec. 18, Volinia township, was commenced in the summer of 1932 by Scott Stammler.

CLARE COUNTY

The first operations in Clare County followed discoveries in Isabella County to the south and gas was found in the Michigan "stray sand" in Grant township northwest of the city of Clare in 1929. Eight gas wells (see table XVI) have been completed in this pool, but up to the present the search for Dundee oil and gas has been unsuccessful (Jan. 1, 1933). Outside the Clare gas field six "wildcat" wells have been drilled and two are drilling. One of these a few miles west of Harrison had a good showing of oil in the Dundee.

The structure of Clare County is known only in a general way by projecting the trends of the anticlines more thoroughly worked out in Isabella and Midland counties. (See pls. IV and V). The Greendale "high" seems to extend across from east of Far-well to near Temple. The northwest projection of the Saginaw trend may cross somewhere between southeastern Arthur township and northwestern Summerfield township. Cross folding with a northeast-southwest trend is apparent near the Clare gas field where the drilling is more closely spaced than in the rest of the county. The intensity and direction of the regional dip varies considerably in different parts of Clare County, but in general when not interrupted by local structures it is south and southwest.

After the discovery of the Clare gas field, the Decem Development Company drilled the first "wildcat" test on the F. S. Salter farm in the NE.¼ NE.¼ sec. 33, T. 18 N., R. 6 W., Freeman township (Elev. 1,071.5 feet). The well was 4,064 feet deep and after going through 463 feet of drift the Parma was struck at 1,050 feet, Michigan "stray sand" at 1,602, the Marshall at 1,657, Lower Marshall red rock at 1,748, the Berea at 2,665, the Traverse at 3,310, and the Dundee at 3,995. Showings of oil were found at 1,050 and 1,480 feet and gas at 3,160 feet. Water in abundance was encountered at 1,065 and 1,622 feet, ¾ bailer full per hour at 3,515, and Monroe (?) black water at 4,064. Operations were abandoned in January, 1930.

The Mammoth Oil Company of Michigan put down a well on property belonging to the Bothwell heirs in the SE.¼ NE.¼ sec. 16, T. 18 N, R. 4 W., Hatton twp. (Elev. 1,017 feet). It was completed at 4,092 feet and found the top of the rock at 515, the Parma at 900, the Marshall at 1,580, Lower Marshall red rock at 1,735, the Traverse at 3,404, and the Dundee at 4,072 feet. Water was struck at 1,602, 3,570-3,615, and 4,092 feet and the hole was abandoned in March, 1932.

The Clare Development Syndicate drilled to a depth of 3,840 feet on the Mary A. Hubel farm in the SW.¼ SW.¼ sec. 27, T. 17. N., R. 4 W., Grant twp. (Elev. 846 feet). The drift was 355 feet thick and the Parma was struck at 1,040 feet, Michigan "stray sand" at 1,384, the Marshall at 1,460, Lower Marshall red rock at 1,555, the Berea at 2,564, the Traverse at 3,105, and the Dundee at 3,798. Water was tapped at 455, 1,384, and 3,833 feet. Abandonment took place in June, 1930.

The Peninsular Oil Company drilled a well 3,978 feet deep on the W. E. Bowler property in the SW.¼ NW.¼ sec. 15, T. 17 N., R. 4 W., Grant twp. (Elev. 945 feet). There was 405 feet of drift and the Parma was at 989, Michigan "stray sand" at 1,446, the Marshall at 1,485, Lower Marshall red rock at 1,625, the Traverse at 3,220, and the Dundee at 3,905 feet. Showings of gas were found at 1,505, 3,220-50, 3,440, and 3,600 and some oil at 3,440-90. Salt water was struck in the Parma at 989, one bailer full in the Traverse at 3,460-75, and brine in the Dundee at 3,977 feet. The well was abandoned in August, 1931.

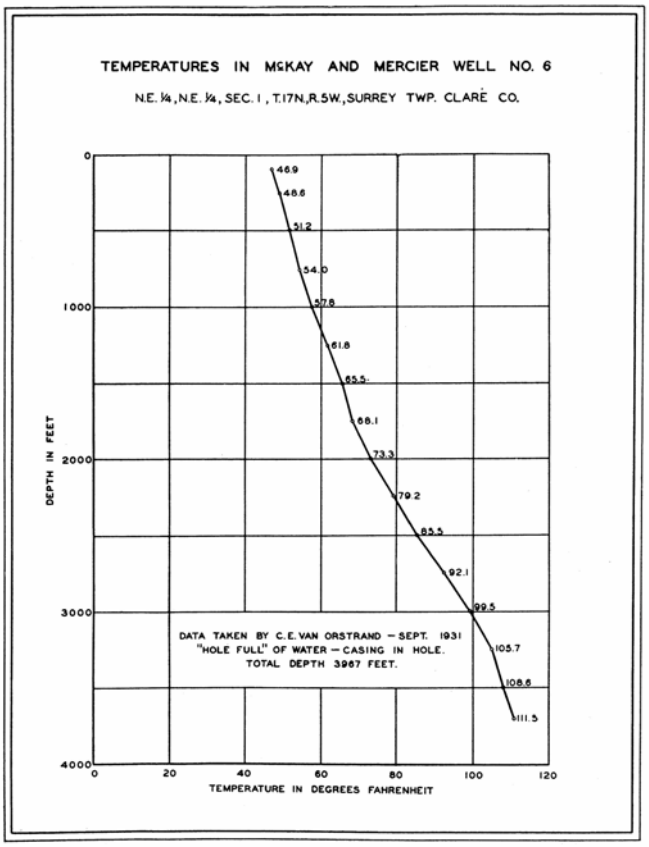

Figure 39. Temperatures in McKay and Mercier Well No. 6, NE.¼ NE.¼ sec. 1, T.17N., R.5W., Surrey twp., Clare County.

Although the logs of most of the wells in the Clare gas field will not be discussed, the Dundee test put down to 3,967 feet by McKay and Mercier on the Jas. McKay location No. 6, NE.¼ NE.¼ sec. 1, T. 17 N., R. 5 W., Surrey twp. (elev. 973 feet) is included here to show the results of temperature determinations. (See fig. 39). These observations of the temperature gradient were made by C. E. Van Orstrand of the U. S. Geological Survey in September, 1931. They seem to indicate an average increase in temperature of 1° Fahrenheit for every 56 feet in depth which according to the curve with but 4 marked changes in slope is comparatively regular. In this well the drift was 470 feet thick and the Parma was encountered at 985 feet the Michigan "stray sand"

at 1,458, the Marshall at 1,528, the Lower Marshall red rock at 1,645, the Berea at 2,657, the Traverse at 3,225, and the Dundee at 3,914. Water was struck at 1,458 feet and the hole filled up 3,400 feet with black sulphur water at 3,956, but the well has not been abandoned. (Jan. 1, 1933)

The Michigan Gas and Oil Corp. drilled a Marshall test 1,535 feet deep on the Daniel Coyne et al property in the SE.¼ SE.¼ sec. 18, T. 17 N., R. 4 W., Grant twp. (Elev. 960 feet). This well encountered 387 feet of drift and struck the Parma at 935, water at 940, the Marshall at 1,530, and salt water at 1,535 feet. The hole was abandoned in December, 1931.

The Theodore Oil Company drilled on property belonging to Thompson Bros, in the SW.¼ NE.¼ sec. 35, T. 19 N., R. 5 W., Greenwood twp. (Elev. 1,216.8 feet). According to scout reports 760 feet of drift was found in this well and the Parma was at 1,275, the Marshall at 1,710 (?), Lower Marshall red rock at 1,795, the Traverse at 3,500, and the Dundee at 4,180 feet. Water which about filled the hole was struck at 1,305, 1,710, and 4,242 feet. A good showing of high grade "live" oil was struck at 4,180-84 feet and made several barrels over night. The hole as completed in December 1932, was drilled to 4,245 feet but after additional testing it now stands at a depth of 4,234 feet.

The wells now drilling (Feb. 1, 1933) are the Ira Scheifley, Tr.—All American Fur Farm No. 1, SW.¼ SE.¼ sec. 21, T. 20 N., R. 5 W., Summerfield twp. (elev. 1,104.8 feet), and the Strange Oil and Gas Company—J. L. Littlefield No. 1, SW.¼ SW.¼ sec. 9, T. 17 N., R. 5 W., Surrey twp. (Elev. 1,047 feet). The Seheifley-Fur Farm well is down 1,000 feet, having struck the Parma (?) at 850 feet, "hole full" of water at 690, and oil with a "hole full" of water at 850 feet. The Strange-Littlefield well is down 3,210 feet and struck the Michigan "stray sand" at 1,578, the Marshall at 1,643, Lower Marshall red rock at 1,746, and the Traverse at 3,385 feet. Water which came up in the hole 70 feet in one hour was tapped at 1,583-86 feet.

GRATIOT COUNTY

The drilling for oil and gas in Gratiot County came largely from efforts to extend the Mount Pleasant production southward and to explore the Howell-Owosso "high" northward. The only commercial wells are in the southeastern corner of the county, and these are small. The "wildcat" test wells in the northern part of the county were fairly well scattered and thus helped to outline structural trends as a guide for future development. In all, fifteen wells have been put down for oil and gas since 1928. The structure as now interpreted is shown in Plates IV and V.

The Alma "high" extends northwest-southeast from Elba township in the southeast corner of the county to Seville township in the northwest corner. It is apparently a regional feature trending southeastward from the Broomfield "high" in Isabella County where gas has been found. The exact off-structure dip and closure of individual anticlines are unknown. The Greendale "high" probably crosses near the extreme northeast corner of the county in Wheeler township, but this area has not been tested. Another high, about which very little is known, seems to trend across the four townships in the southwest corner of the county in a northwest-southeast direction.

Late in 1929, Ridenour and Snyder drilled on the I. J. Nelson farm. NE.¼ NE¼ sec. 25, T.12N., R.4W., Seville township, Gratiot County (Elev. 772 feet). Marshall sandstone was found at 1,055, Lower Marshall red rock at 1,145, the Berea at 2,359, the Traverse at 2,791, Traverse limestone at 2,814, and the Dundee at 3,334 feet. Gas, oil, and water were struck at 3,339 feet. The well soon filled up about 2,000 feet, and at 3,370 feet there was 3,000 feet of water in the hole. It was drilled to 3,395 feet and finally plugged and abandoned.

The Twin City Oil and Gas Company put down a well in the NW.¼ sec. 1, T.12N., R.3W., on the C. H. Bigsby property, Pine River township, Gratiot County (Elev. 740 feet). This test encountered Marshall sandstone at 1,150, Lower Marshall red rock at 1,265, the Berea at 2,465, the Traverse at 2,916, and the Dundee at 3,460 feet. Salt water came in at 2,290 feet, and water was tapped in the Traverse at 3,070 and oil at 3,175 feet. A show of gas and oil was found in the Dundee at 3,475 feet, but water was struck at 3,490 feet, and the hole was plugged and abandoned at that depth.

The Ann Arbor Oil Company drilled on property belonging to J. D. McCallum in the SW.¼ NW.¼ sec. 6, T.12N., R.1W., Wheeler township (elev. 705 feet), where Marshall sandstone was struck at 1,210 feet, typical Lower Marshall red rock at 1,333, the Berea at 2,475, the Traverse at 2,954, and the Dundee at 3,539. The water horizons in the hole were at 30, 360, 455, 3,068, and 3,556 feet, and the well was abandoned as a dry hole in the Upper "Monroe Series" (Detroit River) at 3,827 feet.

A well was put down by the Macston Oil Company on the Cornwell estate in the SE.¼ SW.¼ sec. 27, T.12N., R.1W., Wheeler township (Elev. 708 feet). The Marshall was found at 1,060, Lower Marshall red rock at 1,170, the Berea at 2,285, the Traverse at 2,745, and the Dundee at 3,288 feet. Salt water was struck in the Dundee, and the hole was plugged and abandoned at 3,330 feet.

The Wittmer Oil and Gas Properties Company of Pittsburgh started a well on the W. H. Zimmerman farm, NE.¼ SE.¼ sec. 8, T.10N., R.1W., Hamilton township, Gratiot County (Elev. 697 feet). Drilling difficulty was experienced, and the hole was plugged at 1,140 feet after drilling to 1,200 feet. The Marshall was found at 858 and the Lower Marshall red rock at 963 feet.

Sam. M. Bacon of Saginaw drilled a "wildcat" well on the F. J. Gibbs farm in the NE.¼ SE.¼ sec. 1, T.10N., R.1W., Hamilton township (Elev. 666 feet). Marshall sandstone was struck at 863 feet, Lower Marshall red

rock at 990, the Berea at 2,148, the Traverse at 2,625, the Dundee at 3,086, and black water from 3,135 to 3,185 feet. A showing of oil was found at 2,874 and gas at 3,120 feet, but the hole was plugged and. abandoned in the Upper "Monroe" at 3,420 feet.

W. L. McClanahan put down a test for gas on the Robt. G. Waldron farm, NE.¼ NE.¼ sec. 28, T.10N., R.1W., Hamilton township (elev. 683 feet), in which he found the Parma at 501, the water at 520, a gas show at 550, more gas at 783, the top of the Marshall at 806, and water at 822 feet. The well was finished at 823 feet. It was not a commercial producer but showed the Michigan "stray gas sand" farther south than hitherto known.

The Fish Creek Oil Syndicate of Carson City drilled a test well on the N. Garner farm, NE.¼ SE.¼ sec. 10, T.9N., R.4W., North Shade township, which is reported to have gone to a depth of 800 to 900 feet without encountering the Marshall. Reliable records of the well are not available.

E. O. Pequignot et al drilled a deep well on the August Nass property, NE.¼ SE.¼ sec. 10, T.9N., R.2W., Washington township (Elev. 688 feet). Marshall sandstone was encountered at 803, Lower Marshall red rock at 868, the Berea at 2,092, the Traverse at 2,489, Traverse limestone at 2,529, and the Dundee at 2,975 feet. A showing of gas was found in the Dundee at about 3,020 feet, and the hole filled with water at 3,043, where it was plugged and abandoned.

Miller Bros, of Ashley, Michigan, drilled a Dundee test on the Belle Crook farm in the N.¼ NW.¼ sec. 10, T.9N., R.1W., Elba township, to a depth of 3,159 feet (Elev. 665 feet). The Parma was struck at 500, the Marshall at 712, Lower Marshall red rock at 792, the Berea at 2,063, the Traverse .at 2,465, and the Dundee at 2,960 feet. Water was encountered at several places in the Saginaw formation and at 737 feet in the Marshall. Black water came in at 2,960 feet and possibly more water at 3,129 feet. A showing of gas was found at 500-510 feet, about a half million cubic feet of gas at 715-725 feet, and three showings of oil in the Traverse in the top few feet and at 55 and 145 feet in.

The discovery of shallow gas near Ashley in Elba township in 1927 led to the drilling of several more wells during the next few years. The Wolverine Natural Gas Company put down a test on the Rebecca Kerr farm, SE.¼ SW.¼ sec. 9, T.9N., R.1W., which was dry at a depth of 758 feet. The Parma "sand" was absent, and the Marshall was struck at 748 feet. The same company drilled a dry hole to a depth of 525 feet in the NW.¼ SW.¼ NE.¼ sec. 16, on the Lars P. Anderson farm (Elev. 655 feet). On the northeast corner of this 40 acre tract, Miller and Combs of Ashley brought in a gas well which gauged 1,301,850 cubic feet (Elev. 655 feet). The top of the Parma sand was 484 feet, gas was found at 486-496, and the depth of the well was 502 feet. They also struck 1,800,000 cubic feet of gas at 498-500 feet on the Rebecca Kerr farm, SE.¼ SW.¼ NE.¼ sec. 9 (Elev. 663 feet). A test by Miller and Combs on the J. I. Askegard farm, SE.¼ NW.¼ NW.¼ sec. 9 (elev. 656 feet), came in at 503-511 feet, with an estimated flow of 500,000 cubic feet of gas. It was drilled to the Marshall, found the top at 690, water at 700, and was completed at 712 feet.

ISABELLA COUNTY

The structural geology and the locations of wells in Isabella County are shown in Plates IV and V. Wildcat wells have been drilled in Coe, Deerfield, Denver, Gilmore, Isabella, Lincoln, Nottawa, Sherman, Union, Vernon, and Wise townships. Descriptions of these wells, the depths to the various formations, and some of the findings of oil and gas are given in Table XXI. In this table are included the wildcat wells drilled in the county from Jan. 1, 1928 to Jan. 1, 1933, excepting those close to the Mount Pleasant, Leaton, Vernon, and Broomfield pools.

JACKSON COUNTY

The structural geology of Jackson County is very vague since there are only four deep wells and some indefinitely determined trends of suggested "highs" in adjoining counties. One anticlinal fold seems to extend from near the corner of Hillsdale and Lenawee counties, where they join with Jackson County on the south, to the northwestern corner of the county. There is further evidence of this high in the bedrock topography and certain irregularities in the geologic section of the region. A pronounced bedrock ridge parallels this fold on the southwest, and near Jackson the Michigan formation is missing with the Parma sandstone resting directly upon the Marshall. Another major anticline apparently crosses the northeast corner of the county, and there are also peculiar features of bedrock topography in this district.

The only recent well in Jackson County was drilled by the Hanover Development Company on the Alfred Folks farm, where the location was in the NW.¼ SW.¼ SE.¼ sec. 14, T.4.S., R.2W., Hanover township (Elev. 1,045 feet). The Berea horizon is difficult to identify in this well, but it may be at 900 feet. The Traverse was struck at 1,520 feet, the Dundee at 1,689, and the total depth was 1,727 feet. Water was encountered at 252 and 1,527 feet, and gas showings occurred at 1,525, 1,669, and 1,700 feet.

KENT COUNTY

Kent County is on the west side of the Basin and, except where interrupted by local structures, the regional dip is northeast. Four principal lines of folding seem to cross the county, two in a northeast-south west direction and two in a northwest-southeast direction. There is evidence of a "high" extending from the northwest corner of Byron township through Wyoming township near the east limits of the village of Grandville northeastward in the general direction but a little east of the village of

Alpine. Another more or less parallel fold extends from the vicinity east of Caledonia toward northwestern Lowell township. By projecting structural trends from adjoining counties, northwest-southeast anticlinal folds apparently cross the southwest corner of the county diagonally through the center of Wyoming township and the southeast part of the county near the southeast corner of Lowell township. The drilling in the county has been fairly scattered, but the geologic structure of the area and the exact trends of folding are not very clear.

Activity in the Muskegon field led to operations for oil and gas in this part of western Michigan. In all, six deep wells and one test well were put down in Kent County during the Muskegon boom. Several of these had favorable showings of oil and gas, but none were commercial producers, and development in the county has practically stopped.

Paul Schulte of Chicago started a well near Cedar Springs in 1929, in the NW.¼ NE.¼ sec. 31, T.10N., R.10W. (elev. 870 ± feet), which is now shut down with the tools lost in the hole at 4,650 feet. It was deepened from 3,569 by A. J. Buck of Cedar Springs. The record of the upper part of the hole is rather poor and indefinite, but the Marshall was at about 775 feet, Lower Marshall red rock at 850, the Traverse at 2,440, the Dundee at 2,850, the Sylvania (?) at 3,575, the Salina at 4,046, and the Salina salt beds at 4,150. A showing of oil was found at 2,480 feet. There was a "hole full" of water at 1,200 and 2,483 feet and water in the Dundee and Upper Monroe at 2,890 and 3,015 feet.

Permit	Company.	Farm.	Location.	Sec.	T. — R.	Elev.	Mar.	Red.	Berea.	Trav.	Dundee.	Monroe.	Gas.	Oil.	Water.	T. D.
931	Salt Creek Oil Co.	O. H. Adams	NW., NW. ¼ NW. ¼	4	Coe 13 N., 3 W.	Abandoned at 380 feet.										
738	St. Clair Oil and Gas Corp.	W. H. Thomas	SW. ¼ SW. ¼	28	13 N., 3 W.	810	1,290	1,390	2,540	2,955	3,630				3,649	3,667
1,073	Geneva Oil Co.	Nicholson	SW. ¼ SW. ¼	7	Deerfield 14 N., 5 W.	946	1,370	1,540	2,568	3,097	3,682		1,366		3,725	3,734
1,207	Apache Oil Corp.	F. Epple	SE., SE. ¼ NE. ¼	20	Denver 15 N., 3 W.	715	1,263	1,407								1,510
717	E. Brown Oil Dev. Co.	Geo. Mitchell	S. ½ SW. ¼	35	15 N., 3 W.	729	1,160	1,315	2,550	2,940	3,556			3,048 3,601		3,625
778	Chippewa Oil and Gas Co.	M. Bliss Keeler No. 1	SE. ¼ SE. ¼	27	15 N., 3 W.	739	(?)1,193	1,370		2,946	3,605				3,655	3,664
694	Denver Oil Dev. Co.	R. Adams	NE. ¼ SE. ¼	35	15 N., 3 W.	730	1,185	1,370	2,485	2,970	3,592				3,644	3,654
818	Gordon Oil Co.	Isabella County State Bank	NW., SE. ¼ SE. ¼	8	15 N., 3 W.	744	1,292	1,440	2,510	3,025	3,695			3,720	3,751	3,754
731	J. M. Markle, Tr.	F. H. Dodds No. 1	NE. ¼ NW. ¼	34	15 N., 3 W.	733	1,200	1,335	2,458	2,940	3,546			2,945	3,585	3,594
605	J. M. Markle, Tr.	E. O. Graham	W. ½ NW. ¼	33	15 N., 3 W.	732	1,178			2,975	3,602				3,651	3,680
719	Mid-Michigan Oil Development Synd.	P. J. Marthey	W. ½ NE. ¼	34	15 N., 3 W.	737	1,205	1,375	2,480	2,970	3,597			2,997	3,079	3,652
780	Ohio Producing & Refining Co.	Keeler-Weideman	NW. ¼ SE. ¼	35	15 N., 3 W.	Abandoned at 668 feet.										
1,281	L. G. Thompson	Jno. D. Vandercook	SE., NE. ¼ SE. ¼	24	15 N., 3 W.	Shut down—bad hole at 315 feet.										
806	New York Petroleum Royalty Corp.	Q. L. Hughes	NE., NE. ¼ NE. ¼	19	15 N., 3 W.	753	1,229	1,393	2,443	3,000	3,638		1,164	3,058 3,660	3,702	3,704
1,235	F. L. Maire et al	E. F. Wilson Estate	NE., SE. ¼ NE. ¼	12	Gilmore 16 N., 5 W.	945	1,584	1,745		3,345	3,995				4,109 4,175	4,192
863	J. O. Duryee	Johnson-Bullard	SE. ¼ SW. ¼	10	Isabella 15 N., 4 W.	779	1,485	1,640	2,690	3,200	3,842	3,948		4,452 4,482	3,989 4,020 4,520	4,595
827	Holsinger & Jordan	J. J. Radey	NE. ¼ SE. ¼	23	15 N., 4 W.	754	1,267	1,550	2,625	3,130	3,806					3,891
1,305	W. L. McClanahan, Inc.	John Pollard et al	NE., NW. ¼ SW. ¼	1	15 N., 4 W.	781	1,320	1,430	2,495	3,018	3,674		1,302		3,750	3,797
858	H. E. Pollock	Roy H. Zingery	SW. ¼ SW. ¼	25	15 N., 4 W.	754	1,365	1,500		3,060	3,703				3,743	3,788
730	West Virginia Oil Producing Co.	Jno. Roethlisbery	NE., NW. ¼ NE. ¼	24	Lincoln 13 N., 4 W.	809	1,295	1,400	2,546	3,040	3,632			3,649		3,699
1,153	Deerfield-Nottawa Oil and Gas Co.	Chas. E. Smith & A. J. Tillman	SW., SE. ¼ NE. ¼	35	Nottawa 15 N., 5 W.	823	1,400								1,400	1,411
1,025	Wm. Cline et al	C. K. Eddy Est.	S. ½ SE. ¼	11	Sherman 15 N., 6 W.	920	1,438	1,609							1,515	1,706
686	St. Clair Oil and Gas Corp.	Chas. Marz No. 1	E. ½ SW. ¼	1	Union 14 N., 4 W.	756	1,403	1,525		3,100	3,741		3,653			3,805
1,284	J. C. Arthurs, Inc.	A. Bowman	W. ½ N. ½ NW. ¼	27	Vernon 16 N., 4 W.	844	1,480	1,570	2,590	3,137	3,809			3,809	3,827	3,828
1,070	Gibson, Johnson & Borden, Inc.	W. J. Mahar	NE., NE. ¼ SW. ¼	27	16 N., 4 W.	822	1,369	1,524	2,605	3,098	3,749				3,808	3,832
1,333	Thos. E. Currie et al	Ruth MacKenzie	C., SE. ¼ SE. ¼	34	16 N., 4 W.	812	1,380							1,351	1,345	1,392
1,208	Old Dutch Oil & Gas Co.	B. Loomis	SW., SW. ¼ SE. ¼	16	16 N., 4 W.	852	1,395	1,597		3,174	3,825				3,834	3,834
878	Uhl-Sarver-Raymer Well Drilling Co.	T. McManaman Estate	E. ½ W. ½ SE. ¼	31	16 N., 4 W.	853	1,507	1,665	2,750	3,265	3,898		1,507			4,055
707	H. E. Pollock	B. Campbell	SW. ¼ SW. ¼	11	Wise 16 N., 3 W.	771	1,338	1,460	2,560	3,080	3,755					3,801
823	St. Clair Oil and Gas Corp.	J. E. Walker	NW. ¼ NW. ¼	32	16 N., 3 W.	770	1,340	1,420	2,350	3,075	(?)3,685		1,362		3,768	3,795
1,149	Michigan Gas & Oil Corp.	John Parker	C., NW. ¼ SE. ¼	7	16 N., 3 W.	810	1,331	1,490	2,519	3,075	3,724				3,825	3,831

*This table does not include wells in the Mount Pleasant (Chippewa twp.) Leaton, Vernon, or Broomfield pools.

Table XXI. "Wildcat" Wells in Isabella County.

The Kenyon Company drilled on the Ed. Gould farm, NW.¼ SW.¼ sec. 24, T.9N., R.10W., Courtland township (elev. 911 feet), and found several showings of oil, but the hole was plugged and abandoned at 3,000 feet. They struck the Marshall at 818, Lower Marshall red rock at 971, the Traverse at 2,480, and the Dundee at 2,900 feet. Oil was found at 2,557, 2,578, and 2,619 feet, fresh water (?) at 2,590, and salt water from 2,990 to 3,000 feet.

The East Ohio Gas Company of Cleveland, Ohio, under the name of E. W. Gallagher, Trustee, drilled a well near Silver Lake on the Wm. Pennington farm in the SE.¼ SW.¼ sec. 4, T.8N., R.10W., Cannon township, Kent County (Elev. 868 feet). Marshall sandstone was encountered at 697 feet, Coldwater red rock at 1,770, the Traverse at 2,345, and the Dundee at 2,757. Showings of oil were reported from 2,413 to 2,418, 2,663 to 2,672, 2,785 to 2,789, and 2,815 to 2,830 feet. Salt water was tapped at 2,418 and 2,830 feet.

Dillon and McFredrick put down a "wildcat" test in Cannon township on the J. A. Bullis property in the NE.¼ NW.¼ sec. 28, T.8N., R.12W (Elev. 652 feet). In this hole, Marshall sandstone was struck at 540, the Lower Marshall at 626, Coldwater red rock at 1,630, the Traverse at 2,193, and the Dundee at 2,604 feet. A small amount of oil was found from 2,251 to 2,261 and 2,670 to 2,680 feet. Eight barrels of water per hour came into the hole from 2,261 to 2,275, and it filled up from the brine horizon at 2,296 to 2,331 feet. A small amount of brine was encountered at 2,530 feet and more in the Dundee at 2,680 where the well was abandoned.

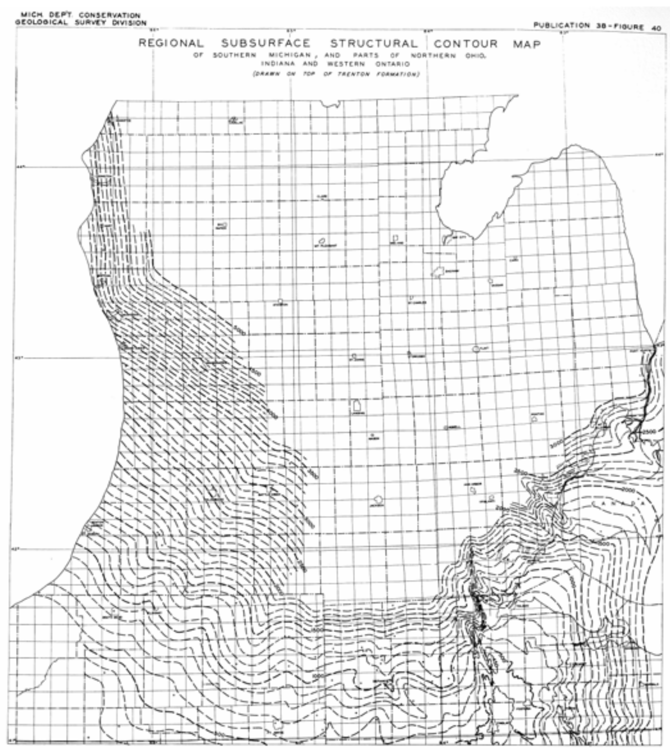

Figure 40. Regional subsurface structural contour map of Southern Michigan, and parts of Northern Ohio, Indiana, and Western Ontario (Drawn on top of Trenton formation.)

A test well was put down by J. Brooks Reed on the A. M. Cordes tract, SE.¼ SW.¼ sec. 1, T.7N., R.12W., Walker township (elev. 863 feet), but this hole was never drilled deeper than the Marshall.

The Mid-Continent Development Company drilled on the Garden Farm addition in the south part of Grand Rapids, sec. 19, T.6N., R.11W., Paris township (Elev. 691 feet). Because of the way the well was promoted and managed, considerable drilling difficulty was experienced in the upper part of the hole. Later, new management took over the project and the well was satisfactorily completed to a total depth of 2,467 feet.

According to the best available records, Marshall sandstone was found at 149, Coldwater red rock at 1,236, the Traverse at 1,790, the Dundee at 2,090, and the Detroit River at 2,235 feet. Showings of gas were found at 325 and 2,244 feet, and the hole filled up with water soon after the latter showing was struck.

W. E. Lang of Lexington, Kentucky, and M. W. Shriver commenced a well on the I. Schondelmayer farm, center of SE.¼ sec. 36, T.5N., R.10W., Caledonia township (elev. 718 feet), which was completed at a depth of 2,224 feet in the name of the Kent-Barry Oil Company. The Lower Marshall was logged at 260, Coldwater red rock at 1,335, the Traverse at 1,812, the Dundee at 2,055, and the Detroit River at 2,195 feet. The depths of water horizons were 162 to 245, 345 to 380, 2,095, 2,195, and 2,218 to 2,230 feet. Small showings of oil were found at 1,885 and 2,095 feet.

LAKE COUNTY

Lake County is on the northwest side of the Michigan Basin where the regional dip is generally southeastward. The structural geology of the county is known only from the four widely scattered wells that have been drilled in four different townships. These wells suggest that two highs cross the region in a northwest-southeast direction, and their trends appear to be extensions of folds worked out in adjoining counties and other districts. An indistinct line of anticlinal folding seems to cross from the southeast corner of Pleasant Plains township near Marlborough to the southwest corner of Sauble township. The other anticlinal trend is across the northeast corner of the county and seems to be traceable from southeastern Ells worth township near Luther toward the corners of Manistee and Wexford counties on the north county line. Several small showings of oil were found in the two wells drilled in the western part of the county.

In 1928-1929, Fred J. Estes of Kentucky promoted a well, which was drilled to a depth of 2,801 feet, on the W. Kellogg property in the NW.¼ NW.¼ sec. 11, T.20N., R.11W., Dover township (Elev. 1,245 feet). Marshall sandstone was found at 1,165 feet, Antrim black shale at 2,685, and Coldwater red rock at 2,045, but the Traverse was not penetrated. Difficulties in drilling caused the hole to be plugged and abandoned.

F. A. Braendle drilled a test to a depth of 3,772 feet on the Jess Cummings farm in the SE.¼ SE.¼ sec. 32, T.18N., R.14W., Sweetwater township (elev. 821 feet), about 4 miles northeast of the small oil and gas wells in Logan township, Mason County. Napoleon sandstone was encountered at 485 feet (?), Lower Marshall red rock at 575, Coldwater red rock at 1,285, the Traverse at 2,135, the Dundee at 2,749, the Detroit River at 2,854, and the Sylvania at 3,655. A showing of oil was found in the Traverse from 2,199 to 2,202 feet, gas in the Monroe from 2,854 to 2,921 feet, and oil just above 3,665 feet. The water horizons were at 495, 2,202, and 3,665 feet, and the hole was plugged on October 24, 1930.

The Super Oil and Gas Company of Ludington drilled on the Edmund Skirven property, SE.¼ SE.¼ sec. 15, T.19N., R.14W., Sauble township, Lake County (Elev. "790 feet). Upper Marshall sandstone was struck at 555, Lower Marshall red rock at 690, Coldwater red rock at 1,280, the Traverse at 2,070, the Dundee at 2,790, the Detroit River at 3,040 (?), and the Sylvania at 3,520 feet. There were showings of oil from 1,730 to 1,750 and from 3,440 to 3,450, and water at 570, 2,205, and 2,870 feet. The total depth was 3,765 feet, where the well was plugged and abandoned in the winter of 1930.

Patterson and Day started a well in 1929 on the property of C. C. Davis et al in the NE.¼ SW.¼ sec. 19, Cherry Valley township (elev. 847 (?) feet), and drilled it to 2,998 feet or just above the Dundee, where it has been shut down ever since. Marshall sandstone was reported at 820 feet, the Lower Marshall at 1,020, Coldwater red rock at 1,647, and the Traverse at 2,536. Water was encountered at 980 and 2,546 feet.

LENAWEE COUNTY

Lenawee County is on the extreme southeast side of the Basin and just off the northwest flank of the Cincinnati arch where this structure plunges toward the Ontario peninsula (See fig. 40). The formations on the west side of this arch dip very steeply into the extreme eastern part of the county, but in the northeastern part of Macon township the Trenton may possibly be relatively high. A plunging nose, which seems to trend in a curve from a few degrees west of north to northwest as it heads toward the center of the basin, begins on the south line near South Fairfield in Ogden township, extends a little west of Adrian and continues diagonally northwestward across Woodstock township in the northwest corner of the county. This region has not been tested for sometime, but gas wells in the drift at Sprunk's greenhouse in Blissfield, and in Addison may lead to new drilling. Three deep wells were put down in the eastern part of the county near the Deerfield anticline where production had been found in the Trenton "rock."

Allen Borton started a well on the S. E. Lawerance farm in the SE.¼ SE.¼ sec. 5, T.6S., R.5E., Ridgeway township, near the village of Britton (Elev. 715 feet). Drilling was carried on intermittently, and operations have been shut down at 1,910 feet since the spring of 1931. The Trenton was not reached. The first rock was the Berea formation, and samples indicated the top of the Antrim at 214, the Traverse at 365, the Dundee at 476 (?), the Detroit River at 595, the Sylvania at 815, and the Bass Island at 856 feet. Showings of oil and gas were not reported in the hole.

A deep well was drilled through the Trenton to a depth of 3,328 feet by the LaDu Oil Corporation on the Anna Long farm, NE.¼ NE.¼ sec. 2, T.7S., R.5E., Deerfield township (Elev. 707 feet). In this hole, the Traverse was found at 190, the Dundee at 320, the Sylvania at 575, the Bass Island at 650, the Niagaran at 1,385, the Cataract at 1,760, the Trenton at 2,373, and Lower

Magnesian group at 3,122 feet. Small showings of oil were found at 850, 950, 1,100, 2,753, and 2,970 feet, and a fair showing of gas was struck from 1,245 to 1,280 feet. Water came into the hole from 3,325 to 3,328 feet.

The D-O-H-I Oil Corporation put down a well on the William Farrow farm in the SE.¼ NE.¼ sec. 13, T.8S., R.5E., Riga township, to a depth of 1,477 feet (Elev. 696 ft). The Traverse was at 115 feet, the Dundee at 215, the Sylvania at 365, the Bass Island at 480, the Niagaran at 1,124, and the Clinton (?) at 1,371. Small showings of gas were reported at 70, 290, 308, 437, 555, 718, 775, and 824 feet, and oil was found in small quantities at 1,371 feet. Water was encountered at 105, 380. 458, 1,272, and 1,375 feet.

LEELANAU COUNTY

The regional dip in Leelanau County is generally southeast, but the rate is practically indeterminable because of the thick glacial drift and scarcity of wells. Undoubtedly, minor folding crosses the county because the trend of Central Michigan structures is in its direction.

The only deep well in the county was drilled in the years 1930 to 1932 by Clyde U. Smith, Trustee, on the Philip Heimforth farm in the SW.¼ SW.¼ sec. 6, T.28N., R.11W., Elmwood township, to a depth of 2,475 feet (Elev. 673 feet). Antrim black shale was first penetrated beneath 435 feet of glacial drift, and then the Traverse was struck at 510, the Dundee at 1,305, the Detroit River at 1,432, the Sylvania at 1,992, and the Bass Island at 2,165 feet. Showings of oil were found at 1,230, 1,242, 1,915, and 1,990 feet and water at 1,230, 1,242, 1,335, 1,350, 1,570, 1,775, 2,125, and 2,360 feet. The water at 1,570 feet was reported to be fresh.

MACOMB COUNTY

The structural geology of Macomb County is uncertain, except in the immediate vicinity of Mount Clemens where most of the wells have been drilled. Here many of the logs are inaccurate. The regional dip in northern Macomb County seems to be almost north or possibly slightly northeast into a major syncline that apparently crosses the northeast corner of the county in Richmond township. A broad local structural arch extending from northeastern Lake township toward northwestern Shelby township is indicated by the contours on the Traverse (see pl. III), and some kind of gentle reversal in dip is suggested by the wells in the north part of Mount Clemens. Possibly this reversal is due to a cross fold that seems to extend southwestward from the vicinity of the village of St. Clair toward the north shore of Anchor Bay, where several wells have been drilled. Except for one hole in the northern part of Macomb County, the testing for oil and gas has been near Mount Clemens. Since 1928, six wells have been commenced and two of them drilled to the Niagaran.

After the completion in 1928 of the Otto Coulon No. 1 well, in the NW.¼ SW.¼ sec. 4, T.2N., R.13E., the St. Clair Oil and Gas Corporation drilled 4 more wells in the same community.

The Otto Coulon No. 2 was in the S.½ N.½ SW.¼ sec. 4, 150 feet from the north and 700 feet from the west property lines (Elev. 598 feet). The Traverse was found at 319 feet, and the well was drilled to 405 feet. Showings of gas were struck at 321, 350, and 400 feet.

The Otto Coulon No. 3 in the same quarter section, but 310 feet from the north and 300 feet from the west property lines, was drilled to a depth of 660 feet (Elev. 593 feet). The drift was 295 feet in depth, the Traverse was at 330, and the Dundee at 555 feet. Mineral water was encountered at the bottom of the hole.

The Frank Blaisdell well in the SE.¼ NE.¼ sec. 5 attained a depth of 1,420 feet but was plugged back to 635 feet (Elev. 598 feet). The drift was 285 feet thick, the Traverse was found at 320, and the Dundee at 547 feet. There was a show of oil in the Dundee at 589 feet.

The only deep well in the Coulon district was the Fred Coulon No. 1, in the SE.¼ SE.¼ sec. 5 (elev. 597 feet), drilled in the fall of 1929. In this well, the drift was 100 feet thick, the Traverse was at 325, the Dundee at 572, the Sylvania at 1,027, and the Salina salt at 1,482 feet. The well was finished at 2,564½ feet in brown lime beneath the salt. Water was encountered at 654, 807, 947, and 1,002 feet.

A test well, 1,208 feet in depth, was put down in 1931-1932 by the Central Development Company on the Brewer property in the SE.¼ SE.¼ sec. 33, T.5N., R.12E., Bruce township (Elev. 853 feet). According to information, this well entered the Coldwater formation at 92 feet and found the Berea at 728, and the Traverse at 1,108 feet. Showings of gas were reported at 609-618 feet and oil at 318 and 1,054 feet. Water, which filled the hole, was struck at 618 feet and sulfur water at 1,204 feet.

H. H. Brown, formerly of the St. Clair Oil and Gas Corporation, drilled a well 2,575 feet deep on the Gregory Krantz estate in Private Claim 193, T.3N., R.14E., Chesterfield township (Elev. 581 feet). The Traverse was penetrated at 435 feet, the Dundee at 670, salt at 1,895, and the Niagaran at 2,364. A small amount of gas was found at 426 feet, gas, oil, and water at 935, and showings of oil at 2,371 and 2,494 feet. Water horizons were at 691, 760, and 2,572 feet. The last showings were shot with 100 quarts of nitroglycerin without appreciable increase, and the hole was plugged and abandoned.

Another well being drilled by H. H. Brown on the Louis Bower et al property, SE.¼ SE¼ sec. 29, T.3N., R.14E., is now down about 495 feet. (Feb. 1, 1933)

MANISTEE COUNTY

The structural geology of Manistee County is very poorly understood, but the general dip is a little south of east at about 35 feet to the mile. A large number of salt wells

have been drilled around Manistee Lake, but with the exception of one well in the northwest corner of Manistee County, there has been no prospecting for oil and gas beyond the immediate vicinity of the city of Manistee. The wells at Manistee indicate an anticlinal fold, but the location of the axis is difficult to determine.

There is evidence of a south dip both at Stronach and on the west side of Manistee Lake, but whether or not this dip has a southwest component cannot be definitely determined. The structure seems to trend from near the northwest corner of sec. 12, Filer township in the city of Manistee, eastward and possibly southeastward across Manistee Lake into sections 7, 8, 17, and 18, Stronach township. Another anticlinal fold possibly crosses Manistee County from the region between Bear and Portage lakes to near the southeast corner.

Ruggles and Rademaker finished a deep well, No. 24, near the salt plant in the SE.¼ NE.¼ sec. 12, T.21N., R.17W., Filer township, to a depth of 5,280 feet in June, 1928 (Elev. 591 feet). The base of the drift was found at 590, the Traverse at 930, the Dundee at 1,590, Detroit River salt at 1,981, the Sylvania at 2,345, Salina salt at 2,960, the Niagaran at 4,195, the Manitoulin at 4,685, and the Trenton at 5,000 feet. Gas showings were found in the Ellsworth formation at 800 feet, the Sylvania at 2,350; oil in the bottom of the Salina at 4,060 feet, and dead oil with some gas in the Niagaran at 4,243 feet. Salt water was encountered at 2,460, 3,620, and 5,185 feet.

John H. Rademaker drilled a brine well to a depth of 2,410 feet on the east side of Manistee Lake in Government Lot No. 1, sec. 7, T. 21N., R.16W., which was completed in August, 1931. Brine was found in sandstone at 2,390 feet.

In November 1929, Tackett and Drake of Chicago started a well on the Manistee Sand and Dock property in the NE.¼ NW.¼ Sec. 13, T.21N., R.17W., which was completed in the Upper Monroe to a depth of 2,000 feet (Elev. 638 feet). The Traverse was struck at 957, the Dundee at 1,645, and Detroit River salt at 1,945 feet. Showings of gas were found in the drift at 430 feet and near the base of the drift at 640 feet, in the Antrim at 855, the Traverse at 1,040, the Dundee at 1,647 and 1,710, and the Detroit River at 1,940 feet. Brine came into the hole at 1,018, 1,060, 1,647, 1,710, 1,875, and 1,940 feet. It was plugged and abandoned in May, 1930.

Smith and Macauley of Detroit drilled on the Lena Piellusch property in the NE.¼ NW.¼ SE.¼ sec. 20, T.21N., R.16W., Stronach town, ship to a depth of 2,041 feet (Elev. 612 feet). The top of the Traverse was at 1,030, Traverse limestone at 1,070, and the Dundee at 1,705 feet. Some gas was found at 1,085 and oil with gas at 2,003 feet. There was salt water in the Traverse beneath the gas at 1,087 feet.

The Swastika Oil and Gas Company of Muskegon put down two wells northeast of Manistee which fairly well established the north reversal of the East Lake anticline. These wells were also interesting in that they were drilled through nearly 600 feet of glacial drift with a light rotary outfit and then completed with cable tools. The first well, 2,023 feet deep, was on the flats northeast of the lake on the property of the Louis Sands Lumber Company in the NW.¼ SW.¼ NW.¼ sec. 6, T.21N., R.16W (Elev. 584 feet). The top of the Traverse was at 910, the Dundee at 1,610, and Detroit River salt at 2,000 feet. Water was encountered at 1,837 feet and a small amount of oil at 1,851 feet, but the hole was plugged and abandoned in the summer of 1930. The second test was on the W. H. Cromer farm in the NW.¼ NW.¼ sec. 34, T.22N., R.16W., Manistee township (Elev. 615 feet). The top of the Traverse was reported in the driller's log at 930 feet, but another source gave it as 1,050 feet, the Dundee was at 1,726½ and Detroit River salt at 2,045 feet. There was a show of gas in the hole at 1,210 feet, and water came in at 980 and 1,731 feet.

The Fisher-Robbins Oil & Gas Company commenced a well on the Chamberlain Estate in the NE.¼ SW.¼ sec. 14, T.24N., R.16W., Arcadia township, which was drilled to 890 feet (Elev. 602 feet). Some gas was found at 478 and 535 feet and water at 530, 712, and 835 feet. According to unreliable reports, the Traverse was at 860 feet, but this has not been confirmed. Operations at the well have been shut down for several years.

MASON COUNTY

The east and southeast regional dip in Mason County seems to flatten somewhat from that in Manistee County, and between Ludington and the southeastern corner of the county it appears to be between 22 and 23 feet to the mile. The only wells in the county are near Pere Marquette Lake in Ludington, between Ludington and Manistee in Grant township, and south of Walhalla in Logan township. From these few wells, it is difficult to determine local structural trends. A broad east-west high seems to extend across the bottom part of the southern row of townships, and the extension of the East Lake anticline in Manistee County may possibly cross the townships in the northeast corner of the county. The Logan township wells suggest a, gentle southeast plunging nose, but the south well of the group, with the Traverse apparently high, was dry.

After the discovery of a small volume of gas in 1927 by the Logan Oil Company near the top of the Sylvania formation in a well in sec. 9, Logan township, the chief stockholders of this company, acting as trustees, started another well on the north side of the Pere Marquette River on the Geo. H. Young farm in the NW.¼ SW.¼ SE.¼ sec. 9 (Elev. 666 feet). This well, the Young No. 2, struck the Coldwater red rock at 1,011, the Traverse at 1,850, the Dundee at 2,426, the Detroit River at 2,552, and the Sylvania at 3,139 feet. Considerable drilling difficulty was experienced .with the hole, and although some favorable showings were found at about the same depth as in the first well, it was plugged and abandoned at 3,294 feet. A showing of Dundee oil was found at 2,439, but water came in at 2,440 feet. The hole also filled up with water from near the top of the Sylvania, but

a break in the pipe at about this time made it almost impossible to determine either the Sylvania gas or water horizons.

The second gas well in the district was the Taggart and Welch, F. Campbell No. 1, in the NW.¼ NW.¼ sec. 16 (elev. 666 feet), and when closed in on November 29, 1928, it was reported to have a capacity of about 500,000 cubic feet. Although drilled to a depth of 3,310 feet, the well was plugged back to 3,275 feet and shot twice, once with 60 quarts of nitroglycerin and once with 80 quarts. The top of the Coldwater red rock was at 1,004 feet, the Traverse at 1,830, the Dundee at 2,425, the Detroit River at 2,551, and the Sylvania at 3,226 feet. There were shows of oil and gas in the Ellsworth beds at 1,620 feet, in the top part of the Dundee, and in the Sylvania gas horizon from 3,234 to 3,238 feet.

Taggart and Welch next drilled on the L. N. Lake property in the NW.¼ SE.14 sec. 10 (elev. 692 feet), and completed an oil well in the Traverse formation which filled up 1,150 feet with oil the first night. About 1,800 barrels were pumped from the well, but at present it is not operating. Coldwater red rock was struck at 1,061 feet and the Traverse at 1,890. The oil and gas "pay" occurred at 1,907½ feet, and the hole was drilled to 1,909 feet.

In an effort to find more Traverse oil, the same operators drilled 2 dry holes in sec. 10. The first of these was on the W. O. Lake farm in the NE.¼ SE.¼ sec. 10 (elev. 702 feet) and was drilled to a depth of 2,700 feet, where it was plugged and abandoned in April, 1929. Red limestone was struck near the base of the Coldwater at 1,074 feet, the Traverse at 1,895, the Dundee at 2,502, and the Detroit River at 2,579 feet. Water, struck at 1,928 feet, filled the hole to within 400 feet of the top. The second test, which was on the Harry Barnett property in the NE.¼ SW.¼ sec. 10, was drilled to about 2,300 feet. It was then allowed to stand with casing in the hole until November 1931, when it was cleaned out and deepened 20 feet. Here was encountered water which almost filled the hole.

The last well in the Walhalla region was the Taggart and Welch & Thompson Brothers—H. A. Barnett in the NW.¼ SW.¼ sec. 16 (Elev. 756 feet). This was drilled to a depth of 3,406 feet. The Coldwater red rock was at 1,131, the Traverse at 1,935, the Dundee at 2,544, and the Sylvania at 3,348 feet. There were showings of oil at 1,960 and 1,980 feet and gas at 3,350 feet. Two gas "pays" of 10,000 cubic feet each were encountered at 3,355 to 3,360 and 3,375 to 3,380 feet. Water was struck at 1,990, 2,015, and 2,558 feet. The quantity of gas was too small to save, and the well was plugged and abandoned in July, 1931.

M. I. Diamond of Chicago and his associates drilled 5 shallow wells and 1 deep well in Grant township in the northwest corner of the county. The discovery of a large flow of gas at the base of the drift in the first well caused the continuation of drilling. The Diamond-Thompson-Holland—M. I. Diamond No. 1 was in the SE.¼ NW.¼ sec. 15, T.20N., R.17W., Grant township (Elev. 654 feet). It was drilled to a depth of 634 feet and gauged 2½ million cubic feet of gas and 230 pounds rock pressure.

The same organization drilled on the Lee A. Lewis farm, in the NW.¼ SW.14 sec. 15, to a depth of 2,385 feet (Elev. 654 feet). The Traverse was encountered at 1,355, the Dundee at 2,035, and the Detroit River at 2,160 feet. Water was found at 1,424 feet and a "hole full" at about 2,260, but no showings of oil and gas were recorded.

The rest of the shallow wells put down by M. I. Diamond were between 600 and 700 feet deep. The J. B. Benson No. 1 was in the SE.¼ SE.¼ sec. 15 and had between 2 and 3 million cubic feet of gas at depths from 630 to 660 feet. At 660 feet, the hole filled up with water. The Joe Adamczak No. 1 was in the SW.¼ NE.¼ NW.¼ sec. 15 and was a dry hole at the same depth. The M. I. Diamond Fee No. 2 was in the SE.¼ NW.¼ sec. 15 (elev. 653 feet) and had gas in a fine sandy gravel from 640 to 643 feet, but it was plugged as a dry hole. The M. I. Diamond Fee No. 1, which was in the NE.¼ SW.¼ sec. 15, had gas at 640 and water at 650 feet.

MECOSTA COUNTY

Mecosta County is centrally located in the Michigan Basin just west of its deepest part and, although the prevailing regional dip is to the northeast, there seems to be also dips to the southeast and northwest. The regional structure is essentially a northeast plunging trough which is crossed by northwest-southeast lines of folding whose noses plunge into this trough. One of these lines of folding is the Broomfield "high" which trends from Isabella County across parts of Sheridan, Fork, and Chippewa townships (See pl. IV). Another line of anticlinal folding seems to cross from the southeast corner of the county toward Big Rapids, and a third may extend from southwestern Deerfield across Aetna township. The first of these "highs" is the only one about which there is a very definite information.

The first deep well in Mecosta County was completed by the Benedum Trees Oil Company on the F. I. Truman property, SW.¼ SW.¼ sec. 26, T.14N., R.8W., Morton township, to a depth of 4,737 feet (Elev. 1,001 feet). The Parma occurred at 885 feet, the Marshall (?) at 1,365, Lower Marshall red rock at 1,565, the Traverse at 3,040, the Dundee at 3,606, the Detroit River at 3,720, and the Sylvania at 4,687 feet. Water was found at 620, 3,612, 4,687, and 4,713 feet, and there was a showing of oil at 3,790 to 3,797 feet.

The Big Rapids Gas and Oil Corporation drilled a test on the Hans Anderson farm, NE.¼ NW.V4 sec. 14, T.15N., R.9W., Colfax township (Elev. 1,013 feet). The Parma was at 845 feet, the Napoleon (Upper Marshall) at 1,343, the Lower Marshall at 1,440, the Traverse at 3,020, the Dundee at 3,610, the Detroit River at 3,685, and the bottom at 3,742. Fresh water was found at 547 feet and brine at 895, 3,100, 3,150, 3,665, and 3,735 feet. A

small show of oil and gas was found at 3,120 and some oil at 3,305 feet, but the hole was plugged and abandoned.

A well was drilled south of Remus by Lewis D. Mehrtens and others on the Michael Baumann farm, SE.¼ SW¼ sec. 21, T.14N., R.7W., to a depth of 3,908 feet (Elev. 1,101.8 feet). This hole penetrated 693½ feet of drift. The stray gas sand in the Michigan series was at 1,498 feet, the Marshall at 1,545, Lower Marshall red rock at 1,655, the Traverse at 3,280, and the Dundee at 3,820. There was a small showing of black oil in the Michigan "sand" at 1,503 feet and brine in the Dundee at 3,895.

Benedum Trees Oil Company also drilled two wells in Sheridan township. The first of these on the William F. Grove Farm, NW.¼ NW.¼ SE.¼ sec. 14, T.15N., R.7W. (elev. 1,021 feet), was completed in the Detroit River formation to a depth of 3,904 feet. This well encountered the Parma at 1,050 feet, the Michigan "gas sand" at 1,387, the Napoleon at 1,491, Lower Marshall red rock at 1,692, the Traverse at 3,221, the Dundee at 3,792, and the Detroit River at 3,892. Gas was found in considerable volume at 1389-1393, 1615-1620, and black oil at 1,692 feet; a little gas was tapped from 2610-2690, but no favorable showings were found in the deeper Devonian formations. There was a "hole full" of water at 690 feet, water at 1,394, 1,395, and 3,860 feet, and a big flow at 3,982 feet. The second well, on the Clarence E. Brand farm, NW.¼ SE.¼ sec. 24, was drilled to a depth of 1,518 feet (Elev. 1,050 feet). The Parma was at 1,010 and the Marshall was at 1,502 feet, with water at 1,517 feet. The hole was plugged in February, 1931.

A further attempt to find the continuation of the gas horizons of the Grove well was made by the American Natural Gas Company on the Elmer E. Brehm farm, SE.¼ SE.¼ sec. 10 (Elev. 1,028 feet). The Michigan "stray gas sand77 was at 1,406 feet, 12 feet lower structurally than in the Grove No. 1, and contained no gas. The Marshall was encountered at 1,488 feet, and brine was tapped at 1,503 feet, the bottom of the well.

MIDLAND COUNTY

The structure of the rocks in Midland County, as interpreted from wells drilled for oil, gas, and brine, is shown in Plates IV and V. The principle known structural features of the county are the Mount Pleasant trough in southwestern Greendale township, Jasper township, and southwestern Porter township; the Greendale "high" in Greendale township, west central Lee township, northeastern Jasper township, and Porter township; the Midland trough in Midland township, Homer township, northeastern Lee township, Jerome township, Geneva township, and southwestern Warren township; and a possible extension of the Saginaw "high" that would parallel the Midland trough on the north. The regional setting of these features is better shown in Plate III, which covers the entire southern peninsula.

The wildcat wells in the county were drilled with hopes of extending the areas of production in the Mount Pleasant, East Extension, and Porter pools. Some of them were along the trend of the Midland "high" and others, where operators anticipated some unusual change in the direction of the fold, were more off the flanks. The wells listed and described in Table XXII are the wildcat wells drilled for oil and gas since January 1, 1928, exclusive of those on the borders of the outlined pools. This table indicates the depths to the important formations penetrated and to the oil, gas, and water horizons. The wildcat wells were drilled in Geneva, Ingersoll, Jasper, Jerome, Lee, Midland, Porter, and Mount Haley townships, and several of them had large enough showings of oil and gas to indicate the extension of old pools or possibly the discovery of new ones.

MISSAUKEE COUNTY

The regional structure of southern Missaukee County seems to be somewhat affected by the northwest prolongation of the Midland trough. In the northern part of the county, the regional dip is mostly southward, but there is evidence of north-south trending folds. The northwest trend of the Greendale "high" apparently crosses the southwestern corner of the county.

The first well in Missaukee County was drilled by Henry Miltner, Trustee, on the Miller-Browarsky-Gottschalk tract, NE.¼ NE.¼ sec. 24, T.24N., R.7W., Pioneer township (Elev. 1,295 feet). This test was the first in the State to find a real flow of "shale gas" in the Antrim black shale. The gas was struck at 2,630 feet. In June 1931, the well was shot with 110 quarts of nitroglycerin between the depths of 2,630 and 2,661 feet, and the initial production of 60,000 cubic feet was increased to 76,000 cubic feet. This gas is still shut in awaiting additional discovery. The formations in the well were penetrated as follows: the Marshall at 1,025, Lower Marshall red rock at 1,115, the Traverse at 2,842, and the Dundee at 3,528 feet. Besides the "shale gas," there was about 12,000 cubic feet of gas at 3,025, and showings of oil at 2,025 and 3,046 feet. The Dundee salt water at 3,580 was shut off in plugging back to shoot the shale gas "pay."

The Pioneer Oil and Gas Company drilled the second well in the region on the G. D. Miller property in the SW.¼ SW.¼ sec. 23, T.24N., R.7W., Pioneer township, to a depth of 3,742 feet (Elev. 1,419 feet). This hole encountered the Napoleon (Upper Marshall) at 1,035, Lower Marshall red rock at 1,175, the Traverse at 2,940, and the Dundee at 3,653 feet. The water horizons were 1,035 to 1,080 feet ("hole full" at 1,040), 1,150 to 1,175 ("hole full" at 1,155), 2,985 to 3,077 ("hole full" at 2,987), and 3,653 to 3,742 ("hole full" at 3,742). Some oil came in with the water at 2,987 feet and, when shut down at 3,055, the hole contained both water and oil.

MONROE COUNTY

The structural geology of Monroe County is interpreted from a subsurface contour map (see fig. 40) drawn on top of the Trenton limestone of Ordovician age. The regional rise of the strata out of the Basin and the north end of the Cincinnati arch brings these rocks within easily accessible drilling range in southeastern Michigan. The formations in western Monroe County dip steeply westward off the arch, but there is a more gentle north dip in the central part of the county that suggests a terrace structure similar to other Trenton "rock" fields. However, the terrace is not flat like in northwestern Ohio. A northward plunging nose trends from Sylvania in Ohio toward Saline in Washtenaw County, and the small oil wells near Deerfield and Dundee are on this nose. It seems to be interrupted diagonally by a northwest-southeast anticlinal fold extending from southeastern Bedford township toward Petersburg. Another broad structural nose plunges from the vicinity of Strasburg toward West Sumpter and the Washtenaw county line, where it meets the north line of Monroe County.

Hess and Roy drilled a Trenton well on the Frank G. Brunt farm, NE.¼ NE.¼ sec. 9, T.8S., R.7E., Bedford township, which was completed in May, 1929 (Elev. 642 feet). The top of the white Niagaran was found at 725, the Trenton at 1,757, and the hole was drilled to 1,907 feet without favorable results.

Permit.	Company.	Farm.	Location.	Sec.	T. R.	Elev.	Mar.	Red.	Berea.	Trav.	Dundee.	Monroe.	Sylvania.	Gas.	Oil.	Water.	T. D.
585	J. C. Arthurs	Geo. Histe	SW., SE. ¼ NE. ¼	10	Geneva, 15 N., 2 W.	681	1,284	1,417	2,502	3,102	3,705					3,770	3,808
767	Geneva Oil Co.	W. Henry	SW. ¼ SW. ¼	33	15 N., 2 W.	706	1,192	1,345	2,455	2,945	3,576						3,682
1269	W. L. McClanahan, Inc.	L. Hughes	SW., NE. ¼ NE. ¼	20	15 N., 2 W.	693	1,223	1,375	2,481	2,978	3,617				3,650		3,671
736	Midland Oil Dev. Co.	Geo. Buck	SE. ¼ NW. ¼	19	15 N., 2 W.	698	1,290	1,420	2,485	2,985	3,620			3,648	3,652	3,656	3,678
662	J. O. L. Spracklin	V. McClintic-Hood	NW. ¼ NE. ¼	29	15 N., 2 W.	711	1,260	? 1,360	2,463	3,010	3,618					3,668	3,677
1258	W. Hunter Atha	Chemical State Savings Bank	C., SW. ¼ SE. ¼	21	Ingersoll 13 N., 2 E.	642	1,100	1,221	2,288	2,834	3,445	3,550	4,607	4,607 4,637	4,651	3,540 4,662	4,662
1300	Michigan Pacific Oil and Gas Co.	Chas. S. Hoyt	NW., NW. ¼ NE. ¼	24	Jasper 13 N., 2 W.	691	1,153	1,280	2,420	2,920	3,486			3,035		3,556	3,561
1255	Fred Sias	Merryfield-M. Nelson No. 1	NE., NE. ¼ SW. ¼	17	Jerome 15 N., 1 W.	659	1,220	1,335	2,467	3,114	3,696					3,808 3,958	3,958
891	Chas. Strange	State of Michigan	NW., SE. ¼ SW. ¼	17	15 N., 1W.	662	1,278	1,390	2,480	3,120	3,705					3,960	3,975
1360	Michigan Gas & Oil Corp., et al.	B. Rayner No. 1	SW., SW. ¼ SW. ¼	6	Lee 14 N., 1 W.	669	1,170	1,295	2,425	2,920	3,540						3,548
1238	E. B. Strom	D. A. Newland	SW. ¼ NE. ¼	19	14 N., 1 W.	667	1,163	1,287	2,390	2,915	3,545			3,560			3,604
1223	Theodore Oil Co.	S. M. Robinson	SW., SW. ¼ NW. ¼	26	14 N., 1 W.	665	1,163	1,269	2,383	2,922	3,551					3,668	3,668
1224	M. D. Wells and G. W. Miller	H. G. C. Thom	S. ½ SE. ¼	9	14 N., 1 W.	656	1,180	1,305	2,425	2,905	3,594					3,835	3,837
1028	Mid-Bay Oil Co.	C. W. Patrick	E. ½ W. ½ NE. ¼	24	Midland 14 N., 2 E.	677	1,180	1,285	2,439	2,962	?				3,800	1,905 3,790	
862	Geneva Oil Co.	M. V. Warken	SW. ¼ SE. ¼	8	Porter 13 N., 1 W.	663	1,060	1,160	2,304	2,820	3,398				3,413		3,464
1170	Michigan Pacific Oil and Gas Co.	Jos. H. Otway, Jr. No. 1	NW., NW. ¼ NW. ¼	26	13 N., 1 W.	683	1,064	1,156	2,281	2,765	3,382			3,417	2,882 3,421		3,443½
1289	Michigan Pacific Oil and Gas Co.	Jno. Otway No. 1	NE., SE. ¼ NE. ¼	27	13 N., 1 W.	687	1,095	1,182	2,304	2,785	3,382					3,477	3,480
1385	Michigan Pacific Oil and Gas Co.	Jos. H. Otway, Jr. No. 2	NE. ¼ SW. ¼	22	13 N., 1 W.	682	1,072	1,165									
1428	M. M. Johnson and V. R. D. Kirkham	Frank Otway	NE., NE. ¼ NE. ¼	27	13 N., 1 W.												
1231	The Pure Oil Company	F. Howland	SW., SW. ¼ SW. ¼	23	13 N., 1 W.	683	1,068	1,165	2,314	2,793	3,383				3,417	3,473	3,473
598	Sun Oil Company	L. H. Doyle No. 1	NE. ¼ NE. ¼	32	13 N., 1 W.	696	1,185	1,275	2,442	2,922	3,522					3,555	3,556
1226	J. M. Markle, Tr.	H. Sims	NE. ¼ SE. ¼	4	Mt. Haley 13 N., 1 E.	647	1,155	1,252	2,375	2,915	3,538				2,418 3,541		3,615
952	Ohio Oil Co.	T. B. Clapp No. 1	W. ½ SW. ¼	34	13 N., 1 E.	687	1,029	1,180	2,317	2,829	3,432				2,950	3,510	3,517

*This table does not include wells in the Mount Pleasant (Greendale Twp.), or East Extension (Greendale, Lee Twps.) pools.

Table XXII. "Wildcat" wells in Midland County.

Sheehan and Cilley put down a hole near Dundee on the Geo. P. Huntley farm in the NW.¼ NW.¼ sec. 15, T.6S., R.6E., Dundee township (Elev. 695 feet). The top of the Trenton was at 2,227 feet, and there was a showing of oil reported at 975 and gas at 2,275 feet, but the hole was abandoned at 2,335 feet.

North of the old Deerfield Pool in western Monroe County, Wm. J. Morris, Trustee, made a Trenton test on the LaPointe & Dusseau farm in the NE.¼ NW.¼ sec. 19, T.6S., R.6E., (Elev. 709 feet). The Sylvania occurred at 270, the Bass Island at 390, the Niagaran at 1,100, and the Trenton at 2,125 feet. The Monroe-Salina showed some oil at 885 feet, and the Trenton had saturation at 2,202, 2,235-2,240, and showings in the cuttings down to 2,253 feet. The well was shot with 220 quarts of nitro-glycerin from 2,202-2,253 feet, and the estimated initial production was 15 to 20 barrels per day.

W. J. Morris also drilled on the Arnold Reau farm in the SE.¼ SW.¼ sec. 18, T.6S., R.6E., (Elev. 706 feet). In this well the Guelph was found at 1,100 feet, the Trenton at 2,147, and, although water was struck at 2,262 feet, drilling was continued to 2,282 feet. Some gas and oil were found at 2,185 feet. The hole was plugged back from 2,282 to 2,262 feet with a lead plug and shot with 200 quarts of nitroglycerin between 2.188 and 2,248 feet, but the quantity of oil was not materially increased. Operations were abandoned in February, 1931.

A third test by W. J. Morris, on the Michael Lidster farm, NW.¼ NW.¼ NW.¼ sec. 18, T.6S., R.6E., was drilled through the Trenton to a total depth of 3,160 feet (Elev. 707 feet). The Sylvania was at 375, the Bass Island at 450, the Niagaran at 1,275, the Trenton at 2,243, and the first sandy beds, probably of St. Peter's age, at 2,965 feet. There were gas and oil at 825 feet and a showing of gas at 2,248, but water came in at 2,597 feet, and the hole was plugged and abandoned on June 10, 1931.

E. L. Dayton, drilled a well near Cone on the Geo. Fasking farm in the NE.¼ NE.¼ sec. 30, T.5S., R.6E., Milan township (Elev. 692 feet). The hole went through the drift into the Bell shale, found the Sylvania at 520 feet and the Bass Island at 710, and it was shut down at 1,035 feet. A showing of gas was encountered at 663 feet. The Fasking No. 2 was in the SE.¼ NE.¼ sec. 30 (elev. 692 feet) and found the Dundee at 120 feet, water at 125, and black water at 640 feet, which filled the hole. This well is shut down at 650 feet.

Alfred Violette of Detroit commenced to drill in the summer of 1930 on the Nachtergale farm in the NE.¼ SW.¼ sec. 15, T.5S., R.7E., London township (Elev. 657 feet). The Sylvania was reported at 290 feet, and at 610 feet drilling operations were suspended and never started again.

MONTCALM COUNTY

The regional structure of Montcalm County is very much like Mecosta, although its location is not quite so far in toward the center of the "basin." The county is probably crossed by at least two lines of anticlinal folding more or less parallel to the Broomfield "high" of Isabella County. Similar northwest-southeast structural troughs to those in the central part of the "basin" separate the "highs." There is some evidence to support the idea that one of the "highs" crosses somewhere along a line from Crystal to Six Lakes and the other from Fenwick to near the village of Amble, which is between Lakeview and Howard City. However, the evidence of these "highs" is fragmentary, because there are only 3 deep wells and 2 shallow Marshall tests in the county. These possible trends must be proved by further geophysical or drilling development.

The first wells in the county were drilled in 1928-29 to the Lower Marshall red rock by the Fish Creek Oil Company of Carson City. The Charles A. Ludwick No. 1 was in the SE.¼ SE.¼ sec. 36, T.9N., R.5W., Bloomer township (Elev. 792 feet). The top of the Marshall in this

well was at 885 feet and the top of the red rock at 985. The Robert and Arthur Montgomery No. 1 was in the SE.14 SE.¼ sec. 27 of the same township (Elev. 758 feet). The top of the Marshall was at 888, red rock at 988, and bottom of the well at 997 feet.

Bale, Hickey, and Snyder Bros, drilled a well to 4,385 feet near Lake-view on the Ernest Snyder farm in the NE.¼ SW.¼ sec. 20, T.12N., R.8W., Cato township (Elev. 938 feet). In this hole, the Parma was at 765 feet, the Marshall at 1,270, Lower Marshall red rock at 1,355, the Traverse at 2,860, Traverse limestone at 2,930, the Dundee at 3,375 (?), the Detroit River at 3,440, and the Sylvania (?) at 4,210. A showing of gas was found at 3,385 and 36° gravity oil at 3,496 feet. The hole was plugged back and shot from 3,496 to 3,506 feet, but the quantity of oil was not sufficient to profitably operate, and abandonment followed in October, 1929. The water horizons in the well were at 3,142 to 3,250 feet with sulfur water at 3,385 and 4,045 feet.

The Ionia-Montcalm Development Company put down a hole on the A. A. Herrick farm in the NW.¼ NW.¼ sec. 26, T.9N., R.6W., Bushnell township (Elev. 778 feet). The depth to the Parma was 445 feet, to the Marshall 949, to Lower Marshall red rock 1,028, to the Traverse 2?647, to the Dundee (?) 3,045, and to the bottom of the hole, 3,065. The only showing was a smell of gas in the Antrim black shale at 2,465 feet. Black sulfur water, which almost filled the hole, was tapped at 3,065 feet.

The Vestaburg Oil & Gas Company of Lansing drilled on the A. Anna farm in the NE.¼ SE¼ sec. 27, T.12N., R.5W., Richland township, to a depth of 3,531½ feet (Elev. 901 feet). The Michigan "stray gas sand" was at 1,223 feet, the Marshall at 1,250+, Lower Marshall red rock at 1,310, the Traverse at 2,930, and the Dundee at 3,456. There was a million cubic feet of gas with water at 1,233-1,250, water at 1,280, a hole full of water at 3,030 and water at 3,458-3,461 feet. The well was plugged and abandoned in July, 1930.

The Hill Top Oil & Gas Company—J. Nobles No. 1, SW.¼ SE.¼. sec. 27, T.12N., R.5W., was never completed, and the A. Anna location followed this unsuccessful drilling project.

MONTMORENCY COUNTY

The important natural gas seepages in Montmorency County have been known for many years and have recently attracted new attention because of showings of gas in a well at Atlanta. These seeps are widely scattered throughout the central part of the county and often take the form of raised mounds similar to mud volcanoes and "boiling" springs. They are most numerous along a general line from sec. 34, T.30N., R.4E., to sec. 30, T.31N., R.1E., and many of them are close to Atlanta, the county seat. One occurrence has been reported from the middle of the Thunder Bay River, NW.¼ NW.¼ sec. 26, T.31N., R.4E., near Hillman. Several wells have been started in the vicinity of Hillman and one at Atlanta, but none of these reached a sufficient depth to test all the possible Devonian "pay" formations. The regional structure shows in general a south dip which is locally southeast or southwest. Possibly there is a broad anticlinal nose trending a little west of north-south through the western tier of townships.

A well was drilled in 1927 on the Geo. Barrie farm, SE.¼ SW.¼ sec. 23, T.30N., R.4E., in which was found 206 feet of drift, black shale at 219 feet, and roily water at 500 feet. Frank Centala drilled on the Carrier farm about a mile north of Hillman in the NW.¼ NW.¼ sec. 24. T.31N., R.4E. (Elev. 768 feet?). The Traverse was struck at 416 feet, and the hole was 565 feet deep.

In the summer of 1929, a well was started on the John Wilder farm in the SE.¼ SE¼ sec. 22, T.31N., R.4E., Hillman township, by Scott Stammler (Elev. 883 feet). Conflicting reports give the top of the Traverse at anywhere from 450 to 500 feet. The well is now shut down at about 1,120 feet.

In 1931-1932, George Stevens of Atlanta started a water well in Atlanta near his house in the NE.¼ SW.¼ sec. 12, T.30N., R.2E., which is now about 1,520 feet deep (Elev. 1,101 feet). Small showings of gas have caused considerable interest in this well, but delays have been frequent on account of light equipment, and the Dundee has not yet been penetrated. The drift was 368 feet thick, and the top of the Traverse was at 903 feet. There was gas in the brown shale at 717 feet, water at 850, and gas at 885, with a rock pressure of 180 pounds and a flow estimated at 20,000 cubic feet.

MUSKEGON COUNTY

The structure of the rocks in Muskegon County is better known than in many other parts of the State. The regional aspects of folding across the county have been interpreted in Plate III, and two contour maps of the Muskegon field (Muskegon and Laketon townships) are shown on a larger scale in Figures 27 and 28. There seems to be two important directions of anticlinical folding across the county, northwest-southeast and east-west. Drilling in the county has been carried on with the idea of finding new areas of production beyond the Muskegon field along both of these "trends." Although wildcatting has been somewhat disappointing, important showings of oil and gas have been found in several of these wells and further prospecting seems warranted in parts of Whitehall, Blue Lake, Dalton, Eggleston, Norton, Sullivan, and Ravenna townships. The structure of the rocks may possibly be favorable in southeast central Whitehall township; northeastern, central, and southwestern Blue Lake township; northwestern Dalton township; southeastern Eggleston township; southern Norton township; southeastern Sullivan township; and southwestern Ravenna township.

The wildcat wells in Muskegon County, exclusive of the oil field in Laketon and Muskegon townships, are listed in Table XXIII. These wells include several test holes drilled for structural information to the red limestone

member in the Coldwater formation. The abbreviated logs of wells in the county drilled for oil and gas are tabulated showing the depths to "key" formations and the oil, gas, and salt water horizons. These wells are in Blue Lake, Cedar Creek, Dalton, Eggleston, Fruitland, Fruitport, Holton, Montague, Norton, Ravenna, Sullivan, and White River townships.

NEWAYGO COUNTY

A great deal of attention was focused on Newaygo County as likely "wildcat" territory after the discovery of the Muskegon field, and in all eighteen locations were made in the county. The county is on the west side of the Basin, and the average regional dip is eastward at 18 to 19 feet per mile. Two east-west anticlinal folds seem to cross the southern part of the county, and two folds with a curving northwest-southeast direction probably extend across the northern part. The east-west folds in southern Newaygo County are indicated near the Garfield-Ashland township line and near the Denver-Dayton and Sherman-Lincoln township lines. The suggested anticlinal folds in the northern part of the county trend from northeastern Big Prairie township to northeastern Beaver township and from northeast central Norwich township to northwestern Home township. The structural conditions in the county are better known in the southern half than in the northern, and it must be emphasized that these suggestions regarding folding in Newaygo county represent present interpretations which probably will be greatly changed by future drilling.

The Ichenberg Bros, et al Grass Lake Ranch well in the SW.¼ NW.¼. sec. 7, T.16N., R.11W. (elev. 1,060 feet), which was started in 1927, was taken over by the Newaygo Prospecting Company in 1929 and drilling resumed. Many delays have ensued, but the present depth is 2,123 feet (Jan. 1, 1933). The well struck salt water at the base of the drift at 740 to 755 feet, a showing of black oil at 772, and the Marshall at 1,195.

The Oceana Oil Corporation—Samuel Stitt No. 1, in the SE.¼ SE.¼ sec. 28, T.15N., R.14W. (elev. 890 feet), was commenced in 1929, but it was taken over by the Beaver Oil and Gas Company in 1932. The drift was 495 feet thick, and the Coldwater red rock occurred at 1,427, the Berea at 1,496 (?), and the Traverse at 2,256 feet. The well was plugged as a dry hole at 2,259 feet.

The Hesperia Petroleum Company started a well in 1929 on the W. A. Jones farm, NE.¼ SE¼ sec. 20, T.14N., R.14W., Denver township (Elev. 786 feet). After a lapse of nearly two years, operations are again under way, and the present depth is 2,360 feet. The Coldwater red rock was at 1,350 and the top of the Traverse at 2,158 feet.

The Pennsylvania Oil and Gas Company drilled a test in 1929 on the W. A. Miller farm in the SE.¼ SE.¼ sec. 33, Goodwell township (Elev. 1,002 feet). The Marshall formation was at 1,065 feet, Coldwater red rock at 2,027, the Traverse at 2,760, the Dundee at 3,247, and the bottom at 3,260. In the top of the Traverse, oil was struck at 2,794 feet, and 800 feet of oil and 1,000 feet of water came into the hole. Water in the Marshall was struck at 1,170 feet and in the Dundee at 3,250 feet. There was a "hole full" at both depths. The well was plugged in January, 1930.

The Newaygo Gas and Oil Company started a deep well on the Bates farm in the NE.¼ SE.¼ sec, 12, T.13N., R.13W., Sherman township (elev. 821 feet), and operations are still under way at 6,002 feet (Jan. 1, 1933). The Marshall was struck at 815 feet, Coldwater red rock at 1,460, the Traverse at 2,408, the Dundee at 2,918, the Monroe at 3,030, the Sylvania at 3,590, the Salina at 4,115-5,475+, and the Niagaran at 5,526. There was water at 3,145 feet and a show of gas at 5,208 feet with much water at 5,215.

Permit.	Company.	Farm.	Location.	Sec.	T. R.	Elev.	Mar.	Red.	Berea.	Trav.	Dundee.	Monroe.	Gas.	Oil.	Water.	Total Depth.
794	Buchanan & Frye	Fruitvale Resort	E. ½ SW. ¼ SE. ¼	6	Blue Lake 12 N., 16 W.	616		984	? 1,327	1,736	2,226				2,229	2,245
269	J. F. Carpenter	J. O. Jensen No. 1	SE. ¼ NE. ¼	2	Cedar Creek 11 N., 15 W.	719		1,218		2,205	2,413					2,461
268	Creek Land Develop. Co.	Chas. Schorr	NE. ¼ NE. ¼	34	11 N., 15 W.	619	212	1,015 1,025		1,785 1,826 l. s.				1,832		1.878
499	Hervey-Bolema Synd.	F. A. Gritzner	SW. ¼ NE. ¼	17	11 N., 15 W.	668		1,081	1,472	1,881	2,265					2,327
1419	Reed Oil Co.	Chas. Ewing	NE. ¼ NW. ¼	7	11 N., 15 W.		Test well									
197	Shifting Sands Land Corp.	Shifting Sands Land Corp.	SW. ¼ NW. ¼	20	11 N., 15 W.	610		1,009	1,375	1,810	2,193				2,175 2,252	2,252
255	Eureka Oil Co.	R. Featherstone	SW. ¼ SW. ¼	35	Dalton 11 N., 16 W.	649		972		1,845	2,142				2,230	2,232
308	P. G. Fennell	B. Gustafson	SE. ¼ SE. ¼	19	11 N., 16 W.	666		998		1,767	2,203				1,782 1,879 2,218	2,310
1295	Muskegon Oil Corp.	M. Bard	NW., NW. ¼ NW. ¼	27	11 N., 16 W.		Test well									
1383	Muskegon Oil Corp.	L. Price	NW., NE. ¼ SW. ¼	12	11 N., 16 W.		Test well									
1418	Muskegon Oil Corp.	H. Kops	E. ½ NW. ¼ NE. ¼	22	11N., 16 W.		Test well									
1425	Muskegon Oil Corp.	O. Trumbull	NW., SW. ¼ NW. ¼	11	11 N., 16 W.		Test well									
1319	Muskegon Oil Corp.	P. Wiersma	NW., SW. ¼ NE. ¼	14	11 N., 16 W.		Test well									
318	Shoreline Corp.	Kelley (Bankers Trust Co.)	NW. ¼ SW. ¼	20	11 N., 16 W.	671		1,045		1,812	2,255					2,487
248	Sun Oil Co.	A. Grelewicz	SE. ¼ NE. ¼	26	11 N., 16 W.	654		1,010		1,808 l. s. 1,773	2,182			1,815	2,255	2,262
74	Kundtz & Hulse, Inc.	H. J. Lageschulte	SW. ¼ NE. ¼	24	Eggleston 10 N., 15 W.	660		1,085	1,210	1,880	2,263					2,275
1151	H. & W. Feicke	H. & W. Feicke No. 1	SE. ¼ SW. ¼	1	Fruitland 11 N., 17 W.	683		1,048		1,775 1,852 l. s.	2,270	2,340			2,340	2,700
1381	H. & W. Feicke	H. & W. Feicke No. 2	SE., SW. ¼ SE. ¼	1	11 N., 17 W.		Drilling									
1095	Reed Oil Co.	C. L. Bullock	S. ½ NE. ¼	15	11 N., 17 W.		Test well									
1036	Reed Oil Co.	H. Mann	N. ½ NE. ¼	29	11 N., 17 W.		Test well									
346	Cloverville Oil Co.	A. Borns	NE. ¼ NE. ¼	12	Fruitport 9 N., 16 W.	651		1,022		1,808	2,213				2,263	2,263
7D	H. Harper	Flora G. Cook No. 1	NE. ¼ NE. ¼	2	9 N., 16 W.	606				1,763	2,125				2,279	
1078	W. E. Lang	F. Jonio	NE., NW. ¼ SE. ¼	30	9 N., 15 W.	639		982		1,715 1,768 l. s.	2,148			1,770	1,795 1,920 2,230	2,250
613	Wright Oil Co.	B. Farr No. 1	NW. ¼ NE. ¼	26	9 N., 16 W.	626		916	1,323	1,669	2,070				1,950 2,158	2,163

*This table does not include wells in the Muskegon field (Muskegon and Laketon townships).

Permit.	Company.	Farm.	Location.	Sec.	T. R.	Elev.	Mar.	Red.	Berea.	Trav.	Dundee.	Monroe.	Gas.	Oil.	Water.	Total Depth.
217	L. C. Patterson	F. Monette No. 1	SW., E. ½ SE. ¼	13	Holton 12 N., 15 W.	755		1,320	1,700	2,082	2,533				2,150 2,450	2,671
695	White River Oil Corp.	A. Collatz-E. Neuerdorff	SE. ¼ NW. ¼	29	Montague 12 N., 17 W.	633		858	1,280	1,710					1,730	2,060+
438	White River Oil Corp.	D. MacDonald	S. ½ NE. ¼ NW. ¼	29	12 N., 17 W.	643		860	1,275	1,657	2,059		1,275 1,700	1,215	2,100	2,100
1043	White River Oil Corp.	W. Lipka	N. ½ NE. ¼ SE. ¼	19	12 N., 17 W.	659		885	1,300	? 1,660	2,076			1,970	1,680 2,108	2,214
943	White River Oil Corp.	J. A. Quinlan	SE., NW. ¼ NW. ¼	29	12 N., 17 W.	638		870	1,300	1,645				1,110		1,725
280	White River Oil Corp.	Village of Montague	SW. ¼ SW. ¼	21	12 N., 17 W.	590		830		1,620	2,025		1,685 1,720		2,065	2,065
113	S. B. Ridenour	Wm. Antisdale	SE. ¼ SE. ¼	2	Norton 9 N., 17 W.	600		905		1,705	2,186			2,186 2,220	1,985	2,237
296	Kemper & Boven, Trustees	F. Sayles No. 1	NW. ¼ NW. ¼	24	Ravenna 9 N., 14 W.		Abandoned									
139	Muskegon Develop. Co.	Haas No. 1	SE. ¼ SW. ¼	26	9 N., 14 W.		Test well									
101	O. C. Fink	C. W. Nash No. 1	SE. ¼ NW. ¼	20	9 N., 14 W.	664	400	1,115	1,136	1,846	2,231				2,306	2,310
412	W. W. Erdman	W. W. Erdman No. 1	SE. ¼ NW. ¼	11	Sullivan 9 N., 15 W.		Abandoned location									
764	H. Hanson Oil Synd.	W. Foot No. 1	NW., NE. ¼ NE. ¼	8	9 N., 15 W.	662	360	1,068		1,810 1,870 l. s.	2,245		2,055	1,810 2,130	2,135 2,300	2,300
741	J. F. Johnston	C. Janicke No. 1	E. ½ NW. ¼	1	9 N., 15 W.	663		1,071	1,480	1,843	2,210					2,260
1154	H. C. Nelson	Arved Nelson	SE. ¼ NW. ¼	24	White River 12 N., 18 W.	667	315	890		1,660	2,072				2,084	2,335
1146	H. C. Nelson	Geo. T. Rose	SE., NE. ¼ NE. ¼	25	12 N., 18 W.		Test well									
1234	H. C. Nelson	A. Runzel	NE., SW. ¼ NE. ¼	11	12 N., 18 W.	679		871		1,635	2,084				1,750	2,100
1384	H. C. Nelson	Geo. Waller	NE. ¼ SE. ¼	14	12 N., 18 W.	655		824		1,620	2,028		1,800			2,077

*This table does not include wells in the Muskegon field (Muskegon and Laketon townships).

Table XXIII. "Wildcat" wells in Muskegon County.

The Sherman Oil and Gas Company drilled on the Joe Hoppa farm in the SW.¼ SW.¼ sec. 22, T.13N., R.13W., Sherman township (Elev. 861 feet). The Traverse was found at 2,410 feet, the Dundee at 2,889, and the well bottomed at 2,960. Traverse water came in at 2,460 feet.

The Shell Petroleum Corporation sunk a well on the Mrs. B. Ridderman tract in the NW.¼ NW.¼ sec. 36, T.13N., R.13W., Sherman township, to a depth of 3,111 feet (Elev. 897 feet). The Marshall was found at 890 feet, Lower Marshall red rock at 970, Coldwater red limestone at 1,670, the Traverse at 2,418, the Dundee at 2,932, and the Detroit River at 3,005. The water horizon in the Traverse was from 2,485 to 2,490 feet, and the Dundee at 3,085 feet. The well was plugged and abandoned in September, 1929.

The D. E. Uhl Company drilled a test on the David E. Uhl ranch in the N.½ SE.¼ sec. 20, T.13N., R.12W., Everett township (Elev. 827 feet). It encountered the Marshall at 853 feet, Coldwater red rock at 1,673, the Traverse at

2,425, the Dundee at 2,920, and the Monroe at 3,155. A showing of gas was found at 2,450 feet in the Traverse and from 3,018 to 3,025 feet in the Dundee, and oil at 3,225 feet in the Monroe. Drilling was carried on to 3,653 feet where the well was abandoned in October, 1929.

The Ranke Oil and Gas Company drilled on the J. Horner farm in the SE.¼ SE.¼ sec. 32, T.13N., R.12W., Everett township (elev. 804 feet), and struck the Traverse at 2,383 feet, and the Dundee at 2,862. Salt water was tapped at 2,428 feet, and the well was drilled into the Dundee to a total depth of 2,925 feet.

The Butler Syndicate made a Traverse test on the Ardell E. Douglass tract in the NW.¼ NW.¼ sec. 26, T.13N., R.12W., Everett township, which was completed in March 1931, at a depth of 2,610 feet (Elev. 876 feet). The Marshall was found at 1,000 feet, Coldwater red rock at 1,832, the Traverse at 2,572, and water at 2,594.

The Atlantic Exploration Company put down a well on the Elwin J. Stone farm, SE.¼ SE.¼ sec. 27, T.12N., R.14W., Sheridan township, to a depth of 2,174 feet (Elev. 725 feet). The Marshall was struck at 575 feet, Lower Marshall red rock at 692, Coldwater red rock at 1,367, the Traverse at 2,140, and Traverse limestone at 2,150. Salt water and a showing of oil were struck at 2,174 feet, and the hole was completed in the fall of 1930.

The Hervey Syndicate started a well in 1929 on the O. E. Atwood and Company tract in the NE.¼ SW.¼ sec. 31, T.12N., R.13W., Garfield township (Elev. 730 feet ?). The drift was 384 feet thick, and the Marshall was struck at 760 feet, Coldwater red rock at 1,390, the Traverse at 2,201, and a showing of oil and water from 2,220 to 2,222 feet. The well has been shut down for over two years.

A well was also drilled by the Hervey Syndicate on the Max Baumgartner farm in the NE.¼ NE.¼ sec. 33, Garfield township (Elev. 747 feet). In this test, the Marshall was found at 598 feet, Lower Marshall red rock at 650, Coldwater red rock at 1,440, the Traverse at 2,236, and Traverse limestone at 2,260 feet. Water was struck in the Marshall at 598 and 631 feet; and gas, oil, and water in the Traverse at 2,288-2,290 feet. The hole was plugged in May, 1930.

A well, started by the Oakwyn Oil Company in the SW.¼ NW.¼ sec. 14, T.12N., R.13W., Garfield township, was drilled to 370 feet and the rig then moved off the location.

The Melrose Oil and Gas Company drilled on the Woodward and Hatch property in the SE.¼ SE.¼ sec. 5, T.12N., R.12W., Brooks township (Elev. 743 feet.) The Marshall was at 770 feet, Lower Marshall red rock at 835, Coldwater red limestone at 1,640, the Traverse at 2,390, the Dundee at 2,846, and the bottom depth at 3,100. In the Traverse, oil and gas, together with some water, was struck at 2,415 feet, and several flows followed. The well was tubed, pumped 15-20 barrels in 24 hours, and later swabbed a similar amount. After pumping for two weeks with hardly any oil resulting, the well was shut down at noon on July 3, 1929. After being shut down only a short time, it flowed nearly 100 barrels of oil. Since then, the well has produced considerable oil at irregular intervals. The hole was drilled below the oil horizon until water was tapped in the Monroe at 3,025 feet, after which it was plugged back to 2,550 feet.

Carl Prather put down a well on the G. B. Stacy farm, SE.¼ NE.¼ sec. 11, T.11N., R.14W., Bridgton township (Elev. 730 feet). The Marshall was found at 531 feet, Coldwater red rock at 1,331, the Traverse at 2,100, and the Dundee at 2,528. Salt water came in at 2,144, and at 2,548 feet, where the hole was plugged and abandoned in June, 1929.

Maire, Caswell, and Smith of Lima, Ohio, drilled on the O. E. Atwood and Company farm in the SW.¼ NE.¼ sec. 6, T.11N., R.13W., Ashland township, to a depth of 2,675 feet (Elev. 617 feet). The Marshall was encountered at 500, Lower Marshall red rock at 570, Coldwater red limestone at 1,292, the Traverse at 2,048, and the Dundee at 2,496 feet. A showing of oil was found in the Traverse, but water was struck beneath the Dundee at 2,660-2,675 feet.

The Atlantic Exploration Company drilled a deep test in Ashland township, NE.¼ SW.¼ sec. 12, on the W. H. Brydges farm (Elev. 883 feet). This well, which went to a total depth of 5,661 feet, was finished and abandoned in the Cincinnatian series without going to the Trenton. The Marshall was at 850, Coldwater red rock at 1,680, the Traverse at 2,417, Traverse limestone at 2,438, the Dundee at 2,857, the Sylvania at 3,455, the Salina at 4,025, the Niagaran at 5,124, and Manitoulin limestone at 5,405. The Traverse "pay" at 2,458 had a gas flow lasting about 12 minutes and a slight showing of oil, which was followed by a big flow of water at 2,459 feet. More water was struck in the Traverse at 2,565 and in the Dundee at 2,957 feet. There was a showing of gas in the Salina at 4,325 and about 60,000 cubic feet of gas in the Niagaran at 5,295 feet. The well was plugged back to this latter depth and shot once with 20 quarts and again with 100 quarts of nitroglycerin from 5,285-5,300 feet, but it was finally completed as a dry hole on September 21, 1930.

The same company drilled on the John Bailey property in the SE.¼ NW.¼ sec. 9, T.11N., R.13W., to a depth of 2,303½ feet (Elev. 781.5 feet). In this hole the Marshall was at 700 feet, red Lower Marshall at 735, Coldwater red limestone at 1,495, and the Traverse at 2,255. There was a show of oil and salt water in the Traverse at 2,296 feet, and the well was plugged in October, 1930.

OCEANA COUNTY

The location of Oceana County directly north of Muskegon County caused the drilling of a large number of widely scattered "wildcat" wells. These indicate that the regional dip, which is north of east in the southern part, changes gradually to southeast in the northern part.

This change is due to the broad regional eastward pitching syncline in the two southern rows of townships. That an east-west to northeast-southwest local anticlinal fold may border this syncline on the south is suggested by the important showings of oil from wells near the south county line and the structural nose close to the south line of Greenwood township. A broader east-west plunging nose that may change in direction to southeast, as it extends into the eastern part of the county, seems to border this major Oceana County syncline on the north through southern Weare, Crystal, and Colfax townships. This may be in some way related to the structure suggested by wells in Leavitt township. Other small structural "highs" are indicated a little east of the southwest corner of Grant township and near the middle of Benona and Shelby townships, but they are yet to be proved.

Drilling activity increased in 1932 with the discovery of oil in the Traverse in the DuVall, Thoren, et al—Weirich No. 1, NE.¼ SE.¼ sec. 31, T.15N., R.16W., Elbridge township (Elev. 722.6 feet). This well has been shut in pending litigation, but several rigs are now on the ground in the locality, and oil and gas operations are in progress throughout the county. The summary of the results of drilling since 1928 will proceed with the townships from north to south.

Varner and Lockwood have started a well on the Orin L. Flood property in the SW.¼ NW.¼ sec. 34, T.16N., R.18W., Pentwater township (elev. 618.3 feet), which has reached a depth of 443 feet. (Jan. 1, 1933).

Muskegon Oil Corporation drilled a test well on the V. J. Boone farm, SE.¼ SE.¼ sec. 3, T.16N., R.17W., Weare township, to a shallow depth.

Chas. W. Teater put down a deep well on the Oceana Live Stock Company (Stewart) ranch in the NE.¼ NW.¼ sec. 11, T.16N., R.15W., Colfax township, to a depth of 3,322 feet (Elev. 800 feet). The bedrock was at 402, the Marshall at 480, Lower Marshall red rock at 540, Coldwater red limestone at 1,160, the Traverse at 1,955, the Dundee at 2,530, and the Sylvania at 3,284 feet. There was a showing of oil at 1,580 feet and water at 420, 2,010, and 3,320 feet. The well was plugged in August, 1930.

Edward DuVall of Blue Island, Illinois, pioneered development in Golden township and completed the first well in September, 1928. This well, which was on the Carrie E. Mears property, NE.¼ SE.¼ NE.¼ sec 36, T.15N., R.19W. (elev. 596 feet), found Coldwater red rock at 685 and the Traverse between 1,500 and 1,550 feet. There was a showing of gas beneath the red rock at 798 and some oil in the Traverse at 1,576 feet. Water was struck at 1,591 feet, where the well was abandoned.

The second well on the Mears property was in the SW.¼ NW.¼ sec. 36, T.15N., R.19W. (elev. 593 feet), and went to a depth of 1,596 feet where water in the Traverse was struck. Coldwater red rock was struck at 700, Traverse limestone at 1,565 feet, and no showings were encountered.

The next project was a well on the C. F. Fiel farm, SW.¼ NE.¼ sec. 31, T.15N., R.18W., which went through the Dundee to a depth of 2,268 feet (Elev. 629 feet). The Traverse "pay" was from 1,635 to 1,645 feet and showed oil, gas, and water. There was more water at 1,840 and some gas at 1,968 feet, and the Dundee was reported at 2,085 feet. The hole was taken over and plugged by the Red Rock Oil and Gas Corporation.

Edward DuVall also drilled on the Wm. Schultz farm, NW.¼ NW.¼ sec. 12, T.15N., R.1SW., to a depth of 2,275 feet (Elev. 669 feet). In this hole, Coldwater red rock was found at 815 feet, the Traverse formation at 1,630, and the Dundee at 2,159. Salt water was tapped at 1,705-10 and 2,030 feet, and there was some gas in the top of the Traverse at 1,627-30 feet. The Dundee pay horizon was at 2,174 feet, but no oil, gas, or water was reported.

The Red Rock Oil and Gas Company put down a shallow test on the M. E. Skidmore farm, SW.¼ NE.¼ sec. 19, T.15N., R.18W., to a depth of 950 feet (Elev. 598 feet). The top of the Coldwater red rock was found at 725 feet.

The discovery well, causing recent activity in Oceana County, (Edward DuVall et al—Oscar Weirich No. 1), was in the NE.¼ SE.¼ sec. 31, T.15N., R.16W., Elbridge township (Elev. 722.6 feet). This test found Coldwater red rock at 1,043 and the Traverse at 1,862 feet. The present depth of the well is 1,894 feet, and it has flowed a total of 400 barrels of oil by heads at the rate of about 90 barrels per day. The pay was struck on July 30, 1932, but the control head has been opened only a few times because the title to the property is being contested. The oil is dark brown, smells of sulfur, and tests 34° Be. gravity at 72° F. temperature.

The second well in the district was the L. E. DuVall No. 1 on the J. C. Wallace Estate, SW.¼ SW.¼ sec. 32, T.15N., R.17W. (Elev. 731.5 feet). Coldwater red rock was found at 1,077 feet, the Traverse at 1,855, Traverse limestone at 1,930, and the bottom of the hole at 1,934 feet. There was a showing of oil at 1,460-65 feet and water at 1,934, which filled the hole.

A. S. Cochran drilled on the Hannum farm, SW.¼ NE.¼ sec. 31, T.15N., R.16W., to a depth of 2,407 feet (Elev. 720 feet). The Coldwater was encountered at 505, Coldwater red rock at 994, Traverse limestone at 1,900, and the Dundee at 2,399 feet. Water was struck at 1,903, and the hole filled up with water at 2,406 feet.

The Pennsylvania Oil and Gas Company drilled in 1929 on the Bert Snow farm, NW.¼ SE.¼ sec. 23, T.15N., R.15W., Leavitt township (Elev. 830 feet). The Marshall was found at 540, Lower Marshall red rock at 620, Coldwater red limestone at 1,240, the Traverse at 2,072, the Dundee at 2,565, the Detroit River at 2,637, the Sylvania at 3,248, the Bass Island at 3,290, and the bottom of the hole at 3,503 feet. Several important showings of oil and gas were found at 1,380, 2,666, and 3,252-64 feet. Water was reported at 417, 595, and 2,098 feet. The well was shot twice with 30 quarts of

nitroglycerin between 3,252-3,264 and 2,663-2,670 feet, but it was finally plugged and abandoned.

The Johnson Oil and Refining Company put down a well on the M. Sippy farm, NE.¼ NW.¼ sec. 14, T.15N., R.15W., to a depth of 3,305 feet (Elev. 827 feet). The Marshall was at 252, Coldwater red rock at 1,239, the Traverse at 2,010, Traverse limestone at 2,061, the Dundee at 2,559, the Detroit River at 2,634 (?), and the Sylvania at 3,235 feet. A showing of gas at 2,085 and a rainbow of oil at 2,695 feet were found, but water came in at 2,065-70 and 2,695 feet. The hole was plugged and abandoned in August, 1930.

In 1932, the Johnson Oil and Refining Company drilled on the A. F. Sippy farm in the NE.¼ SW.¼ sec. 27, T.15N., R.15W., and after finding the Coldwater red rock at 1,322 abandoned the test at 1,335 feet (Elev. 844 feet.) They have commenced the Sippv No. 2 in the SE.¼ NW.¼ sec. 24, T.15N., R.15W.

The Muskegon Oil Corporation drilled a shallow test on the F. Burmeister farm, SE.¼ NE.¼ sec. 34, T.14N., R.18W., Benona township. Edward DuVall also drilled in the NE.¼ NE.¼ sec. 1 of the same township on the Byron Curtis farm (elev. 672 feet) to a depth of 1,365 feet and found the upper red rock of the Coldwater at 845 feet. A showing of oil was encountered beneath the red rock in a shaly lime horizon at 913 feet.

The Muskegon Oil Corporation put down a Traverse test on the Jerry Zavel property, SE.¼ SW.¼ SW.¼ sec. 8, T.14N., R.17W., Shelby township (Elev. 774 feet). This well, after going through 430 feet of drift, struck Coldwater red rock at 1,025 and the Traverse at 1,780 feet. Salt water was found in the Traverse at 1,875, and the total depth was 1,890 feet.

The Oceana Petroleum Company (later Blue Arrow Petroleum Company) drilled a deep well on the J. Vanderwaal farm, SW.¼ NE.¼ sec. 33, T.14N., R.17W., Shelby township, near the village of New Era (Elev. 769 feet). Coldwater red rock was at 1,075 feet, the Traverse at 1,840, the Dundee at 2,330, the Detroit River at 2,450, the Sylvania (?) at 2,848, Salina salt at 3,179, the Niagaran at 4,045, the Manitoulin at 4,380, and the Trenton at 4,760. The hole was drilled 115 feet in the Trenton to a depth of 4,875 feet. Salt water was encountered at 1,915, 2,334-40, and 3,360 feet, and the well was abandoned on December 24, 1931.

The Muskegon Oil Corporation put down a shallow test well on the Mrs. Mildred Shaw farm, SW.¼ NE.¼ sec. 27, T14N., R.16W., Ferry township.

Shuler, Brooks, and Jetter started a well on the G. A. Beem farm, SE.¼ SE.¼ sec. 27, T.14N., R.15W., Newfield township (elev. 785 feet), which has been shut down since 1929 at a depth of 2,653 feet. The Marshall red sandstone was at 640, Coldwater red rock at 1,313, the Traverse at 2,116, the Traverse limestone at 2,147, and the Dundee at 2,595 feet. The salt water in the Traverse was struck at 2,160 and in the Dundee at 2,647 (?) feet.

The Sankey Oil and Gas Company drilled on the Frank Darlington property, SW.¼ SE.¼ sec. 9, T.14N., R.15W., to a depth of 2,796 feet (Elev. 831 feet). The Marshall was found at 647, Coldwater red rock at 1,372, the Traverse at 2,160, and the Dundee at 2,680 feet. There was a showing of oil at 2,680-83 feet and of gas at 2,684 feet. Salt water was struck at 541, 2,650, and 2,689 feet, and the well was plugged in September, 1929.

The Muskegon Oil Corporation drilled a Coldwater red rock test on the Wm. E. Kinster farm, SE.¼ SW.¼ sec. 17, T.13K, R.17W., Grant township. The Iroquois Oil Company drilled in 1929-30 on the Iroquois property, SW.¼ SE.¼ NW.¼ sec. 35, T.13N., R.17W., to a depth of 2,236 feet (Elev. 650 feet). In this well, the Marshall was found at 378 feet, Coldwater red rock at 970, the Traverse at 1,735, Traverse limestone at 1,775, and the Dundee at 2,216. There was a light show of oil at 1,829 feet, and water at 1,775, 2,008, and 2,236 (?) feet.

The North American Trust Company also drilled to 2,298 feet on the Iroquois Oil Company tract in the NE.¼ NW.¼ sec. 25, T.13N., R.17W. (Elev. 745 feet). The Marshall was near the base of the drift, but not definitely identified, and Coldwater red rock was at 1,016, the Traverse at 1,795, Traverse limestone at 1,839, and the Dundee at 2,251 feet. The water horizons were at 1,855-1,910, and 2,265 feet, and the well was abandoned in June, 1930.

The Fruitvale Land and Lot Owners put down a well to the Traverse on the C. J. Sipple Company property, SW.¼ SW.¼ sec. 23, T.13N., R.16W., Otto township (elev. 681 feet), which found a good showing of oil and gas at 1,950-54 feet. After drilling to 1,960 and allowing to stand, there was 130 feet of oil in the hole. Tubing and rods were run, and during one week the well pumped 30 barrels of oil. Another week it pumped 20 barrels of oil along with water, and there was about 900 feet of fluid in the hole. The well was finally plugged and abandoned at 1,968 feet. According to reports, the Marshall was at 620 feet, Coldwater red rock at 1,335, the Traverse at 1,908, and Traverse limestone at 1,948.

A. Anderson, Trustee for the same group, drilled a well on the Freedman and Strauss property, NW.¼ NW.¼ NW.¼ sec. 35, T.13N., R.16W., which is now shut down at 2,342 feet (Elev. 625 feet). Coldwater red rock was at 1,017 feet, the Traverse at 1,853, Traverse limestone at 1,898, and the Bell shale at 2,270. A showing of oil, gas, and water was struck at 1,905 feet.

The Decem Development Company put down a well 2,625 feet deep on the farm belonging to T. Veenstra and Sons in the SW.¼ SE.¼ sec. 26, T.13N., R.15W., Greenwood township (Elev. 768 feet). The Marshall was at 470, Lower Marshall red rock at 545, Coldwater red rock at 1,278, the Traverse at 2,015, and the Dundee at 2,505 feet. Salt water was struck at 2,153, 2,245, and 2,618 feet, and the well was plugged in June, 1929.

OGEMAW COUNTY

This county is on the northwest side of the Michigan Basin and structurally about 1,000 feet higher than its deepest part. The regional dip is generally southwestward, except where interrupted by local folds. The most pronounced of these folds, which is sometimes known as the West Branch anticline, has several hundred feet reversal and strikes northwest across Mills and probably eastern West Branch townships. The extension of this fold northwestward seems to veer somewhat to the north. (See pl. III.) A smaller anticlinal fold trends diagonally across Logan township in a northwest-southeast direction. Except for private core drilling and geophysical surveys, the rest of the county is entirely unexplored.

The Sun Oil Company drilled a dry hole in 1931 on the Frank Bernard property in the SE.¼ SE.¼ sec. 16, T.22N., R.4E., Logan township, to a depth of 3,025 feet (Elev. 841 feet). The Berea was at 1,435, the Traverse at 1,965, the Dundee at 2,735, the Detroit River at 2,925, and total depth at 3,020 feet. Gas in small quantities was found at 1,460 and 2,332-35 feet, and oil at 1,980-82. Salt water was encountered at 1,982-87, and at 2,905 feet black water filled up the hole 2,500 feet in ten days.

The Pure Oil Company drilled the first deep well on the West Branch structure on the William T. Yeo property, NE.¼ NE.¼ sec. 2, T.21N., R.2E., Horton township (Elev. 832 feet). The Berea was struck at 1,167, the Traverse at 1,680, the Dundee at 2,482, the Detroit River at 2,755, and the Sylvania at (?) 5,100 feet. Showings of oil and/or gas occurred at 1,830, 2,086, 3,583, 3,592, 3,604, and 5,180 feet. Salt water was struck at 2,086, 2,690, 2,720, 3,250, 5,044, 5,061, 5,124 feet, and the hole was completed and plugged in September, 1932.

OSCEOLA COUNTY

Osceola County is in the general trough of the Michigan Basin where it commences to pitch southeastward toward center. There are only two deep wells in the county, but they suggest that the Broomfield "high" extends diagonally northwestward across Evart and the northeast corner of Hersey townships. The Mount Pleasant trough probably continues from southwestern Clare and northwestern Isabella counties northwestward across the central region of Osceola County. The northwest extension of the Greendale "high" may cross some part of Marion township and the northeast corner of Middlebranch.

The Mellon-Pollock Oil Company of Pittsburgh put down a well on the Elwyn Johnson farm, SE.¼ SW.¼ sec. 35, T.18N., R.10W., Lincoln township (Elev. 1,227 feet). The Parma was found at 1,020, the Marshall at 1,436, Lower Marshall red rock at 1,625, the Traverse at 3,130, and the Dundee at 3,734 feet. The total depth was 3,836 feet. A show of gas was struck at 3,400, water at 3,748, and oil with some water from 3,822½ to 3,827 feet. This showing made 4 barrels of crude in 8 hours. More water came in at 3,833 and at 3,836 feet, and the hole filled up 1,000 feet in 30 minutes. The well was completed as a dry hole in October, 1930.

Ed. DuVall started a well at Reed City in the NE.¼ SE.¼ see. 9, T.17N., R.10W., Richmond township, but failed to land the drive pipe and the test was abandoned at 545 feet.

Core testing was carried on in the county by the Grayling Development Company et al., and in conjunction with the Sun Oil Company a large hole was drilled in the SW.¼ SE.¼ sec. 2, T.17N., R.9W., Hersey township (Elev. 1,059 feet). About 10,000 cubic feet of gas was struck at 1,298 feet and a little more gas at 1,335. The top of the Michigan "stray sand" was at 1,324, the Marshall at 1,400, and the bottom of the hole at 1,512 feet. The well was plugged and abandoned in August, 1931.

OTTAWA COUNTY

Many wells have been drilled in Ottawa County as a result of the Muskegon field and, although commercial production has not been found, there have been several favorable showings of oil and gas. The regional position of the county with respect to the major structure of the State is similar to Muskegon County, and in the eastern and northern parts the formations are found at similar depths. The southeastern corner of the county is somewhat farther up the side of the Basin than Muskegon County. In general, the regional dip is northeast at the average rate of about 18 or 19 feet per mile.

The southeast extension of the Muskegon anticline should continue across some of the townships in northeastern Ottawa County. This trend may be in a general northwest-southeast direction from the northwest corner of Polkton township to the southeast corner of Tallmadge. Wells have not been drilled in this district, but the abnormally wide spacing of contours (see pl. III) and the continuity with the direction of the northwest-southeast axis of the Muskegon fold seem to be evidence of this trend. A well in the southern part of Crockery township, which was regionally high, may have been on the west flank of the fold.

A broad trough seems to extend almost north-south across the county from the Zeeland-Jamestown township line toward the center of Chester township. Parallel highs apparently cross the eastern half of Jamestown township and the western half of Zeeland township. That some kind of a structure exists between Holland and Zeeland is indicated by the showings of oil in the Terbeck well, sec. 21, T.5N., R.15W. North of Holland, an east-west anticlinal fold across southern Olive township probably accounts for a showing of oil in the Traverse in the Telder well, sec. 35, T.6N., R.15W.

The deepest well* in the State was drilled by the Michigan Petroleum Company on the Charley E. Moe

farm, SW.¼ SE.¼ SE.¼ sec. 6, T.9N., R.13W., Chester township (Elev. 704 feet). According to scout reports, this well found the rock at 251, Coldwater red rock at 1,278, the Traverse at 2,020, the Dundee at 2,433, and the Trenton at 5,031 feet. The total depth was 6,310 feet. There were showings of gas at 1,345 and 5,303 feet, and salt water at 2,075-80, 2,493, and 5,490 feet. The hole was completed as a brine well in October, 1930.

Howard L. Foster put down a well in 1930 on the Jacob W. Bush property, NW.¼ SW.¼ sec. 4, T.9N., R.13W., (elev. 719 feet), which found the Coldwater red rock at 1,310, the Traverse at 2,039, and the Dundee at 2,439 feet. The total depth was 3,036 feet.

Howard L. Foster also drilled on the Sophia L. Seelman tract, SE.¼ SW.¼ sec. 7, T.9N., R.13W., to a depth of 2,656 feet (Elev. 714 feet). The Marshall was at 370, Coldwater red rock at 1,258, the Traverse at 1,955, the Dundee at 2,397, and the Detroit River at (?) 2,510 feet. Fresh water was tapped at 306 feet and salt water at 2,032, 2,400 and 2,510 feet.

The Spring Lake Oil Syndicate put down a test in 1928 on the Eibert Vos property, SW.¼ of SE.¼ sec. 14, T.8N., R.16W., Spring Lake township (Elev. 519 feet). The Coldwater red rock was at 985 feet and the Traverse at 1,740, with the total depth at 1,820 feet. Salt water was struck in the Traverse at 1,815 feet.

The Ottawa Petroleum Company drilled a well in Crockery township on the Comstock Konkle farm, NW.¼ SE.¼ sec. 27, T.8N., R.15W. (Elev. 609 feet). This test struck Coldwater red limestone at 945, the Traverse formation at 1,681, the Dundee at 2,066, and was bottomed at 3,116 feet. The salt water horizons occurred at 1,905, 1,980, 2,190, and 3,105-10 feet. The well was plugged in October, 1929.

The Wright Oil Company organized by Kelly Goldboss of Chicago put down a deep well on the Joseph Kluting farm, SW.¼ NW.¼ sec. 10, T.8N., R.13W., Wright township (Elev. 737 feet). Lower Marshall red rock was at 415, Coldwater red rock at 1,275, the Traverse at 2,005, the Dundee (?) at 2,502, Salina salt at 3,246, the Niagaran at 4,190, the Manitoulin at 4,375, and the total depth at 4,750 feet. There were showings of gas at 1,318, 3,540, 4,160-78, 4,400 feet, and the water was struck at 2,050, 2,151 and 2,445 feet. Drilling operations were carried on during 1929-30, but the well was not plugged until January, 1932.

R. R. Miller et al drilled a Trenton test near Agnew on the Paul Sako property, NE.¼ NW.¼ sec. 27, T.7N., R.16W., Grand Haven township (Elev. 613 feet). Coldwater red rock was found at 745, the Traverse at 1,476, the Dundee (?) at 1,850, the Sylvania at 2,370, the Bass Island at 2,439, the Salina at 2,515, the Manitoulin at 3,432, and the Trenton at 3,710 feet. The depth of the well was 3,839 feet, and it was abandoned in October, 1930. There were showings of oil at 3,089-3,130 and 3,852½-57½ feet. The lower "pay" horizon was shot with 60 quarts of nitro-glycerin which somewhat increased the flow of gas. Salt water was struck at 1,578-83 feet.

The first well in East Olive township was on the Fred Stone farm, sec. 3 (p. 265, Pub. 37, pt. III). In 1929, the Dixie Oil Company drilled on the G. H. Telder property, SW.¼ SW.¼ sec. 35, T.6N., R.15W., to a depth of 2,205 feet (Elev. 615 feet). This well encountered Coldwater red limestone at 822, the Traverse at 1,536, Traverse limestone at 1,594, the Dundee (?) at 1,797, and the Detroit River (?) at 1,886 feet. A showing of oil was struck at 1,603 feet, but water came in at 1,810 and 1,900 feet, resulting in abandonment.

Corbitt and Thornton drilled a well 2,007 feet deep on the Ponstantine farm, SW.¼ NE.¼ SW.¼ sec. 21, Blendon township, which was completed a dry hole at 2,032 feet (Elev. 655 feet). The depth to Coldwater red rock was 885, to the Traverse 1,590, to Traverse limestone 1,653, and to the Dundee 1,830 (?) feet. Salt water was struck at 1,670-75 and 1,790 feet.

The Muskegon Oil Corporation put down a well near Holland on the J. Essenburg farm, SE.¼ SW.¼ sec. 13, T.5N., R.16W., Park township (elev. 605 feet), in which Coldwater red shaly limestone was struck at 675 and the Traverse at 1,392 feet. Water was tapped in the Traverse at 1,535, and the well was abandoned in March, 1929.

The Henry Vrieling No. 1 well of the Ottawa Development Company in Lot 2, SE.¼ sec. 21, T.5N., R.15W. (elev. 602 feet), was the first in Ottawa County to show any substantial amount of oil. This oil was in the Traverse from 1,495 to 1,520 feet, and the pay was shot. The original quantity of 1 to 2 bailers full was increased to about 3 barrels the next morning, but the well was finally plugged and abandoned as a dry hole. Coldwater red rock was at 721, the Traverse at 1,426, the Monroe at 1,659, and the bottom of the hole at 1,966 feet. Salt water was tapped at 1,645, 1,652, and 1,695 feet.

The Muskegon Oil Corporation drilled shallow red rock core tests on the L. E. Bareman farm, SE.¼ SW.¼ sec. 8, T.5N., R.15W., and on the J. C. Dunton farm, NE.¼ NE.¼ sec. 19, T.5N., R.15W.

The Ottawa Development Company put down its third test in the vicinity of Holland on the H. Terbeck farm, SE.¼ SE.¼ sec. 16, T.5.N., R.15W., Holland township, to a depth of 1,624 feet (Elev. 618 feet). Coldwater red rock was struck at 754 and the Traverse at 1,510 feet, but the Traverse "pay" carried no oil, and the well was plugged and abandoned.

*The Newaygo Gas and Oil Company Bates No. 1 in the NE.¼ SE.¼ sec. 12, T.13N., R.13W., Sherman township, Newaygo County is now over 6400 feet deep (July 1, 1933).

SAGINAW COUNTY

Saginaw County has been the scene of a small amount of drilling since 1928, including several inside locations in the old Saginaw Pool, one deep well on top the Saginaw anticline, and several tests seeking extensions

to the Greendale, Saginaw, and Birch Run structures. The southeast extension of the Greendale "high" through Porter township. Midland County, into Jonesfield township, Saginaw County, is fairly well established, but where it goes from there is a mooted question. At first, it was thought to be headed toward St. Charles, but two structurally low wells in this general vicinity suggest that it may be farther north running in a more easterly direction and joining with the fold near Birch Run. Another possibility is that it may trend farther to the south toward the southeast corner of Maple Grove township.

New commercial pools have not been found along the northwest or southeast directions of the Saginaw anticline, and developments in these areas have been discouraging*. Comparisons with the Muskegon and Mount Pleasant structures show that the trace of the axis of this fold may be more arcuate than originally thought. If this supposition is true, then an eastward extension of production from Saginaw through southern Buena Vista, township in the general direction and vicinity of the Michigan Central branch to Denmark Junction is possible.

The nose of the Saginaw structure seems to plunge steeply northwestward into a north-south saddle, but beyond this saddle to the northwest the same line of folding may trend across the northeast corner of Tittabawassee township. A favorable showing of oil in a well near Freeland may have some bearing on this interpretation of the Saginaw "high." The trough which trends from near Bay City toward "North Star, Gratiot County, seems regional in scope, however, and may modify all of the major lines of northwest-southeast folding in this part of the State. This is suggested by structural conditions in the western and southwestern parts of Saginaw County.

Alvin H. Weber, Trustee, drilled a well on the Win. Kirchner farm, NE.¼ SW.¼ NE.¼ sec. 15, T.13N., R.3E. (Elev. 674.4 feet). The Marshall was at 1,040, Lower Marshall red rock at 1,145, the Berea at 2,203, the Traverse at 2,816, and the Dundee at 3,450 feet. Gas and oil were struck at 3,664, but salt water came in directly below at 3,665-68 feet, and the next morning there was 1,800 feet of fluid in the hole. Of this, 500 feet was oil, a sweet crude of 31° Be. gravity. After some testing, the well was drilled on to 4,375 feet, where it was finally abandoned. More salt water was found at 4,200-4,210 feet.

W. Hunter Atha drilled on the T. A. Murphy property in the SW.¼ NE.14 sec. 22, T.12N., R.2E., Richland township, to a depth of 3,358 feet (Elev. 642 feet). The Marshall was at 940, Lower Marshall red rock at 1,045, the Traverse at 2,656, the Dundee at 3,222, and salt water came in at 952 and 3,354 feet. The well was completed in August, 1932.

The Saginaw Prospecting Company and Sun Oil Company drilled several inside locations in the Saginaw Pool from 1928 to 1932, but the well of chief interest was the deep test of the former company on the Saginaw Water Works property, SW.¼ NE.¼ sec. 14, T.12N., R.4E., City of Saginaw (Elev. 599 feet). In this well, the Parma was penetrated at 310, the Marshall at 625, Lower Marshall red rock at 744, the Berea at 1,811, the Dundee at 2,913, the Detroit River at 3,147, the Sylvania at 3,882, and it went to the depth of 3,970 feet. Oil was originally found in the Berea, and the additional "pays" after deepening into the Dundee and Detroit River formations were at 2,970-76, 3,225, 3,551-55, 3,624, 3,780-82, and 3,861 feet. The horizon at 3,551-55 showed hydrogen sulfide gas, oil, and water. The oil was 44° Be. gravity and in sufficient quantity to swab 40 barrels the first 24 hours and 7 barrels per day thereafter. The numerous salt water horizons in the Monroe series occurred at 3,131-47, 3,235-51, 3,525-30, 3,861-67, and 3,882-93 feet.

Dr. L. C. M. Conley of Detroit drilled a deep test on the Conrad Kueffner farm, SE.¼ SE.½ sec. 32, T.12N., R.6E., Blumfield township, which finished at the depth of 3523 feet (Elev. 632 feet). The Marshall was found at 600, Lower Marshall red rock at 695, the Berea at 1,846, the Traverse at 2,326, the Dundee at 2,922, and the Detroit River at 3,105 feet. Several oil showings were found in this hole, but it was finally abandoned in January, 1930.

The Smith Petroleum Company drilled a shallow test on the Clara M. Studor property in the NE.¼ SE.¼ Sec. 14, T.11N., R.2E., Fremont township (elev. 614 feet), which found the Marshall at 855 and Lower Marshall red rock at 955 feet. The total depth was 980 feet, and the well was finished in June, 1932.

Win. E. Caster et al also drilled a test near St. Charles on the Sidney S. Williston farm in the NW.¼ SW.¼ sec. 22, T.11N., R.3E., Swan Creek township (Elev. 585 feet). The Parma was struck at 390 feet and contained an oil show and a hole full of water. The Marshall was at 745, Lower Marshall red rock at 842, the Berea at 1,938, and Berea salt water at 1,973-76 feet. The well was completed on April 8, 1932 to a depth of 1,995 feet.

A new well near Birch Run was put down by the Smith Petroleum Company very close to some old Dundee production on the Mike Courtney lease, NE.¼ sec. 29, T.10N., R.6E., Birch Run township. This test was on the John Poellet farm in the NW.¼ NE.¼ SW.¼ sec. 29. (Elev. 640 feet). The Marshall sandstone was found at 378 feet, the Berea at 1,592, and the hole was lost at 1,672 feet, plugged and abandoned.

S. M. Bacon and others drilled a deep well on the George Soniers farm, NW.¼ NW.¼ sec. 35, T.9N., R.1E., Chapin township, which was completed in September 1930 as a dry hole at 5,340 feet (Elev. 683 feet). The depth to the Marshall was 655 feet, to the Berea 1,956, to the Traverse 2,377, to the Dundee 2 837, to the Detroit River 3,103, to the Sylvania 3,730, to the Bass Island 4,034, and to the Salina salt 4,347. Water was struck at 985 and 2,908 feet, a smell of oil at 3,080 and 3,160 feet, and an oil showing at 3,906 feet.

The Smith Petroleum Company put down a well on the Miller Chase farm in the NE.¼ NE.¼ sec. 21, T.9N., R2E., Brady township, to a depth of 2,960 feet (Elev. 669 feet). The Parma was at 470, the Marshall at 675, Lower Marshall red rock at 827, the Berea at 1,949, the Traverse at 2,375, and the Dundee at 2,849 feet. Black water came in at 2,960 feet, where the hole was abandoned on October 12, 1930.

*In December 1932, a small oil well in the Berea was brought in by the Smith Petroleum Company on the Johns et al farm, SE.¼ SW.¼ SW.¼ sec. 21, T.10N., R.6E., Birch Run township (Elev. 640 feet). Marshall sandstone was found at 326, the Berea at 1,530, and the "pay" at 1,534-40 feet. After shooting with 70 quarts of nitroglycerin from 1,532½ to 1,551½ feet, the well made (Jan. 1, 3933) about 8 to 10 barrels of oil and 15 to 20 barrels of water daily.

SHIAWASSEE COUNTY

The structural geology of Shiawassee County is closely related to the northwest extension of the Howell anticline, Livingston County. The regional dip, is generally northwest, with the main anticlinal folds plunging in that direction, and the rate seems to be somewhat greater than in adjoining counties. Apparently the axis of the Howell "high" veers somewhat to the north in crossing Shiawassee County, but it again takes the general northwest course before it crosses Gratiot County. The trend is approximately from the southeast corner of Perry township to the northwest corner of Owosso township and thence more to the west across Fairfield township to Elba township, Gratiot County.

The discovery of Traverse oil in west central Shiawassee County, together with the regional contours (see pl. III) indicated by the new wells, suggests cross structure (at an angle to the northwest-southeast trend) in the vicinity of Shiawasseetown. There seems to be an almost north-south high branching off the main Livingston County arch (Howell anticline) from south central Antrim township to northeast Caledonia township. However, it is also possible that the fold may extend more nearly in a northeast-southwest direction.

The structural lows, as now defined, extend from near Shaftsburg in Woodhull township toward Ovid and Elsie, and from Lennon in Venice township to a little east of Chapin. These structural troughs vary in width and are probably crossed by minor highs which may have trapped small local oil and gas pools.

C. H. Ladd, Trustee, started a well in 1931 on the Fred Brooks farm, SW.¼ NE.¼ sec. 33, T.7N., R.3E., Caledonia township (elev. 811 feet), which is now shut down at 1,260 feet. Samples of the cuttings indicate that the Lower Marshall was struck at 425 and the Coldwater at 620 feet.

The Owosso Prospecting Company drilled on the Frank Thompson property, SE.¼ SE.¼ sec. 14, T.7N., R.3E., to a depth of 2,588 feet (Elev. 747 feet). The depth to the Marshall was 296, to the Lower Marshall 320, to the Berea 1,636, to the Traverse 2,071, and to the Dundee 2,502 feet. Salt water was found at 296, 320, 1,686, 2,140-47, and 2,136 feet, and the well was completed in January, 1931.

The discovery of oil in the Traverse in the O. L. Barnebey—John M. Galloway No. 1, NW.¼ NE.¼ sec. 11, T.6N., R.3E., Shiawassee township, was made in May, 1930 (Elev. 784 feet). The Marshall was found at 140 feet, the Lower Marshall at 200, the Berea at 1,350, the Traverse at 1,850, some gas at 1,807, an oil showN at 1,807-10, and the oil "pay" at 1,810-14. The initial production was estimated at 40 barrels, but the well made 180 barrels the first 24 hours and 500 barrels in all. A week after completion it was pumping 15 barrels of oil and 50 barrels of water per day. The hole was deepened in August to 2,410 feet, the Dundee was found at 2,197, and the Monroe at 2,265 feet, Salt water was struck at 1,375, 1,900, 2,260 feet, and black water at 2,268-73 feet. After being plugged back to 1,840 feet, the well was shot three times, but the shot went off twice in the Antrim and once in the pay, ruining the hole. It was abandoned in June, 1931.

The Glennbrook Oil Company sunk a well on the Frank Strauch farm, NE.¼ NW.¼ sec. 11, T.6N., R.3E., to a depth of 2,010 feet (Elev. 812 feet). The Marshall was at approximately 240 feet, the Berea at 1,418, and the Traverse at 1,800. The top of the Traverse limestone was at 1,835 feet, and there was one showing of oil at 1,808 and another at 1,844 feet, but water was struck directly underneath the second showing. Other water bearing beds were at 245, 275, and 770 feet.

O. L. Barnebey drilled a second well which was on the W. A. Grumley farm, NW.¼ NE.¼ sec. 14, T.6.N., R.3E. (Elev. 794 feet). In this test, the Marshall was found at 170, the Lower Marshall at 200, the Berea at 1,380, the Traverse at 1,709, Traverse limestone at 1,705, and the total depth was 1,843 feet. Salt water was struck at 880, 1,390, 1,802, and 1,830 feet, and abandonment took place in November, 1931.

O. A. Daniels started operations on several community leases in southwestern Shiawassee County and drilled one deep well on the Miles Craw-ford farm, NW.¼ SE.¼ sec. 1, T.5N., R.1E., Woodhull township (Elev. 848 feet). The depth to the Marshall was 697 feet, to the Lower Marshall" 790, to the Berea (?) 1,930, to the Traverse 2,313, to the Dundee, 2,660, to the Detroit River 2,856, and to the bottom of the hole 2,965. Some gas and water were found in the Upper Marshall and a showing of gas and oil in a "pay" horizon at 2,313 feet; salt water at 2,050-65 and 2,295-2,315 feet; and black water at 2,794 feet. The well was plugged and abandoned. The Hugattie Oil Company, previously organized by O. A. Daniels in the Muskegon field, sunk a test on the Budd Pulver farm, NE.¼ NE.¼ sec. 21, (elev. 841.5 feet), in which the Marshall was found at 762 feet and the Lower Marshall at 800. The well is shut down at 920 feet.

The Amber Oil Company put down a well on the C. Lobdell farm, SE.14 SW.¼ sec. 24, T.5N., R.3E., Antrim township, to a depth of 1,870 feet (Elev. 855 feet). The Berea was at 945, the Traverse at 1,326, the Dundee at

1,730, and the Monroe at 1,848 feet. Salt water was struck at 1,430 feet, and the well was completed and plugged in November, 1930.

ST. CLAIR COUNTY

St. Clair County is on the southeast border of the Michigan Basin and well down on the west flank of the northeast end of the Cincinnati arch. A line of folding which seems to be a continuation of the "highs" early worked out in the vicinity of Oil Springs and Petroleum, Lambton County, Ontario, extends across the northern part of the county. Regionally, the county may be in a saddle joining the Michigan "basin" and the Appalachian geosyncline, and this may account for some of the folding which crosses the trend of the Cincinnati arch in this particular region.

The anticlinal folds are only partially worked out in eastern St. Clair County, but they are projected into the western part of the county to indicate possible trends. These "highs" seem to extend northwest-southeast from the southeast corner of Fort Gratiot township to the northwest corner of Clyde township, thence nearly east-west across Greenwood, Brockway, and Lynn townships; east-west from the northeast corner of Port Huron township toward Goodells; and apparently southeast from St. Clair toward Fair Haven. A syncline or trough extends southeastward across the county from the middle of Berlin township to near Marine City in southern China township, and thence eastward into Ontario.

The wells are not scattered-enough to accurately determine the regional dip, but in general it is west and northwest into the Basin. The Devonian rocks either underlie the drift or are relatively close to the surface, the Traverse, Dundee, and Monroe beds occurring at shallow depths.

Smith and Perry drilled in 1930 on the Chas. Gardner farm, NE.¼ NE.¼ sec. 28, T.8N., R.16E., Grant township (elev. 729 feet), and found the Traverse at 499, the Dundee at 873, and water at 1,265 feet. The total depth was 1,270 feet.

B. P. Pattison put down a shallow well on the Sarah M. Routley property, NW.¼ SW.¼ sec. 21, T.7N., R.17E., Fort Gratiot township (elev. 614 feet), on the Port Huron anticline and struck the Dundee at 603 feet with a showing of oil from 633 to 660 feet. After drilling to 1,200 feet, the hole was plugged back to 655 feet and shot with 60 quarts of nitroglycerin between 633 and 655 feet. Operations are shut down, but the test has not been plugged and abandoned.

The Diamond Crystal Salt Company (Division of General Foods Corporation) drilled its No. 13 well in Lot No. 3 south of Pine River (elev. 585± feet), and about 600 feet east of the No. 12 well that had initially 1,200,000 cubic feet of gas in the Salina from 2,483 to 2,500 feet. This new well was completed late in 1928 as a small producer of gas. Well No. 14 was drilled on the west outskirts of St. Clair village on Private Claim 306, T.5N., R.16E., about 300 feet from the St. Clair Oil and Gas Corporation—Theodore Ruff No. 1. This hole penetrated the Berea at the base of the drift, the Traverse at 540, the Dundee at 790, the Detroit River at 895, the Sylvania at 1,280, the Bass Island at 1,375, Salina salt at 1,655, and went to 2,203 feet without production.

The St. Clair Oil and Gas Corporation drilled 4 wells in the vicinity of St. Clair, one of which encountered pre-Cambrian rocks. The Theodore Ruff well, west of town, was in Private Claim No. 306, T.4N., R.16E., south of the road and east of Pine River (Elev. 620 feet). The Traverse was at 520, Traverse limestone at 552, the Dundee at 790, salt (?) at 1,780, and the bottom of the hole at 2,645 feet. Sulfur water was struck at 900 feet and salt water at 2,640-45 feet.

The well on the Mary E. Fitton property in the SW.¼ SW.¼ sec. 3, T.4N., R.16E., China township, was sunk to 2,785 feet (Elev. 630.5 feet). The Traverse was found at 540 feet, the Dundee at 812, the Detroit River at 920 (?), the Sylvania at 1,318, the Bass Island at 1,410, Salina salt at 1,675, and the Niagaran at 2,685. The total depth was 2,785 feet. Mineral water was struck at 900-920 feet, and the hole was plugged and abandoned in July, 1930.

The St. Clair Oil and Gas Corporation—Fannie McCartney No. 1 was in the NW.¼ NE.¼ sec. 26, T.5N., R.16E., St. Clair township (Elev. 628 feet). The drift was 190 feet thick, and the Traverse was at 575, the Dundee at 840, the Detroit River at 960, the Sylvania at 1,460, the Salina at 1,700, the Niagaran at 2,735, and the bottom of the hole at 2,760. Mineral water was struck at 960 feet, and there was a showing of oil and gas from 2,735 to 2,752, which was shot with 140 quarts of nitroglycerin. The hole was plugged and abandoned in July, 1930.

The deep well that went into granitic rocks was the Geo. Hurst No. 1, SE.¼ NW.¼ sec. 26, T.5N., R.16E. (Elev. 620 feet). This test struck the Traverse at 575, the Dundee at 820, the Monroe at 950, the Sylvania at 1,100, Salina salt at 1,690, the Niagaran at 2,745, the Manitoulin at 2,970, the Trenton at 3,695, the Beekmantown at 4,590, and the Lake Superior (Potsdam) at 4,675 feet, and was finished below 4,950 feet. The water horizons were at 910, 3,662, and 4,675 feet. The well was abandoned in May, 1930.

Alfred C. Waters, Trustee, put down a shallow well on the Johnson tract, Private Claim No. 5, T.2N., R.16E., Clay township (elev. 577 feet), and encountered 23,000 cubic feet of gas at 113 feet and water at 160 feet. The Traverse was at 348, Traverse limestone at 350, and the total depth was 365 feet.

The Islands Oil and Gas Company of Pontiac drilled on Harsens Island on the Peter Krispen farm, Private Claim No. 4, T.2N., R.16E., and the well is now shut down at 2,400 feet (Elev. 577 ?feet). The Bedford formation was the first rock struck, and the depth to the Traverse was

330, to the Dundee 565, to the Detroit River 680, to the Sylvania 960, to the Bass Island 1,045, to Salina salt 1,540, and to the Niagaran 2,135 feet. The bottom of the hole was in the Cataract formation. Salt water was struck at 735 and 965 feet, and in the Niagaran (?).

VAN BUREN COUNTY

Van Buren County is on the southwestern margin of the Michigan Basin, where the regional dip is northeast at about 11 to 12 feet per mile. The Devonian "pay" rocks are shallow, the Traverse being found at depths ranging from 850 to 1,100 feet. The Trenton of Ordovician age is within easy reach of the drill. From the present evidence, the folds seem to be broad, gentle flexures that trend northeast-southwest and plunge toward the center of the "basin." However, the gentle regional dip suggests that there may be east-west or northwest-southeast folds that have not yet been found because of the lack of sufficient data.

The known lines of anticlinal folding, where favorable oil showings were struck, extend from southwestern Decatur township to southeastern Almena township and southeastern Covert township to northwestern Bloomingdale township. Attention was first directed to Van Buren County by the discovery of a shallow oil well in the Traverse south of Decatur where several wells were drilled. Most of these wells were dry. The Traverse production did not hold up and since there was no oil in the Trenton, operators have been slow to start new projects.

In the north part of the county, Gibson, Johnson, and Borden, Inc., and the Dixie Oil Company drilled on the John Krocke et al farm in the SE.¼ NW.¼ sec. 23, T.1S., R.16W., Geneva township, to a depth of 2,001 feet (Elev. 672 feet). This well struck Coldwater red rock at 450 feet, the Traverse at 1,049, Traverse limestone at 1,083, the Dundee (?) at 1,215, the Detroit River at 1,308, the Sylvania at 1,485, and the Bass Island at 1,566. The water horizons were encountered at 1,090-97, 1,560, and 1,720 feet. The hole was completed in April, 1930.

The Bi-County Fuel and Gas Company put down a Trenton test on the Emmanuel Old Home property, SE.¼ NE.¼ sec. 34, T.2S., R.17W., Covert township (Elev. 690 feet). Beneath the drift, the rock at the surface was in the Ellsworth formation. The Traverse was struck at 932, the Detroit River at 1,150, the Sylvania at 1,729, the Niagaran at 2,000, the Trenton at 2,352, and the well was drilled to 2,536 feet. There were showings of gas at 967, 1,030-34, 1,093-1,150, 1,729-85 feet, and water at 1,093, 1,550, 1,785, 2,463, and 2,530 feet. The hole was plugged and abandoned in December, 1929.

The Kirby Orchard Company drilled a well on their farm in the NW.¼ NW.¼ sec. 26, T.2S., R.17W., Covert township, which is now shut down at 1,020 feet (Elev. 702 feet). The drift was 362 feet thick, and the Coldwater red rock was at 410 feet, top of Traverse limestone at 1,012, and a show of gas at 1,020 feet. Directly below the gas horizon, the hole filled with water. Operations on this well have been suspended now for about two years.

The Vermont Petroleum Development Company of Rutland, Vermont, drilled on the Anton Fier farm in the E.½ SW.¼ sec. 31, T.4S., R.14W., to a depth of 1,309 feet (Elev. 752 feet). The red limestone in the Coldwater was found at 377 feet, the Traverse at 882, the Monroe at 1,185, and the Sylvania (?) horizon at 1,254. A showing of oil was struck at 933 feet, water at 954, and heavy black oil at 1,260. The hole was plugged and abandoned in June, 1928. The same company also put down a well on the L. Witkowski tract in the SE.¼ NW.¼ sec.21,T.4S., R.14W., Decatur township. In this test, the depth to the Coldwater red limestone member was 450 feet, to the Traverse 938, to the Monroe 1,177, and to the bottom of the hole 1,426. An oil showing was reported at 1,218-20 feet, and salt water struck at 1,018 almost filled the hole at 1,175 feet. The well was plugged and abandoned in August, 1928.

In 1928, a test was started on the Burget High farm, SW.¼ NW.¼ sec. 33, T.4S., R.14W., by the Decatur Lease Holding Company. They had trouble with the drive pipe at 370 feet, where it became "frozen," and the well was never completed.

The Wolverine Oil and Exploration Syndicate put down a Trenton test in 1929 on the A. D. Vought farm, SE.¼ NE.¼ sec. 32, T.4S., R.14W., which reached a depth of 2,523 feet (Elev. 761 feet). This was the third well on the Vought farm, two shallow tests having been drilled in 1927-28. The red rock member of the Coldwater was struck at 409 feet, the Traverse at 915, and Traverse pay at 969 to 979½ feet. The pay was shot with 40 quarts nitroglycerin from 909½ to 979½ feet, and according to reports the production was increased from 16 barrels before the shot to 50 barrels afterwards. On the 28th of August, 1929, the well was pumping between 10 and 11 barrels per day, but in the winter of the same year it was deepened to the Trenton. According to the samples of the cuttings, the Dundee (?) was at 1,075, the Detroit River at 1,160, the Sylvania at 1,275, the Bass Island at 1,320, the Niagaran at 1,625, the Manitoulin (?) at 2,220, and the Trenton at 2,420 feet. No water or oil was reported from the Trenton, and the well was abandoned in April, 1930.

The Dayton Oil and Gas Company drilled a well on the Carl W, Warner farm, SE.¼ NW.¼ sec. 29, T.4S., R.14W. (Elev. 754 feet). Red limestone in the Coldwater was found at 365 feet, the Traverse at 875, the Dundee (?) at 1,040, the Detroit River at 1,125, and the Sylvania at 1,200 feet, and the hole was drilled to 1,301 feet. There was a small showing of oil from 924 to 929, more oil from 948 to 950, water at 1,125, and gas at 1,135 feet. The well was completed in July and abandoned in October, 1930.

WAYNE COUNTY.

Since 1927 when the W. E. Ellis well, NE.¼ NE.¼ sec. 35, T.4S., R.10E., was drilled 2,820 feet deep, into the Trenton with a small showing of oil (Pub. 37, pt. III, pp. 205, 214, 215) there has been no further prospecting for oil and gas in the Detroit River area. However, in view of deepening the Livingstone Channel along the course of the river east of Grosse Isle new structural subsurface studies were carried on. Some of the excavation already under way corroborates these studies and because of the regional importance of structure in this district, they are presented here. (See fig. 41).

The Stony Island anticline described by W. H. Sherzer (Pub. 12, p. 214) was first recognized in an earlier excavation of the Livingstone Channel. The observations at that time showed the strike of the axis as about N.40°W., and the steeper southwest limb dipping S.50°W., in the bed of the river at an angle of 1°58' or 181.2 feet per mile. The new determinations indicate the strike of the axis of the fold as approximately N.30°W., and the southwest steep dip varying between 158.4 and 190.6 feet per mile or an angle of 1043' to 2°4'. These check very closely, as can be readily seen.

The rocks in the Anderdon quarry across the river near Amherstburg, Ontario, dip strongly in a S.23°W. direction, at an angle of more than 3° 15' in the Patrick quarry near the south end of Grosse Isle in a S.30°W. direction at an angle of 1°30' to 2°, and in the Sibley quarry between Trenton and Wyandotte in a S.85°W. direction at an angle of 2° 10' to 2°30'. These figures in comparison to the direction of dip in the bed of the river suggest a progressive northward change in the trend of the axis of the anticline on the Ontario side from north-south to northwest-southeast, and thence more northerly again after crossing the river. This seems to be borne out by recent explorations for glass sand south of Amherstburg. The structure as most recently interpreted and drawn on top the Sylvania sandstone is shown in Figure 41. It extends in a direction a little west of north from near Bar Point to Amherstburg, and thence gradually veers from N.30°W. to almost N.50°W. The northwest prolongation of the axis (called Wyandotte anticline by E. A. Smith in Pub. 14, pp. 105, 106) apparently goes through somewhere between Sibley quarry and Wyandotte, but the unreliability of many well records in this vicinity makes it questionable whether the structure is forked as shown or simply indented by a local depression.

The magnitude and the changing direction of the axis of the Stony Island anticline is about the same as other structures in Michigan where oil and gas is found. (See pls. IV and V)

It is seemingly a fold coming off the north end of the Cincinnati arch where that feature plunges to the northeast. (See fig. 40) Farther to the northwest and almost in direct line with the trend of this fold is the Howell structure, Livingston County. It would seem fairly logical to assume, therefore, that these two structures are on the same line of folding and should join across Wayne County along a general trend between South Lyon, Oakland County, and the vicinity of Wyandotte. (See pl. III). The frequent showings of oil and gas in water wells west and south of Bedford and in the area northwest, southeast, and north of Wayne (Pub. 12, pl. XXV) may not only be due to the exposure of Antrim shale beneath the drift, but also to up-dip migration localized on the flatter northeast side of this structure. Much is yet to be learned about the structural geology of Wayne County.

The Solvay Process Company drilled their No. 36 salt well in 1930 on Brady Island, T.2S., R.11E., to a depth of 1,620 feet.

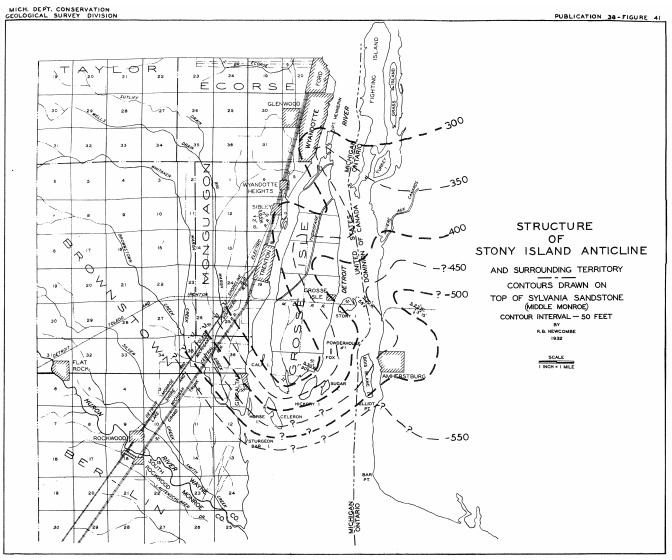

Figure 41. Structure of the Stony Island anticline and surrounding territory. (Contours drawn on top of Sylvania sandstone.)

Approximately 2 million cubic feet of gas was found in a water well about one mile from Belleville, and the discovery started some activity near this village. The well was about 87 feet deep, and the gas had a rock pressure of 16 pounds. Other shallow wells were drilled in the district with water well machines, but gas flows were found in only a few cases, and the volume was comparatively small. No deep tests were made, and interest in the region has now died down.

WEXFORD COUNTY

The rocks in Wexford County dip southeastward at about 21 or 22 feet to the mile, but there is very little known about the structural geology of the county. During 1930-31, three deep wells were drilled, but two of these were within a mile of each other and showed only the local dip. However, it is probable that the extension of the Greendale "high" from central Michigan will extend across the northeast part of the county and include sections of Haring, Cedar Creek, Colfax, and Greenwood townships. The belt extending diagonally across the center of the county from the southeast corner to the northwest corner seems regionally low and

a continuation of the Mount Pleasant trough (See pl. III). The Broomfield "high" may extend into the county and continue across the western and southwestern parts.

The two wells north of Cadillac seem to throw some light on structural conditions in this part of the county. Considering the prevailing regional dip, the northerly one of these wells, which had several important showings, of oil and gas, is higher than it should be. The dimensions and trend of the fold causing this accumulation are difficult to determine on the meager evidence available, but these wells seemingly indicate favorable prospects to the north and northeast.

The first deep well to penetrate bedrock in Wexford County was the Marble-Cowe Oil Company—Chas. E. Smith No. 1 in the NE.¼ NE.¼ NW.¼ sec. 28, T.22.N., R.9W., Haring township (Elev. 1,296 feet). The glacial drift was 720 feet thick, and the rocks at the base were in the Saginaw formation. The Bayport was at 910, the Marshall at 1,410, the Berea at 2,260, the Traverse at 3,120, the Dundee at 3,800, the Detroit River at 3,900, and the bottom of the hole at 3,950 feet. Showings of oil were found at 3,905 and 3,912-35 feet, and the "pay" horizons were shot with 100 quarts of nitroglycerin without favorable results. The water horizons were at 1,330-34, 1,395, and 3,950 feet. Abandonment took place in September, 1930.

C. E. Smith, Trustee, drilled north of Smith No. 1 on the John Jorgensen property, SE.¼ NW.¼ sec. 21, T.22N., R.9W., to a depth of 4,141 feet (Elev. 1,321 feet). The record was poor in the upper part of the hole, but the Marshall was encountered at 1,370, the Traverse at 3,100, the Dundee at 3,812, and the Detroit River at 3,895 feet. Showings of oil were found in several horizons in the well. At 3,167 feet, there were about 1½ barrels of oil, but water came in at 3,170. Oil was struck at 3,215 with water underneath at 3,216-19; at 3,948-50 with water at 3,955; and at 4,005 with water at 3,970-4,005 feet. Gas was struck above this last "pay" at 3,995 feet. None of these showings made commercial production, and the well was plugged in May, 1931.

The Cummer-Digging Company drilled a well 3,860 feet deep on their own property in the SW.¼ NW.¼ sec. 26, T.23N., R.11W., Antioch township (Elev. 1,325 feet). This test, which was regionally farther up the dip than the other two in Wexford County, struck the Marshall at 750 feet, the Lower Marshall at 825, Coldwater red rock at 1,640, the Traverse at 2,485, the Dundee at 3,180, the Detroit River at 3,285, and Detroit River salt at 3,432. There were no showings of oil and gas, and water was struck in the Traverse at 2,490 feet. The well was completed and plugged in October, 1931.

MISCELLANEOUS COUNTIES

The remaining counties in which drilling for oil and gas has been carried on are put together in a miscellaneous group. In some of these counties, preliminary core drilling and geophysical prospecting have been included in the development program of interested companies. In each, there has been anywhere from one to four deep wildcat tests.

The reason for discussing miscellaneous counties in a group apart from the others is because there is so little geological information about them, and the showings of oil and gas have not been large enough to attract widespread notice. Their prospects for oil and gas may be as great or even greater than other counties where geological structure is better known or showings have been more favorable.

Alcona County: In 1929, C. Wilbur White of Chicago, drilled on the John McDonald farm, SW.¼ SE¼ sec. 22, T.26 N., R.8E., to a depth of 600 feet (Elev. 670 feet). A showing of gas, with water directly beneath was reported at 240 feet, and the hole filled up with water at 510 feet. The formation record was difficult to interpret in all its details.

Alpena County: The Bradley Oil and Gas Company drilled a shallow Dundee test on the Fred N. Potter farm, SE.¼ SE.¼ sec. 20, T.31N., R.8E. (elev. 670 feet), in which the Dundee was struck at 725, water at 762, and the hole was bottomed at 862 feet. The well was abandoned in November, 1929. The Riverside Syndicate drilled a second well on the Potter farm, SE.¼ SW.¼ sec. 20 (elev. 670 feet), in which water was struck at 60 feet, the Dundee at 563 (?), water at 580, the Detroit River at 800, and a showing of oil at 807 feet. The well was completed in October 1930, at 836 feet.

The Exploration Company put down a well on the Thos. Wilson farm in the NE.¼ NE.¼ sec. 7, T.32N., R.6E., Long Rapids township, to a depth of 1,317 feet (Elev. 820 feet). The Dundee was found at 423, the Detroit River at 665, and the Sylvania at 1,249 feet. There was a showing of oil at 325-30 feet. Water was struck at 870 and 910-45 feet, black sulfur water at 950-85, and black water at 1,143. The well was plugged in March, 1930.

Notman and Aubin drilled on the Robert F. Diemond property, NE.¼ NE.¼ sec. 25, T.30N., R.6E., Wilson township (Elev. 845 feet). The depth to the Traverse was 488 feet, to the Dundee 1,260, and to the bottom of the hole 1,285. Water was struck at 720, 940, and 1,276 feet. The hole was abandoned in November, 1929.

Barry County: The Muskegon Development Company drilled in Barry County on the William Hughes farm, NW.¼ SW.¼ sec. 34, T.1N., R.9W., to a depth of 1,980 feet (Elev. 950 feet). The well went through 202 feet of drift into the Marshall and found the red rock in the Coldwater at 1,202, the Traverse at 1,630, the Dundee at 1,861, and the Detroit River at 1,970 feet. About one-half barrel of water per hour was struck in the Dundee at 1,888-94, and the test was abandoned in October, 1930.

The Barry Oil Development Company commenced a well on the A. O. Kinne farm, NE.¼ NW.¼ NE.¼ sec. 11, T.3N., R.8W., Hastings township (elev. 891 feet), which struck the Marshall at 385 feet, the Lower Marshall at 550, the Coldwater at 600, and it is now down to 1,140 feet.

Berrien County: The Blatchford Oil and Gas Exploration Company of Chicago drilled on the J. K. Blatchford property, NW.¼ SW.¼ sec. 11, T.5S., R.17W., Watervliet township (Elev. 650 feet). The Traverse was at 910, Traverse limestone at 997, the Detroit River (?) at 1,170, the Sylvania (?) at 1,690, and the total depth was 1,861 feet. A showing of gas was struck in the Traverse, and gas and oil in the Monroe at 1,702-06 feet. There was a "hole full" of salt water at 1,285, 1,340, 1,483, 1,693, and 1,750 feet. The well was finally abandoned as a dry hole in February, 1930.

Gibson, Johnson & Borden, Inc., and the Dixie Oil Company put down a shallow well on a community lease (Smith farm) in the NW.¼ SE.¼ SW.¼ sec. 15, T.4S., R.18W., Benton township, to a depth of 882 feet (Elev. 644.5 feet). The Coldwater red rock was found at 240, the Traverse at 745, and water in the Traverse at 795 feet. The well was completed in June, 1930.

W. E. Eldredge, Trustee, drilled a well on the Fred J. Wetterau property, SE.¼ of NW.¼ SE.¼ sec. 10, T.8S., R.21W., New Buffalo township (elev. 667 feet), which struck the Traverse at 365 and the Monroe-Salina at 545 feet, and was finished at 1,775 feet in June, 1930. Salt water was found at 453, sulfur water at 545, more salt water at 660 and 1,425, and fresh water at 1,715 feet. Emil Michalski, Trustee, down the Wetterau No. 2 well nearby in the NW.¼ SE.¼ sec. 10, T.8S., R.21W. (elev. 671 feet), which encountered the Traverse at 387 feet, and was completed as a dry hole at 462 feet.

Branch County: Gibson, Johnson & Borden, Inc., drilled the only recent deep well in Branch County on the Miles Teller farm, Center, N.½ NE.¼ sec. 11, T.8S., R.8W., Noble township (Elev. 946 feet). The depth to the Traverse was 925, to the Dundee 1,070, to the Detroit River 1,140, to the Sylvania 1,259, and to the bottom of the hole 1,385 feet. Water horizons were encountered at several places in the drift, and salt water was, struck at 1,005, 1,130, and 1,360-85 feet. The well was completed in August, 1930.

Calhoun County: The St. Clair Oil and Gas Corporation put down a deep well north of Marshall on the O. S. Hubbard farm, SW.¼ NE.¼ sec. 14, T.2S., R.6W., Marshall township, to the depth of 4,571 feet (Elev. 963.5 feet). The Coldwater red shale (Berea horizon?) was struck at 1,315 feet, the Traverse at 1,632, the Dundee at 1,830, the Detroit River at 1,920, the Sylvania at 2,320, the Bass Island at 2,435, the Niagaran at 2,960, the Trenton at 3,963, and the St. Peter at 4,564. A showing of gas and "hole full" of water were reported at 2,900 feet. The well was plugged in September, 1931.

Cheboygan County: W. M. Brown et al drilled in the SE.¼ NE.¼ sec. 12, T.33N., R.3W. (elev. 778 feet), to a depth of 1,694 feet, and the Traverse limestone was at 115, the Dundee at 795, and the Detroit River at 1,045 feet. The well was plugged in January, 1929. In the second well on the Brown property, near the first location in about the center of the same forty acre tract (elev. 778 feet), the Traverse was found at 115, the Dundee at 783, water at 820, and the Monroe at 1,040 feet. A showing of oil at 1,185 feet was shot with 60 quarts of nitroglycerin without favorable results, and the well has been shut down at this depth ever since.

Clinton County: Wm. E. Caster put down a shallow well on the Julia S. Curtis farm, NW.¼ NW.¼ sec. 12, Duplain township, to the depth of 670 feet (Elev. 696 feet). The Parma was at 465, Parma water at 520, the Marshall at 655, and the well was abandoned in November 1931.

Delta County: The only recent test for oil in the Upper Peninsula was drilled 1,250 feet deep by A. P. Crell on the Bay de Noc Company property, SW.¼ SW.¼ sec. 20, T.42N., R.19W. The first rocks penetrated in the well were in the Cincinnatian group, and the Trenton was found at 355, the St. Peter at 635, the Beekmantown at 780, and the Lake Superior at 990 feet. Water was struck in the St. Peter and Lake Superior formations, and the hole was completed as a fresh water well in October, 1929.

Eaton County: A few shallow core tests and 4 deep wells were put down in Eaton County from 1928-32. E. W. Heisey and C. A. Ralph drilled on the J. Parker farm in the NW.¼ NE.¼ sec. 17, T.4S., R.5W., Roxand township, to a depth of 2,322½ feet (Elev. 882 feet). The Parma was at 400 feet, the Marshall at 560, Coldwater red rock at 1,819, the Berea at 1,891, and the Traverse at 2,202. Water was struck at 200, 400, 585, and 2,262 feet. The hole was abandoned in December, 1930.

Norris and Smith put down a well on the Frank J. Wright farm, SW.¼ SW.¼ sec. 28, T.3N., R.5W., Chester township (Elev. 926 feet). The Parma was struck at 215, the Marshall at 514, the Coldwater at 794, Coldwater red rock at 1,735, the Berea at 1,787, the Traverse at 2,018, and the hole was drilled to 2,183 feet. There was fresh water at 685 and 1,350, and salt water at 2,165 feet. The well was plugged in July, 1929.

Norris and Smith drilled another well in Eaton County on the Gertrude and Lois Kruzen property, SW.¼ NW.¼ sec. 28, T.2N., R.5W., Carmel township (elev. 904 feet), which found the Marshall at 310, Coldwater red rock at 1,590, and the Traverse at 1,910 feet. Salt water was struck at 2,018, and the hole was abandoned at 2,025 feet,

The Wittmer Oil and Gas Properties Company of Pittsburgh drilled at Bellevue on property of the Alpha Portland Cement Comany, NW.¼ SW.¼ sec. 28, T.1N., R.6W., Bellevue township (Elev. 864 feet). In this test, the Marshall was struck at 200 feet, the Lower Marshall at 260, Coldwater red rock at 1,370, the Berea (?) at 1,422, the Traverse at 1,720, the Detroit River at 2,030, the Bass Island at 2,585, Salina salt at 3,200, the Niagaran at 3,410, the Manitoulin at 3,675, the Trenton at 4,263, and the depth was 4,405 feet. The water horizons were at 200, 1,827-35, 3,025, and 3,075 feet. The well was abandoned in September, 1930.

Emmet County: The North States Oil Company started a well on the K. R. Beak property, SW.¼ SW.¼ sec. 16, T.37N., R.5W., Center township, which was drilled to 1,200 feet (Elev. 737 feet). The Traverse formation was found beneath 409 feet of drift, and the Dundee was at 592 feet.

Genesee County: Gibson, Johnson and Borden, Inc., drilled on the Earl Munsell property, NE.¼ NW.¼ sec. 21, T.9N., R.7E., Thetford township (Elev. 792 feet). The Parma was at 204 feet, the Marshall at 490, the Lower Marshall at 585, the Berea at 1,700, the Traverse at 2,163, and the total depth was 2,503 feet. There was water in the Coldwater at 1,115 and a "hole full" in the Traverse at 2,230 feet. The well was plugged and abandoned in December, 1930.

Huron County: The Pure Oil Company, after test well prospecting, drilled 3 deep wells in northwestern Huron County. The first, on the John Dressier farm, NW.¼ SW.¼ sec. 26, T.16N., R.9W., Fair Haven township, went through the Dundee to the depth of 3,005 feet (Elev. 601 feet). The second, on the William Radloff property, in the SE.¼ SE.¼ sec. 5, T.15N., R.10E., Brookfield township, finished as a Berea test at 1,584 feet (Elev. 633 feet). The third well was on the John Englehardt farm, NE.¼ SE.¼ sec. 36, T.16N., R.9W., and was completed at 1,540 feet (Elev. 622 feet). All these wells were plugged and abandoned in 1929.

The Pacific Exploration Company of New York City did some structural test drilling and then put down a deep well on the Wm. Ballagh farm, NE.¼ NW.¼ NW.¼ sec. 32, T.15N., R.12E., Sheridan township, to 4,095 feet (Elev. 744 feet). The hole entered the rock in the Marshall formation, and the Lower Marshall was at 70 feet, the Berea at 1,402, the Traverse at 1,961, the Dundee at 2,645, the Detroit River at 3,014, and the Sylvania (?) at 3,925. Water was struck at 703, 1,424-80, 2,840-80, and 3,615 feet. The well was completed during August, 1932.

Ingham County: In 1929-30, the Hilmur Oil Company of Lansing drilled a well to the Dundee on the E. C. Potter farm, NW.¼ NW.¼ sec. 21, T.4N., R.2E., Locke township (Elev. 915 feet). The depth to the Parma was 421, to the Marshall 760, to the Lower Marshall 815, to the Berea 1,940, to the Traverse 2,313, to the Dundee 2,595, and to the bottom of the hole 2,625½ feet. Water was struck in the Dundee at 2,619½-2,625½, and the well was abandoned in February, 1930.

The same organization, under the name of Amos Turner, Trustee, drilled on the E. Doolittle farm, NE.¼ NE.¼ sec. 14, T4N., R.2E., to a depth of 651 feet (Elev. 899 feet). The Marshall was struck at 625 feet and being structurally low, the well was abandoned.

Iosco County: The Sun Oil Company carried on some test well drilling and put down a deep well on the E. A. Miller farm, NW.¼ NE.¼ sec. 31, T.22N., R.5E., Reno township (Elev. 818 feet). The Lower Marshall red rock was at 303 feet, the Berea at 1,580, the Traverse at 2,158, the Dundee at 2,923, and bottom of the hole at 3,163. Water was struck at 730, 1,230, and 1,267 feet, and black sulfur water at 3,151 feet. Small showings of gas were reported at 1,225 and 3,153 feet, but the hole was plugged in January, 1930.

D. E. Wilson, Trustee, drilled in the same township on the W. J. Hill farm, SE.¼ SW.¼ sec. 19, T.22N., R.5E. (Elev. 828 feet). The depth to the Marshall was 280 feet, to the Lower Marshall 360, to the Berea 1,652, to the Traverse 2,190, to the Dundee 2,976, and to the bottom of the hole 3,156. Water was struck at 767, 1,325, and 3,156 feet. The well was abandoned in July, 1930.

Gibson, Johnson & Bordon, Inc., put down a test on the Robert H. Watts farm in the center, S.½ NW.¼ sec. 34, T.22N., R.6E., Grant township (Elev. 684 feet). The Marshall was encountered at 335, the Lower Marshall at 435, the Berea at 1,795, and the Traverse at 2,430 feet. The well was finished at 3,040 feet without reaching the Dundee, and water was found at 300, 885, 1,175, 1,885, and 1,935 feet. The well was plugged in October, 1930.

Kalamazoo County: Reid & Mackey and Norris & Smith drilled a well to the Trenton on the Burt Caldwell farm, NW.¼ SW.¼ sec. 32, T.1S., R.12W., Alamo township (Elev. 790 feet). The red limestone in the Cold water was at 740 feet, the Traverse at 1,270, the Dundee at 1,480, the Detroit River at 1,580, the Sylvania at 1,776, the Bass Island at 1,950, the Niagaran at 2,527, the Manitoulin at 2,704, the Trenton at 3,168, and the total depth was 3,348. Sulfur water was struck in the Sylvania at 1,835 and salt water at 3,280 and 3,294-96 feet. A gas and oil showing was found at 1,343; oil, gas, and water at 1,352, and gas at 1,880 feet. The well was completed in September and plugged in November, 1930.

Kalkaska County: After considerable core testing, the Grayling Development Company, together with the Muskegon Oil Corporation, drilled a deep well on State land in the NW.¼ NW.¼ sec. 16, T.26N., R.5W. (Elev. 1,120 feet). This hole was drilled into the Dundee formation and finished at 2,887 feet, where it was plugged and abandoned in May, 1930.

Oakland County: The Milford Oil and Gas Syndicate drilled on the John Houghton property in the SW.¼ SE.¼ sec. 1, T.2N., R.7E., Milford township (Elev. 969 feet). Below 243 feet of glacial drift, the well penetrated the Coldwater formation and found the Berea at 569 feet, the Traverse at 905, the Dundee at 1,236, the Detroit River at 1,428, and the Sylvania at 1,750. The total depth was 2,038 feet. Water was struck at 257, 575, and 1,257 feet, a showing of oil at 1,113, and sulfur water at 1,600 feet. The well was completed in March, 1932.

The Smith Petroleum Company drilled just off the north flank of the southeast extension of the Howell "high" on the W. K. Smith farm, SW.¼ NW.¼ sec. 15, T.1N., R.7E., Lyon township, to a depth of 1,035 feet (Elev. 936 feet). The hole went through 267 feet of drift into the Berea, and the Traverse was struck at 520, the Dundee at 830, and the Detroit River at 1,020. Water came in at

270-80, ½ bailer full heavy oil and water at 527-31, and black water at 920 feet. Abandonment took place in March, 1932.

Presque Isle County: Claude F. Palmer put down a well for the Lobdell-Emery Manufacturing Company on the Albert E. Meyer property, SE.¼ SE.¼ sec. 26, T.35N., R.2E., Allis township (Elev. 787 feet). The depth to the Dundee was 187 feet, to the Detroit River (?) 480, to the Sylvania 950, to the Bass Island, 1,294, and to the bottom of the hole, 1,402. Water was struck in the Sylvania at 1,100 feet, and the well was abandoned in October, 1930.

Roscommon County: Several core holes were put down in Roscommon County by the Grayling Development Company, but no deep tests resulted from this prospecting. The development of the West Branch structure in Ogemaw County may soon lead to drilling in the western part of this county.

Sanilac County: The old well on the Frank Obee farm, SE.¼ SE.¼ sec. 17, T.14N., R.14E., Minden township (elev. 805 feet), was drilled deeper in 1930, but very little accurate detail was learned about the well. According to reports, the Berea was at 1,170, salt water at 1,200-10, and the Traverse at 1,660 feet. The present depth is 1,676 feet.

The Sanilac Prospecting and Development Company put down a well near Lake Huron on the Lizzie Murry property, SE.¼ NW.¼ sec. 16, T.13N., R.16E., Forester township (elev. 592 feet), which struck the Berea at 492, the Traverse at 888, the Dundee (?) at 1,512, and continued to 1,610 feet, where it is now shut down.

The Shepherd Oil and Gas Company drilled a well on the Art. Vincent farm, in the NW.¼ NW.¼ sec. 6, T.10N., R.16E., Lexington township, to the depth of 2,012 feet (Elev. 752 feet). The Berea was at 521, the Traverse at 980, and the Sylvania at 1,927 feet. Showings of gas were reported at 1,370, 1,758, and 1,932 feet and oil at 1,955 feet. The water horizon in the Dundee was at 1,635 feet, and the well was completed as a dry hole in November, 1931.

The K-Barr Oil and Gas Company drilled on the Joe Kolodziej farm, in the NE.¼ NE.¼ sec. 28, T.11N., R.15E., Washington township, and the well is now shut down at 1,975 feet (Elev. 779 feet). The Berea was at 542, the Traverse at 1,019, the Dundee at 1,586, and the Monroe at 1,719 feet. The black water was struck at 1,642 and a showing of gas at 1,758 feet, but operations on the well have been suspended since early in 1932.

St. Joseph County: Mrs. Lillian Mahnke commenced a well on the L. Mahnke farm in the SW.¼ NW.¼ sec. 2, T6S., E.11W., Lockport township, which has now reached the depth of 1,025 feet (Elev. 833 feet). Red rock in the Coldwater was at 445 and 512, and the Traverse was at 940 feet.