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.

[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.

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."

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 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.

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, Deerfield 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

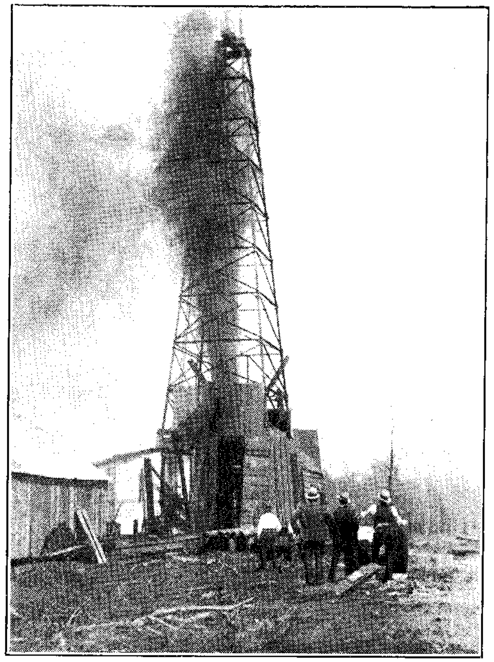


Plate VI—A. A large flowing well being "brought in" on State lease in East Extension of Mount Pleasant field. Its initial 24 hours' production was 2,650 barrels.

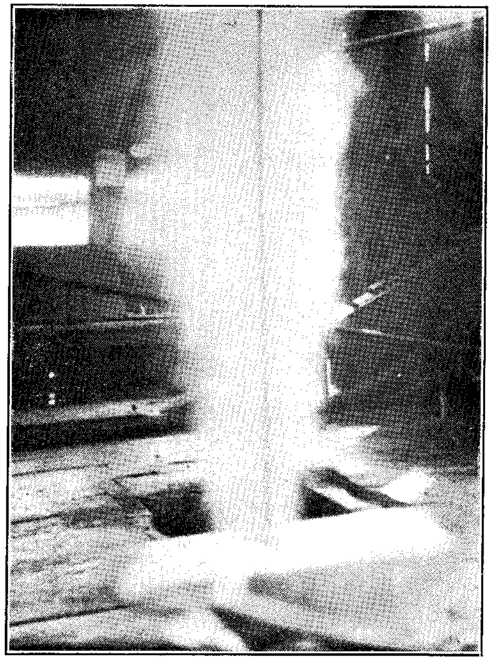
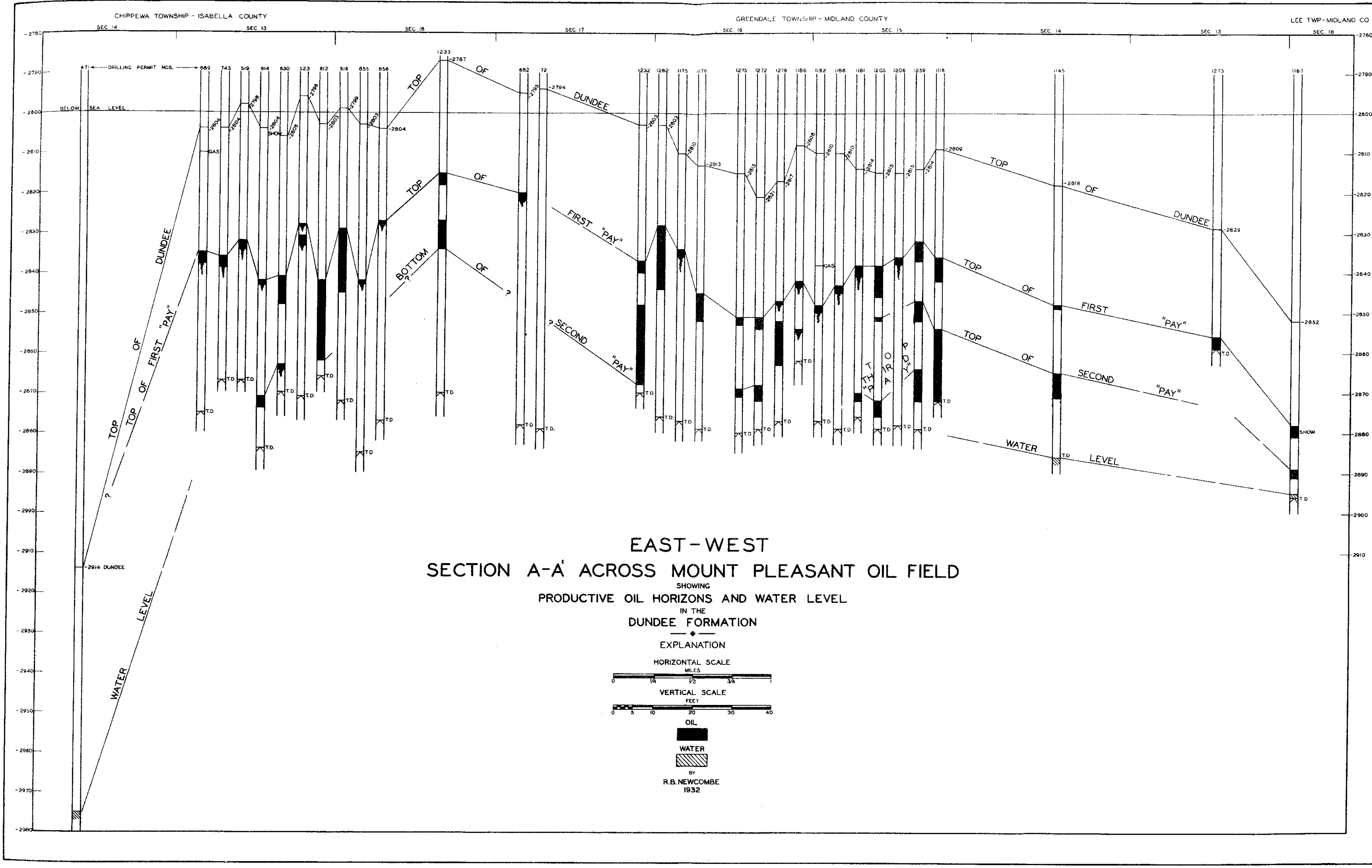
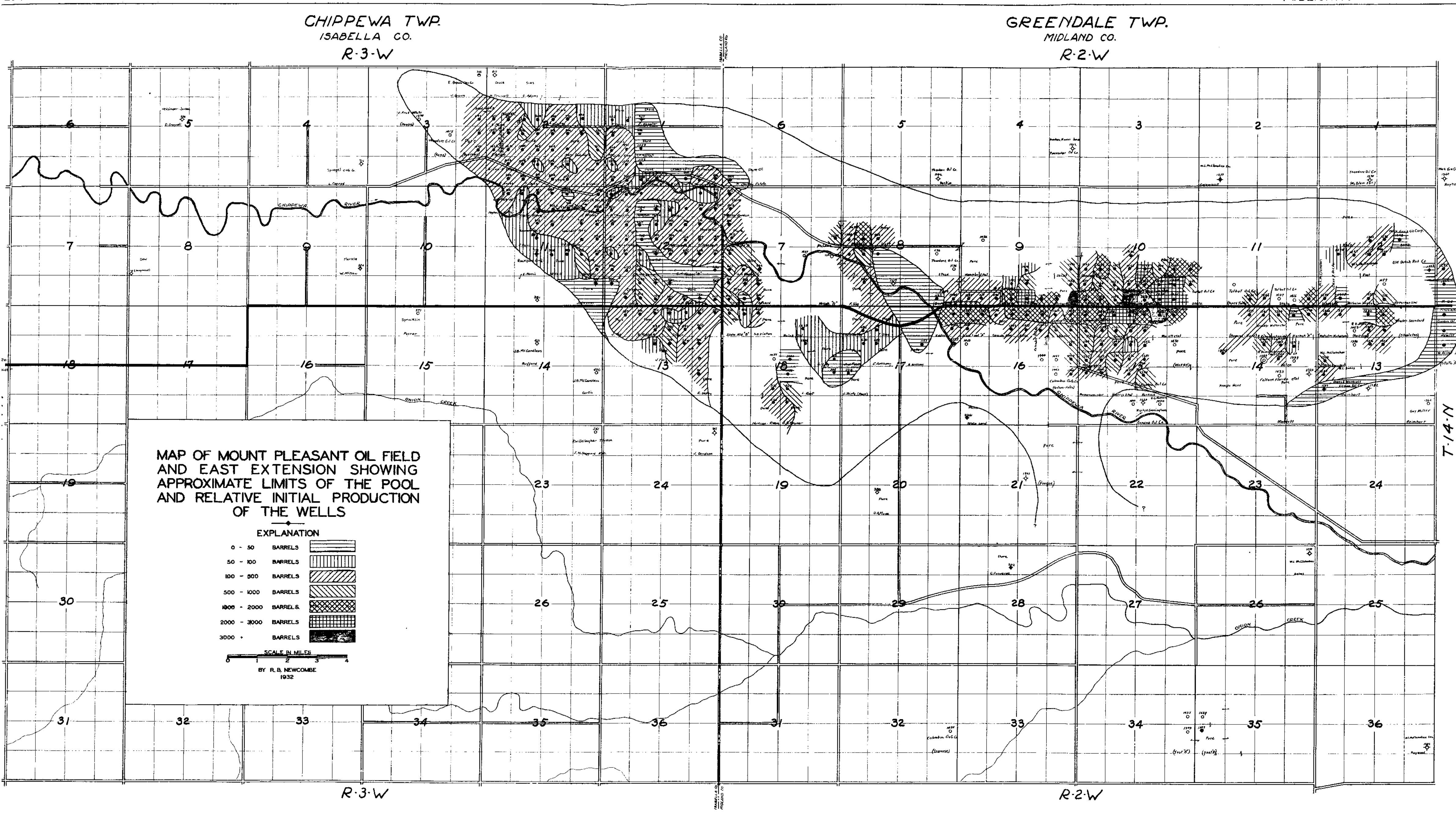


Plate VI—B. A large gas well in the Broomfield gas field being "brought in". (Note the drilling line coming out of the hole).



EAST-WEST
SECTION A-A' ACROSS MOUNT PLEASANT OIL FIELD
SHOWING
PRODUCTIVE OIL HORIZONS AND WATER LEVEL
IN THE
DUNDEE FORMATION

BY
R.B. NEWCOMBE
1932


CHIPPEWA TWP.
ISABELLA CO.
R·3·W
GREENDALE TWP.
MIDLAND CO.
R·2·W
CHIPPEWA RIVER
ONION CREEK
T·14·N
MAP OF MOUNT PLEASANT OIL FIELD AND EAST EXTENSION SHOWING APPROXIMATE LIMITS OF THE POOL AND RELATIVE INITIAL PRODUCTION OF THE WELLS
EXPLANATION
0 - 50 BARRELS
50 - 100 BARRELS
100 - 500 BARRELS
500 - 1000 BARRELS
1000 - 2000 BARRELS
2000 - 3000 BARRELS
3000 + BARRELS
SCALE IN MILES
0 1 2 3 4
BY R. B. NEWCOMBE
1932
R·3·W
R·2·W

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.

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.

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.

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

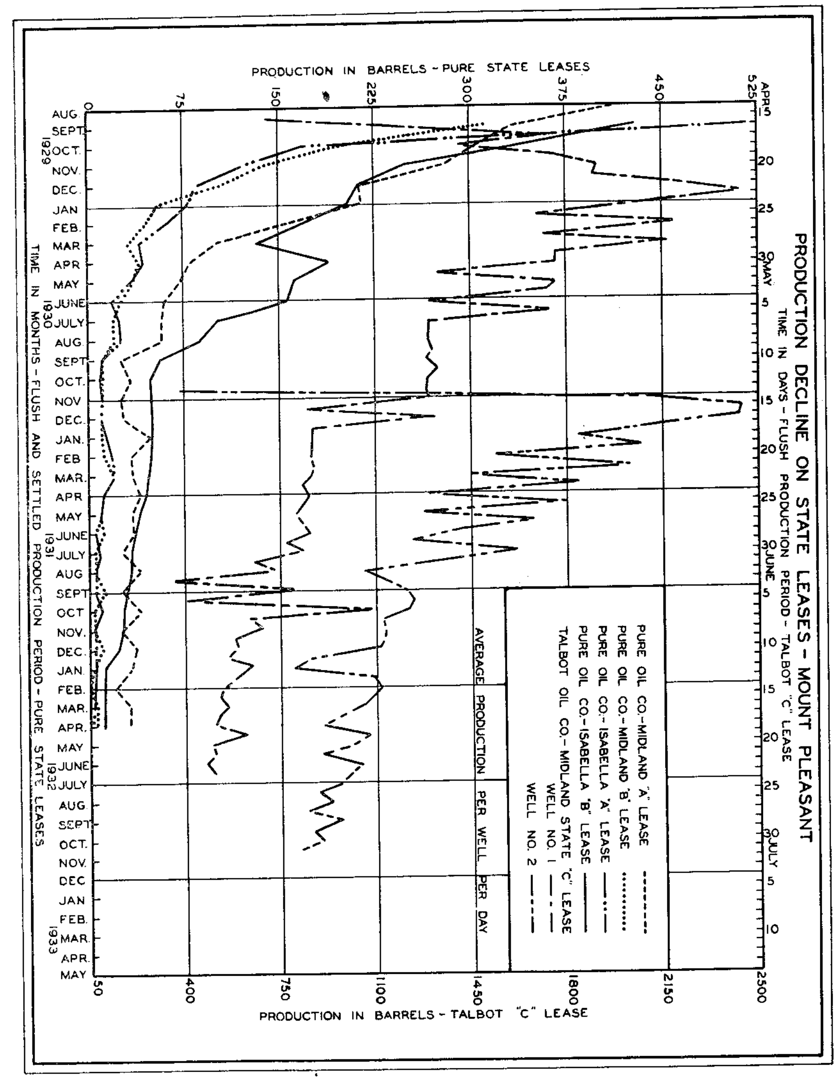


Figure 33. Production decline on State leases in the Mount Pleasant field and East Extension.

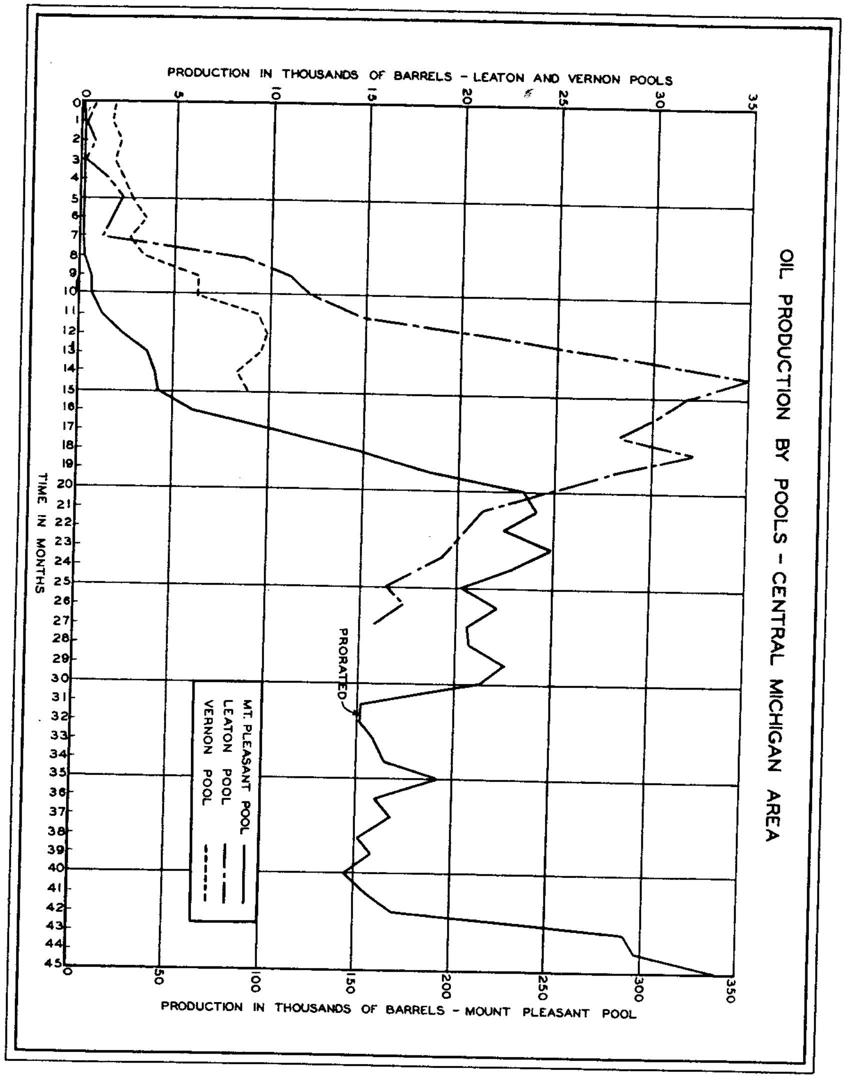


Figure 34. Graph showing fluctuation in monthly production by pools in the Central Michigan Area.

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. Flow 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.

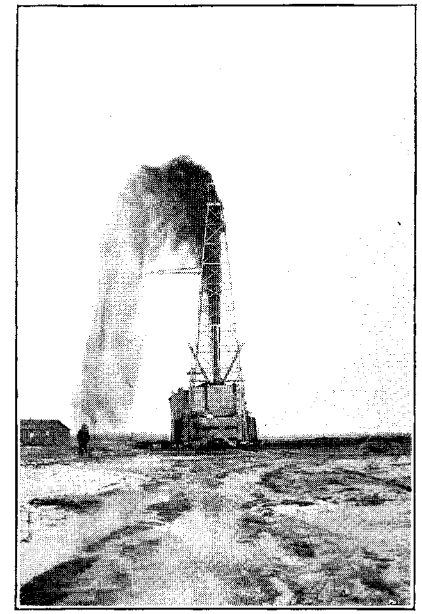


Plate VII—*A*. Well making a flow of oil after being "shot" with nitro-glycerin.

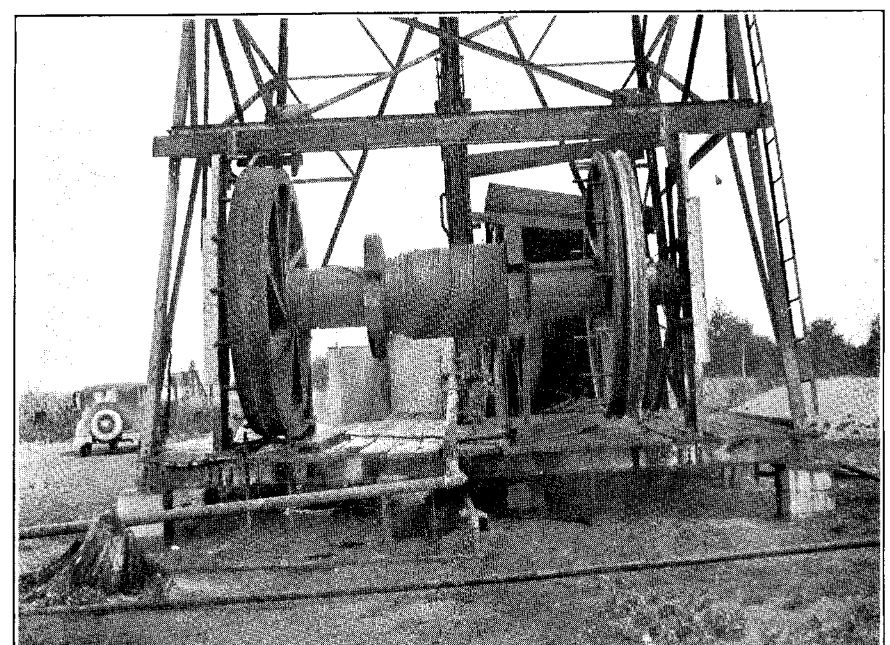


Plate VII—*B*. Floor of oil derrick set on concrete corner posts showing steel bull wheel, well head connections, flow line, and location of slush pits (to the right).

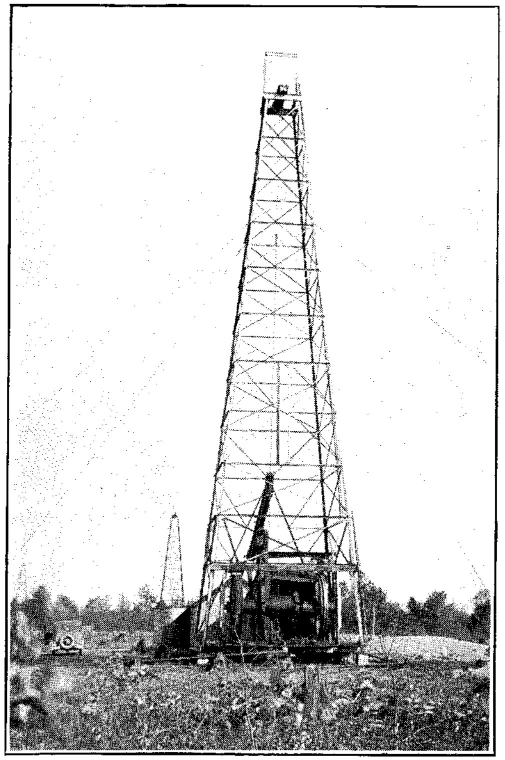


Plate VIII. Standard steel derrick with 4 guy wires (note the normal spacing of wells).

The 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.

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.

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 5½ 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.

TABLE XII.—*Properties of Central Michigan Dundee Crudes*

Location		A.P.I. Gravity	Flash O. C. °F.	B. S. & W. %	Sulphur (B) %	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 XIII.—*Analyses of Crudes From Central Michigan Area*

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	

TABLE XIII.—*Analyses of Crudes From Central Michigan Area*—Continued

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 XIV.—*Properties of Gasolines*

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

TABLE XIV.—*Properties of Gasolines*—Continued

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		

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.

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.*"

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

The properties of six Dundee straightrun gasolines, with different endpoints, 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°F. 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.

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 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 Com-

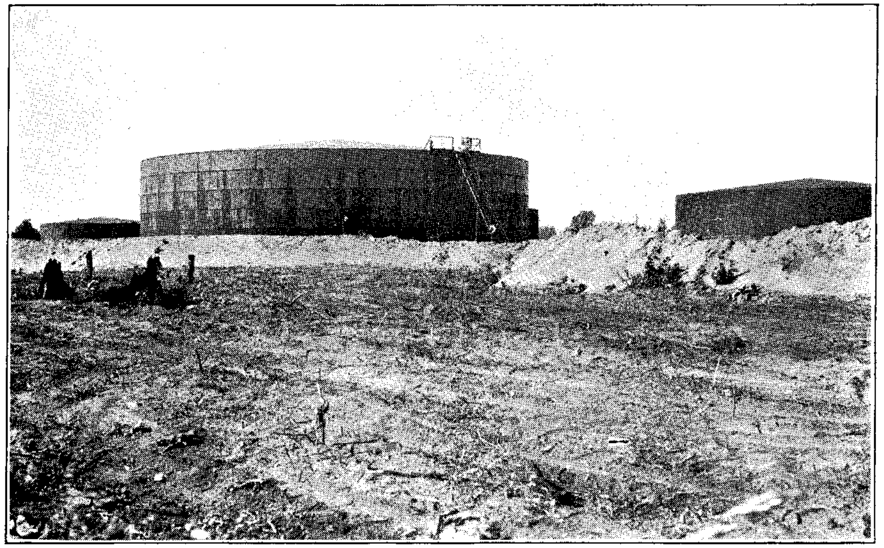


Plate IX. Storage tanks (55,000 barrels capacity) on Purtell Tank Farm of the Pure Oil Company. (Note the earthen dikes thrown up around the tanks for fire protection).

pany, 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.

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.

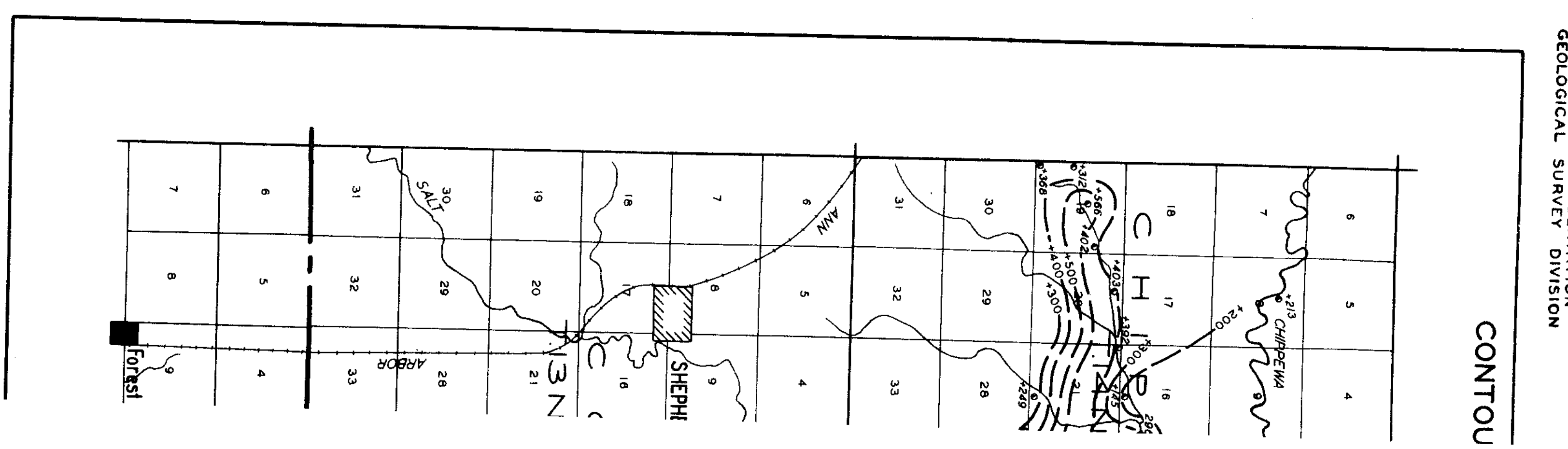
Formation.	Depth.	Location of Well.	Sp. Gr.	$CaCl_2$.	$MgCl_2$.	NaCl	KCl.	Br_2.
Parma	845	Sec. 14, T. 15 N., R. 9 W.	1.169	4.44	1.64	16.50		.0751
Parma	1,025	Sec. 31, T. 16 N., R. 4 W.	1.207	4.05	1.75	19.31		.0689
Marshall	710	Sec. 16, T. 9 N., R. 1 W.	1.096	2.21	.87	7.92		.040
Marshall	1,238	Sec. 23, 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

TABLE XV.—*Analyses of Central Michigan Brines*—Continued

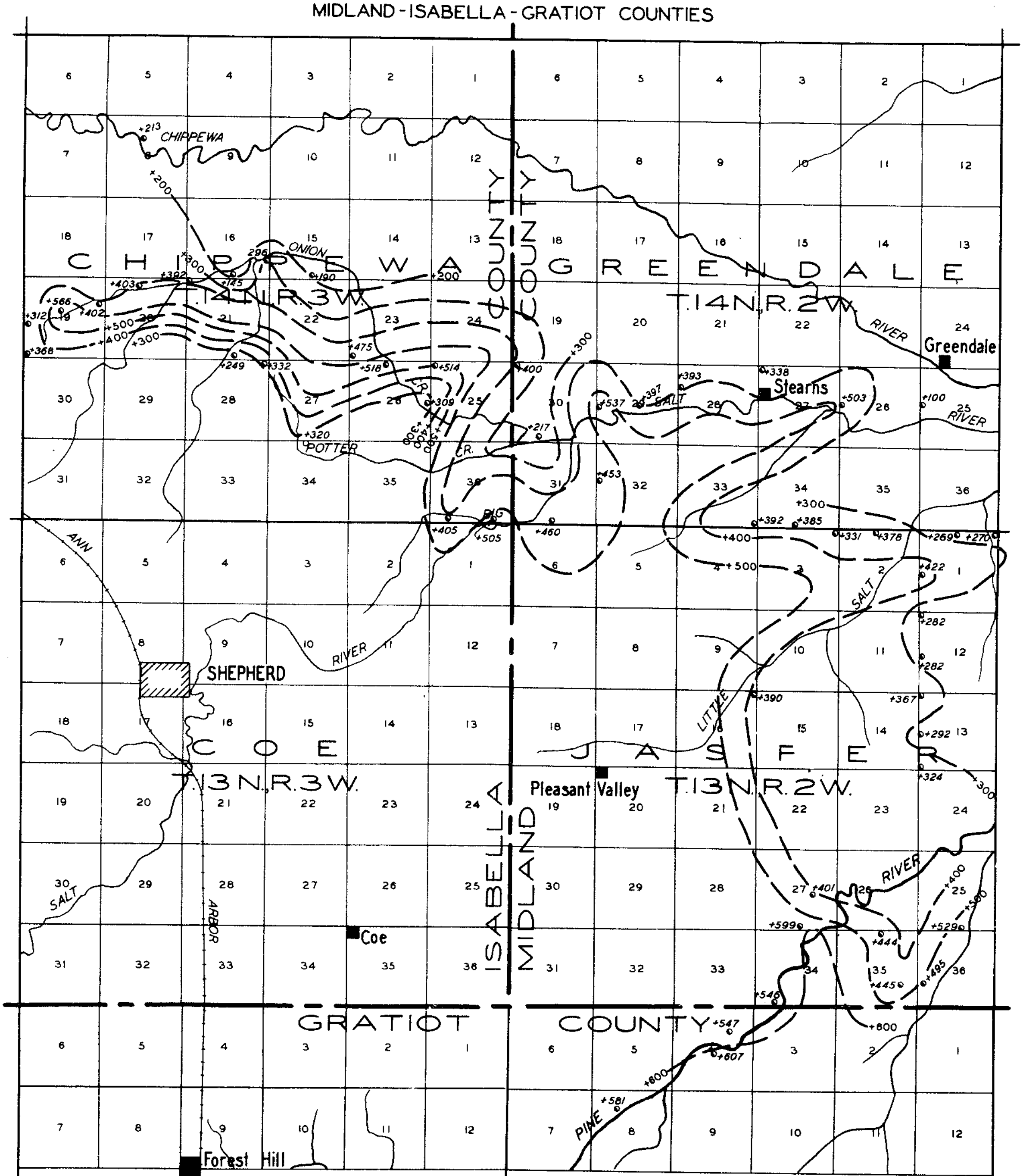
Analyses in Parts per Million.

	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.



CONTOUR MAP OF EQUAL STATIC WATER HEAD
MARSHALL BRINE
MIDLAND - ISABELLA - GRATIOT COUNTIES



CONTOUR INTERVAL 10 FEET
SCALE:- 1 INCH = 1 MILE
BY R.B. NEWCOMBE
1932

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.

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

[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).

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.

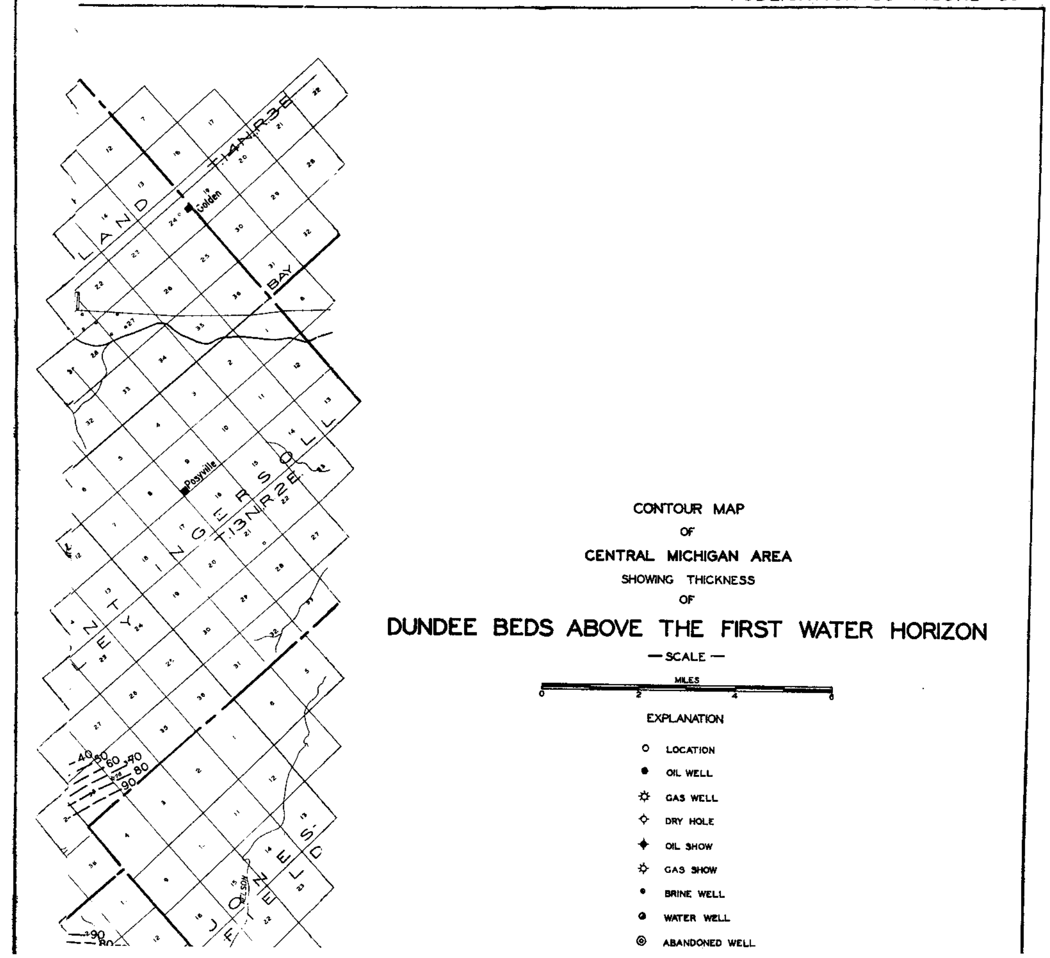
It is usually comparatively easy to recognize the Monroe "black water" when encountered in a well. Aside from the chemical differences, the black color, the rank odor, and the occurrence in dolomitic rocks are generally sufficiently convincing evidence.

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.

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 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.

TABLE XVI—*Summary of Wells in Central Michigan Gas Fields**

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.

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."

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.

[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).

TABLE XVII.—*Annual Oil and Gas Production in Central Michigan Area* [a]

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

TABLE XVII.—*Annual Oil and Gas Production in Central Michigan Area* [a] —Continued

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.

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 in 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.

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

[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).

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 3,640 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.

[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).

TABLE XVIII.—*Deep Wells In Livingston County*

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.

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.

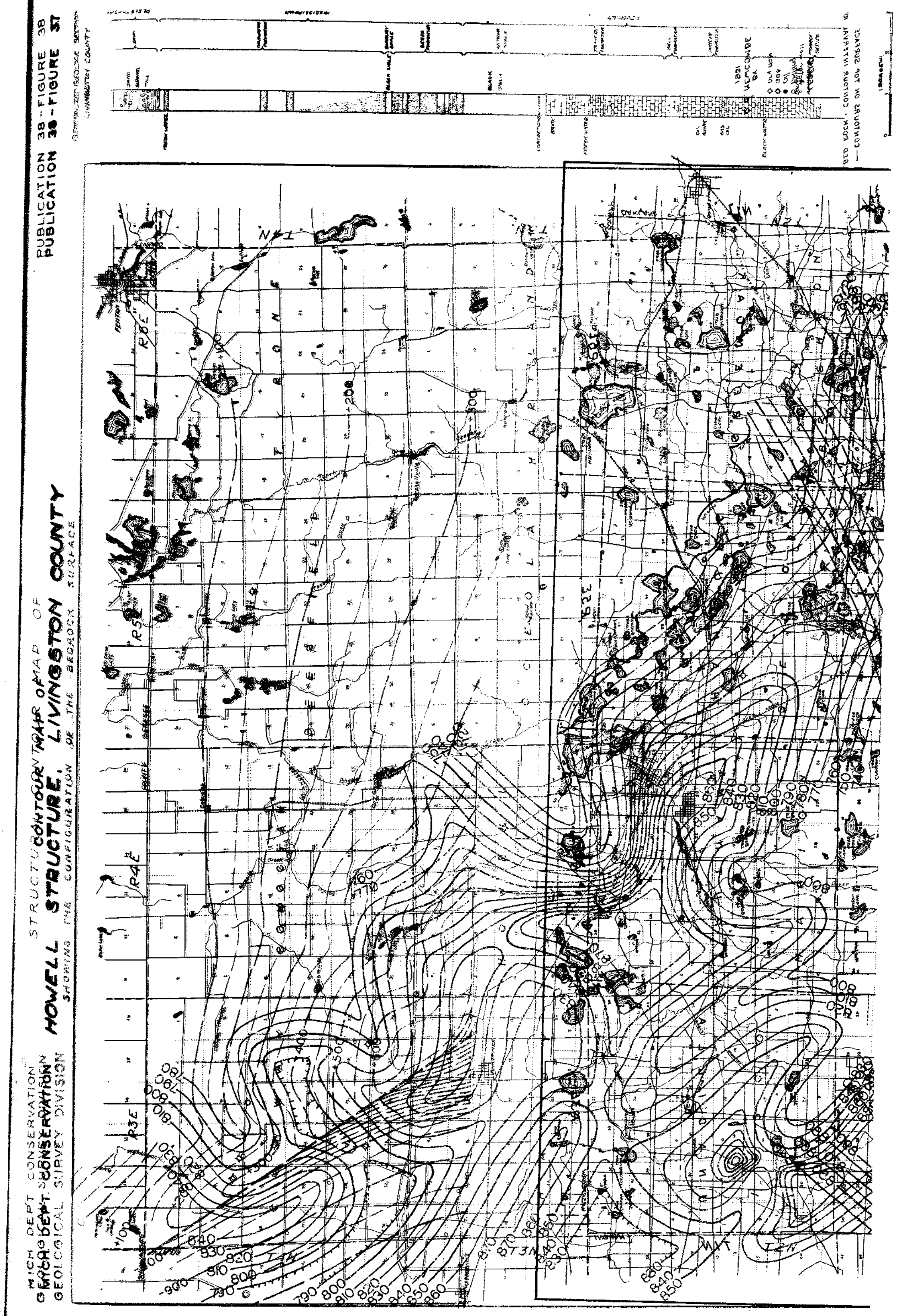
SILURIAN

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.

STRUCTURE

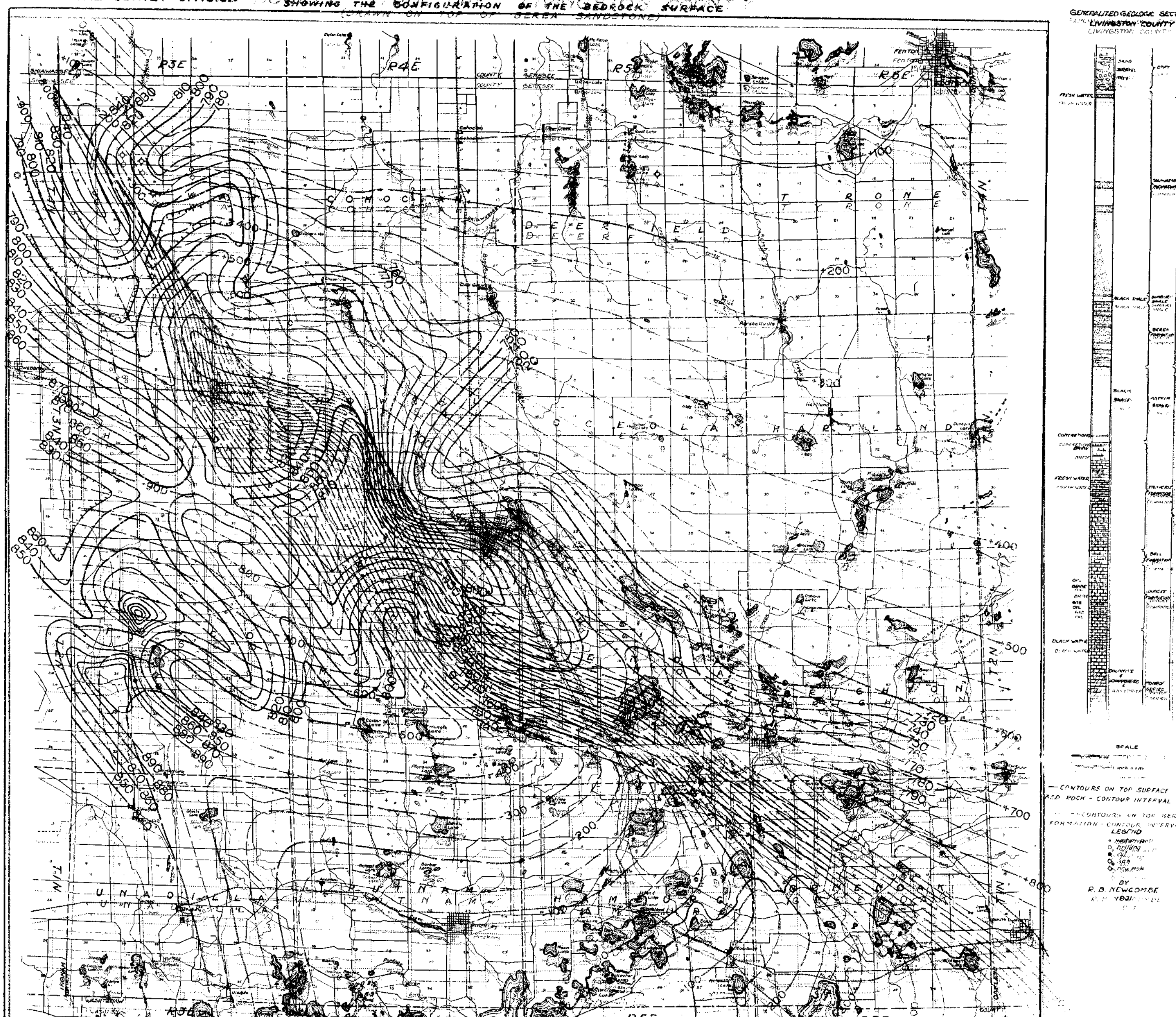
The normal regional strike of the rocks in Livingston County is N.26°E., and the general regional dip is northwest with younger beds



MICH DEP'T CONSERVATION
GEOLOGICAL SURVEY DIVISION

CONTOUR MAP OF HOWELL STRUCTURE, LIVINGSTON COUNTY
SHOWING THE CONFIGURATION OF THE BEDROCK SURFACE
(DRAWN ON TOP OF BEREA SANDSTONE)

PUBLICATION 37 - FIGURE 31



THIS MAP IS ONLY TENTATIVE AND SUBJECT TO CHANGE

... formation is made up of blue to gray and greenish gray ... dolomitic limestone. Some of the lower ... series, which is from 80 to 120 feet ... numerous layers, nodules, veins, and stringers of gypsum. ... Marshall is white to greenish gray ... abundant quantities. If low structurally, some of ... thickness varies from 120 to 150 feet. ... formation contains beds of gray micaceous sand... is prevalent in wells low structurally ... the structure. The Lower Marshall ...

... of gray to blue shale, sandstone, and ... are the first encountered by wells ... Livingston County and "off structure" they ...

... to 20 feet thick and indicates nearness ... formation is gray to brown pyritous ... limy sandstone. Beds of gray shale ... the Bedford formation. The total thick...

... from 220 to 230 feet of black and ... about 50 feet above the base probably ... common to this part of the formation. ... shaly and cherty in the upper members, ... show about 280 feet of the strata. The ... color. The Bell formation when not ... from 35 to over 50 feet in thickness. ... of buff to brown limestone, which is ... lower part. These sandy beds may be ... of the eastern states. There is no ... the Dundee and the Monroe, and the ... to correlate. The Dundee appears ...

... penetrated by only a few wells in Living... formation, including beds of brown to ... is about 600 feet thick. The Sylvania ... and gray dolomite and white sandstone ... of the lower beds are cherty.

... brown to gray dolomite and sandy dolo... well.

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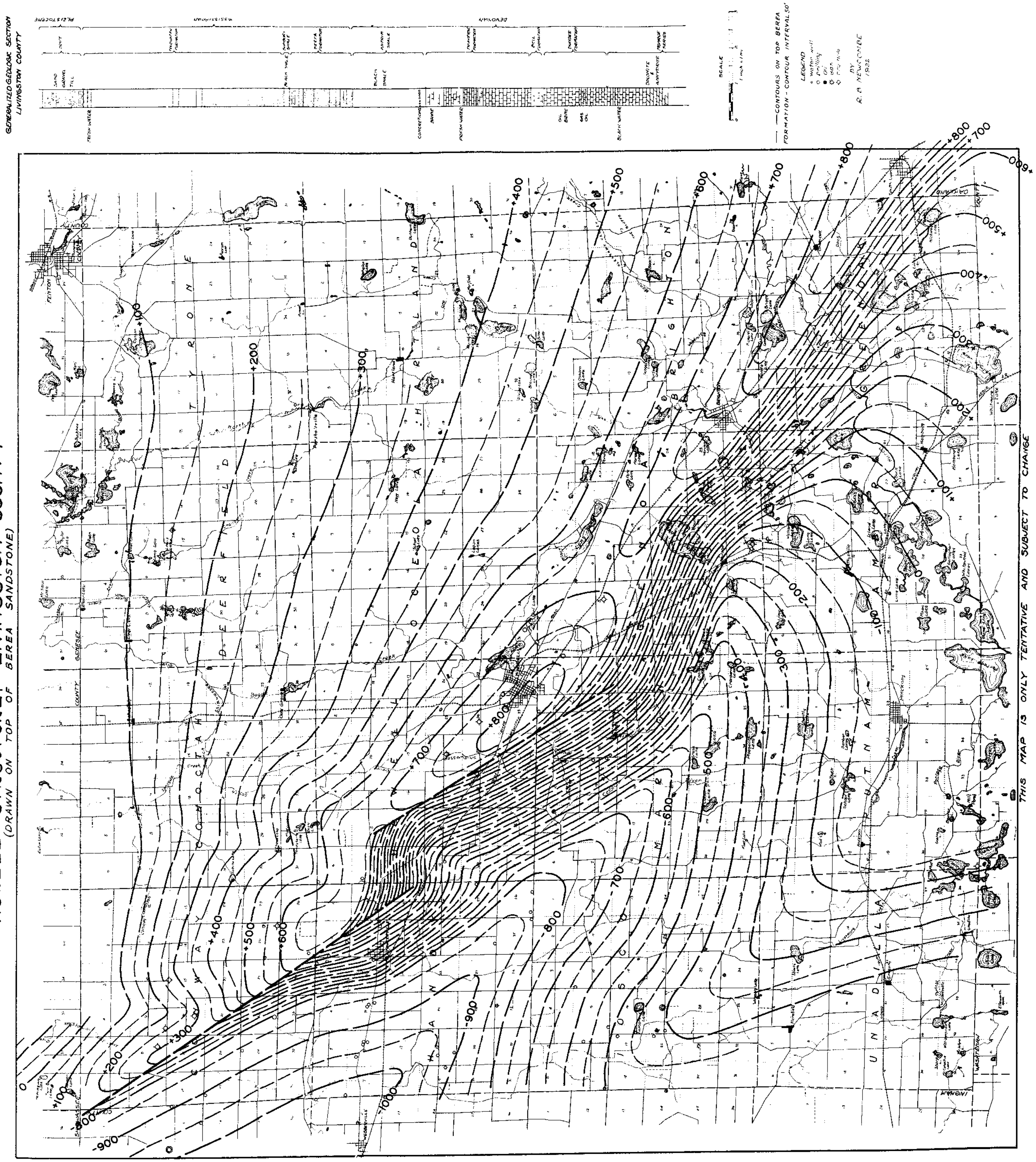
... rocks in Livingston County is ... regional dip is northwest with younger beds ...



GEOLOGICAL SURVEY DIVISION PUBLICATION 38 - FIGURE 21
MICH. DEPT. CONSERVATION GEOLOGICAL SURVEY DIVISION
STRUCTURAL CONTOUR MAP OF HOWELL STRUCTURE, LIVINGSTON COUNTY (DRAWN ON TOP OF BEREA SANDSTONE)
THIS MAP IS ONLY TENTATIVE AND SUBJECT TO CHANGE

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rim formation includes from 220 to 230 feet of black and e. A dolomitic zone about 50 feet above the base probably e large concretions, common to this part of the formation.

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

dee formation is made up of buff to brown limestone, which is argillaceous in the lower part. These sandy beds may be o the Oriskany sandstone of the eastern states. There is no at the base between the Dundee and the Monroe, and the lolomitic beds are difficult to correlate. The Dundee appears 75 to 200 feet thick.

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

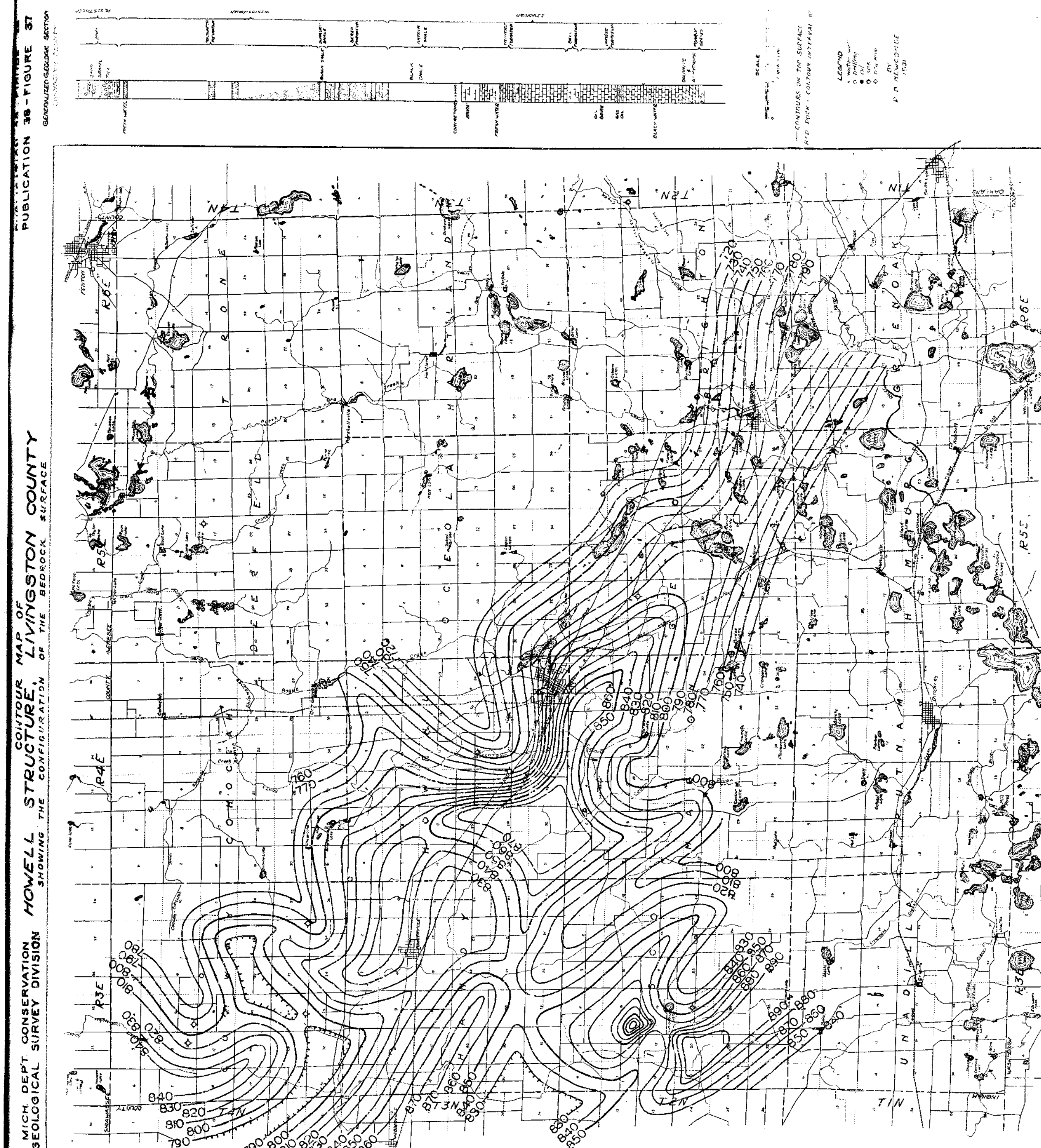
SILURIAN

Island formation of brown to gray dolomite and sandy dolo- feet thick in the Ross Robb well.

00 feet of Salina was penetrated in the same well, but the formation was not reached. The entire Salina formation is t much thicker than this. It is made up of salt, gypsum and hale, bituminous limestone, and dolomite.

STRUCTURE

al regional strike of the rocks in Livingston County is d 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.

[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.

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 re-cemented 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.

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.

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.

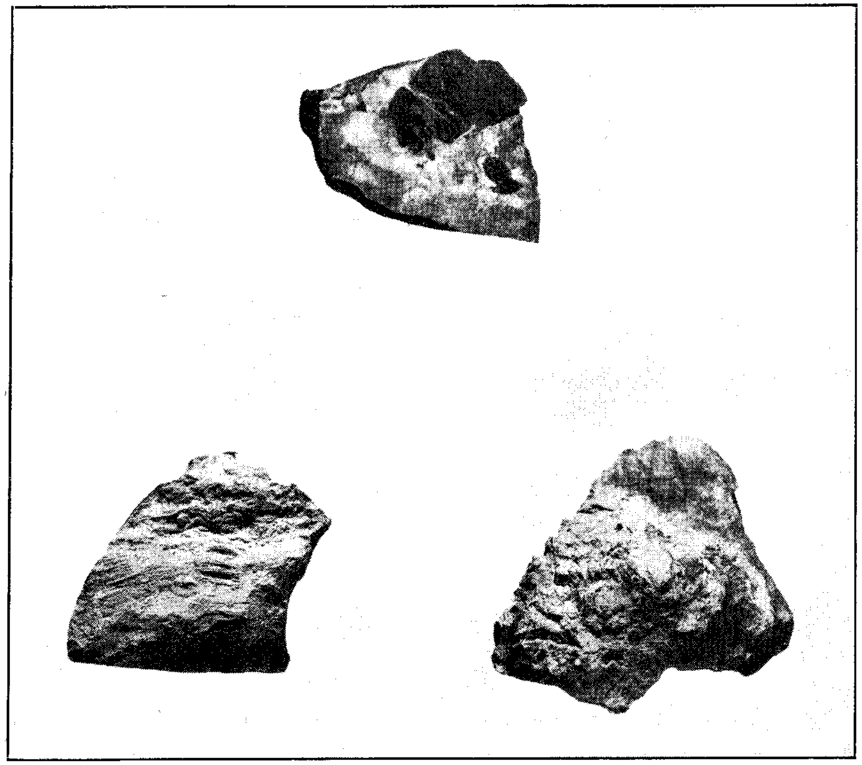


Plate X. Samples of fault breccia taken from the Tooly well, section 28, Howell township, Livingston County. Specimens show the grooved and striated surfaces, the angular recemented fragments, and the calcite cementing material. (These samples furnished by Mr. J. Tooly and Mr. John Wesley Kinsler of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

Table XIX.—*Record of Crude Oil Company's and Empire Oil and Refining Company's J. Tooly No. 1*

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 XX.—*Record of Crude Oil Company's and Empire Oil & Refining Company's G. A. Wilkinson No. 1*

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

TABLE XX.—*Record of Crude Oil Company's and Empire Oil & Refining Company's G. A. Wilkinson No. 1*—Continued

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	1,268
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

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., Fraser 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 nitroglycerin 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.