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THE OCCURRENCE OF OIL AND GAS IN MICHIGAN

BY

RICHARD A. SMITH

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1912.

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LETTER OF TRANSMITTAL.

To the Honorable the Board of Geological and Biological Survey of the State of Michigan:

GOV. WOODBRIDGE N. FERRIS, President.
HON. WM. J. MCKONE, Vice-President.
HON. FRED L. KEELER, Secretary.

Gentlemen:—

I have the honor to present herewith Publication 14, Geological Series 11, a monograph on the subject of the occurrence of oil and gas in Michigan. The recent activity in drilling for oil and gas has not only stimulated the issue of this volume but has also contributed directly to the information contained in it. Much of the data contained in this work is new, including the records of a considerable number of important deep wells, but a large part of it has been compiled from various sources.

For many years the Southern Peninsula of Michigan has offered a tempting field for exploratory work designed to test the possibilities for the occurrence of oil and gas. Although with the minor exception of the Port Huron field all such efforts have resulted in a discouraging monotony of disappointments; the activities of recent years lends force to the observation that repeated failures serve only to stimulate rather than to retard these adventurous projects.

The time is approaching if not actually at hand in most parts of this country, when valuable mineral deposits may be found no longer without the application of vast labor and expense to underground explorations of one or another kind. Surely this is true of the State of Michigan, and probably nowhere within our borders may success attend the efforts of the prospector unaided by generous financial support. Any project devoted to the discovery of valuable minerals must therefore be considered as a purely financial adventure and this applies with peculiar force to explorations for oil and gas in Michigan.

It is trite to remark that a financial adventure should be preceded and controlled by a careful weighing of the possibilities for success. This is a moral as well as a business responsibility which is particularly incumbent on those who control the expenditure of the capital of a company, association, or corporation. Unfortunately this responsibility has been so frequently violated through fraudulent intent in some instances and ignorance in others, that a warning should be sounded throughout the state as a guard not only against fraudulent schemes of promotion, but against that credulous class of so-called ''oil smellers'' or ''locators'' whose operations are no less fantastic than their claims to unusual or occult powers are crass and audacious. The ''oil smeller'' or ''locator'' is not always a calculating fakir. Among them are a few who seem to be honest but these present a curious study of more interest to the psychologist than to the geologist, and to the former they may be consigned without further remark.

The professional promotor, when guided by moral as well as business sense, is a legitimate and oftentimes necessary factor in many modern financial and industrial undertakings, but the element of mere luck or chance, which the partial and oftentimes complete absence of determinative data in many localities must always leave open to the prospector, not only provides a cloak for rascality but also a basis for the play of credulous imagination on which the unscrupulous promotor builds his fortune. Men of sound judgment in matters of general business, as well as others, continue to seek pots of gold at the end of the rainbow, following those whose sole claims to leadership reside in unscrupulousness, suave audacity, clever deceitfulness, and a smattering of technical jargon, meaningless to themselves but nevertheless a bait for the unwary layman.

As may be suspected, the promoter and the ''locator'' often share the work as well as the gains attaching to a successful ''fleecing'' of a whole community. In many instances, their common solicitude for a wider distribution of prosperity invites a participation of the people in general through the medium of carefully prepared ''literature'' amply illustrated with pictures of derricks, drilling outfits, views in the oil fields, gushers, and perhaps a sketch showing the exact position of the ''vein'' or ''pool'' which is expected to be opened by the application of the stockholders' money if enough remains for the purpose after promotion charges have been carefully set aside. Lacking only the actual odor of crude oil, which can hardly be transmitted by mail, these gems of persuasive advertising are calculated to produce an anticipation of realities which are doomed to materialize only in the imaginations of the investors.

Among the numerous drilling operations of recent years are a number which may be termed ''community projects.'' The incentive to these undertakings is a general desire for exact information relative to the formations and their contents coupled with a hope, not to say expectation, of developing a valuable local resource. Such efforts should be encouraged, but only under a full realization of the relative probabilities for financial loss or gain on the part of those whose means are involved. None who can ill afford the risk of loss should be encouraged to enlist in these enterprises.

Those who engage permanently in the oil business recognize the principle that the chances for loss are in inverse ratio to the number of well advised separate adventures embraced. A small amount of money staked on a single, or a limited number of projects is almost certain to be dissipated. On the other hand, a large amount of money involved in many separate and well advised operations is almost equally certain to be multiplied. To illustrate this principle, it may be remarked that a single well drilled in the most favorable locality in Michigan would have only a very remote possibility of encountering oil in commercial quantity, but the drilling of one hundred wells in five favorable localities would stand a very reasonable, though far from assured, chance of success. A thousand dollars invested in the latter enterprise would be a much sounder investment than the same amount invested in the former. It is the operation of this principle which renders so extremely hazardous an occasional investment in operations confined to a single test well, or a single locality.

The natural conditions governing the occurrence of oil and gas are well known to geologists, but unfortunately the geologic data in different regions or localities are rarely so precise and determinate as to warrant unqualified statements in the one or the other direction in advance of exploration. There is a large area in Michigan where oil or gas is not to be sought under any circumstances because of the age and character of the rocks. I refer to the copper and iron bearing region of the Northern Peninsula; i. e., that part of the state underlain by pre-Cambrian rocks. In a considerable part of the remainder of the State the occurrence of oil and gas in commercial quantity is a possibility and in some localities a very reasonable probability. Common prudence would demand that the areas where the conditions are known to be favorable should receive first attention through a fair and adequate test. Too frequently, initial disappointments terminate a well conceived plan of exploration before conclusive results either positive or negative are obtained. Negative results are always ultimately if not immediately useful, and, therefore, records of all explorations should be carefully preserved.

It has been remarked above that the absence of ample and reliable data, from which the geologist may draw sound conclusions, and the element of luck or chance renders unsafe in many parts of Michigan any unqualified statement relative to the presence or absence of commercial quantities of oil or gas, but while the soundness of any calculation or conclusion must always be governed largely by the fullness and reliability of the basal data, the lack of complete information need not stay a conclusion or hypothesis on which to base expenditures in exploration. Indeed ultra conservatism is rarely creative; it is desirable only to eliminate waste through ignorance or fraud and on the other hand to encourage and assist worthy projects for exploration. It is with this double purpose in view that this volume has been presented to the public. If it accomplishes these purposes the care, labor, and expense which has been devoted to it will have been well repaid.

Very respectfully yours,
R. C. ALLEN,
Director.

June 18, 1914.

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INTRODUCTION.

In 1860, A. Winchell, published in the First Biennial Report of the Geological Survey of Michigan a number of records of deep borings and referred to the possibilities for the occurrence of oil in the eastern part of the State, especially in the vicinity of Port Huron. Further records of borings were given in Volume III by Dr. C. Rominger in a report on the geology of the Lower Peninsula of Michigan. In Volume V, Dr. A. C. Lane published a large number of well sections with special reference to the occurrence of oil and gas. The introduction, written by Dr. L. L. Hubbard, is a brief discussion of the origin of salt, gypsum, and *petroleum*. Brief chapters on oil and gas together with the records of many borings were published by Lane in the Annual Reports for 1901, 1903, 1904, and 1908. The Mineral Resources for 1911, Publication 8, Geological Series 6, contains a short chapter on the occurrence of oil and gas in Michigan.

The above reports contain most of the published information with the exception of that to be found in the geological reports of the various counties.

Since Michigan lies adjacent to the oil and gas producing territories of Ontario, Ohio, and Indiana, it has received for many years much attention from oil and gas operators. Many explorations have been made, but thus far the results have been meager. Only at Port Huron, Allegan, and Saginaw have oil and gas been struck in quantities approaching commercial importance. The known presence of oil formations, the many small showing of oil and gas, and the abundance of oil and especially gas seepage in certain portions of the State, however, have kept up a keen interest in the possibilities for the occurrence of oil and gas in larger quantities. During the past three years especially, there has been a continuous demand on the part of the oil operators and the general public for information relative to the oil and gas possibilities in Michigan, and fifty or more drilling operations have been made and projected.

A large part of the recent drillings were located with due regard to known geological conditions, but unfortunately a considerable number of explorations were started upon the most chimerical notions of geology, which is not surprising when it is considered that most of the explorations in Michigan have been made by operators from the oil fields of adjacent states.

The data furnished by the many explorations of recent years has been published only in part. The object of this report is to bring together all the available data relative to the occurrence of oil and gas in Michigan in such a form as to make it effective in more intelligently directing explorations.

The plan of the report embraces, (1) An outline of the geology of the Paleozoic formations, (2) A brief discussion of the more prominent theories on the accumulation of oil and gas, but more particularly of the anticlinal theory of accumulation, (3) A history of the explorations by districts or fields with the records of borings, (4) A discussion of the care and regulation of oil and gas wells and an outline of needed legislation relative to deep borings, and (5) A brief statement of the possibilities of the black shales of Michigan as a source of oil and gas.

The well records given in detail do not include all of the deep borings in the Paleozoic area. Many wells have been drilled of which the Geological Survey has no records, or only imperfect ones. At many places, several borings have been closely spaced, and of these only the more accurate records have been given, but whatever information the others afford has been included in the discussions preceding the records given. Most of the records have been revised, especially the older ones, to bring them into harmony with present geologic knowledge.

For convenience in discussing the history of the oil explorations, the state has been arbitrarily divided into districts and fields. As there are no sharp lines of separation between any of these, some wells included in one district may have been placed with equal propriety in another. The territory in the vicinity of Saginaw and of Port Huron, properly parts of the central and the southeastern districts respectively, have been deemed worthy of separate treatment as oil fields on account of the structural conditions and the large amount of exploration made in each.

In all oil fields, there is always a greater or less number of "dry" holes or wells of small production which are abandoned. Usually the drillings pass through one or more water or brine bearing formations and the "dry" holes and abandoned wells form a serious menace to the life and productivity of a field through the ingress of water into the oil sands. On the other hand, oil and gas wells are a source of danger to mining industries, but more especially to that of coal, through the escape of gas into the mines with consequent explosion. So acute is the situation in some states that stringent laws have been passed regulating the drilling and care of oil and gas wells. Besides being a source of injury to oil fields and a menace to life and property in coal mining regions, abandoned wells, in some cases, cause contamination of potable water supplies through the entrance of salt water; or, vice versa, valuable brines or mineral waters may be polluted by surface or fresh waters.

In Saginaw Valley and in the vicinity of Grand Rapids, the potable waters have been ruined through the ingress of brines or mineral waters, and the purity and strength of the brines in the former district are now being menaced by the entrance of surface or fresh waters through abandoned salt wells, the casings of which have been destroyed by the corrosive action of the brines. The regulation and care of oil and gas and other borings has become a subject of such importance to the State that a discussion of the methods and means of conserving oil and gas, water, and other mineral resources has been included as an appendix to this report.

ACKNOWLEDGMENTS.

The information contained in this report has been compiled from so many sources that proper acknowledgment cannot be made to each of the investigators whose works have been freely drawn upon. The outline of the geology of the Michigan Basin has been taken largely from the writings of A. C. Lane, C. Rominger, and A. Winchell. The stratigraphy of the formations has been compiled chiefly from Lane's Geological Section as published in the Annual Report for 1908. Much information on local geology has been afforded by the reports on Huron and Alcona counties by A. C. Lane, on Monroe and Wayne counties by W. S. Sherzer, on Sanilac by C. H. Gordon, on Bay by W. F. Cooper, on Tuscola by C. A. Davis, and on Arenac by W. M. Gregory.

The various bulletins of the U. S. Geological Survey and the State geological reports have been freely consulted for the material in the chapter on the accumulation of oil and gas. The statement and the history of the development of the anticlinal theory with particular reference to its practical application has been compiled from the publications of I. C. White and E. Orton.

Much other information bearing upon the limitations of the anticlinal theory has been gleaned from the investigations of N. M. Fenneman, F. G. Clapp, R. W. Stone, M. J. Munn, W. T. Griswold, H. S. Gale, R. Arnold, C. W. Hayes, Wm. Kennedy, C. H. Wegeman, and others as found in the many bulletins published by the U. S. Geological Survey.

The history of the drillings and the records have been compiled from the several reports of the Michigan Geological Survey, particularly Volumes V, VII, and VIII, the Annual Reports for 1901, 1903, 1904, and 1908, and Publications 2, 12, and 15. Many of the records

were previously unpublished, or published only in part. In compiling these, much valuable information was obtained from the field notes of Dr. A. C. Lane and W. F. Cooper. Special acknowledgment is hereby extended to the officials of the Saginaw Development Company for their many courtesies and hearty co-operation in carefully preserving sets of samples and compiling the information afforded by their drillings in the vicinity of Saginaw.

Most of the information in Appendix A on the regulation and care of deep borings has been obtained from Bulletin 65 and Technical Paper 53 of the U. S. Bureau of Mines. Much other data, however, has been gleaned from the reports of the State geological surveys and of the State mine or oil and gas inspectors, particularly of California, Oklahoma, Ohio, Indiana, and Wyoming.

In the discussion of the commercial possibilities of the black or bituminous shales in Appendix B, much valuable information was obtained from the Summary Reports, and especially from the Joint Report on the Bituminous or Oil Shales of New Brunswick and Nova Scotia and on the oil Shale Industry of Scotland by R. W. Ells, Nos. 55 and 1107 of the Mines and Geological Survey Branches of the Department of Mines of Canada. It is to be regretted that the writer did not have the opportunity of reading the bulletin now in preparation by the U. S. Geological Survey on the Oil Shales of Utah and Colorado.

CHAPTER I.

THE MICHIGAN BASIN.

MAJOR STRUCTURE.

The term, *Michigan Basin,* is applied to a broad, shallow structural basin occupying part of western Ontario, the eastern half of the Northern and the whole of the Southern Peninsula of Michigan, eastern Wisconsin, northeastern Illinois, northern Indiana, and northwestern Ohio. Its average diameter is about 500 miles and the deepest part appears to be near the geographical center of the Southern Peninsula. The total depression of the lowermost Paleozoic formations at the center has been variously estimated at from 5000 to 7000 feet. Recent drillings in the central part of the Basin favor the larger figure.

The Michigan Basin is a composite, comprising a series of sedimentary formations which form a gigantic nest of very broad and extremely shallow warped basins whose diameters decrease regularly from the bottom upward (Fig. 1.) Were the rims of these basins uncovered by draining the lake basins and removing the glacial drift, they would form concentric belts about the central or uppermost formation (Fig. 2.) The depth of the Basin is so small in comparison with its diameter that the inclination of its several members is ordinarily between 25 and 50 feet per mile, and rarely exceeds 60 feet.

MINOR STRUCTURES.

The formations constituting the Michigan Basin are locally gently folded and, in some cases, slightly faulted. So far as known, the folds occur mainly near the margin of the Southern Peninsula and in Western Ontario. Of the anticlines or upward folds (Fig. 2), the six best developed ones in the Southern Peninsula are in the vicinity of Saginaw, Port Huron, Stony Island (Detroit river), Wyandotte, Niles, and Khagashewing Point (Little Traverse Bay). A very low, broad and ill defined anticline extends through Washtenaw county with its crest apparently near Ann Arbor. All of the anticlines, excepting those near Saginaw, Niles, and Ann Arbor, are relative y low and short. (See Chaps. IV, V and VII). Inconclusive evidence points to the probable existence of additional anticlines in the vicinity of New Baltimore, Macomb county, near Manistee, and near Fowler-

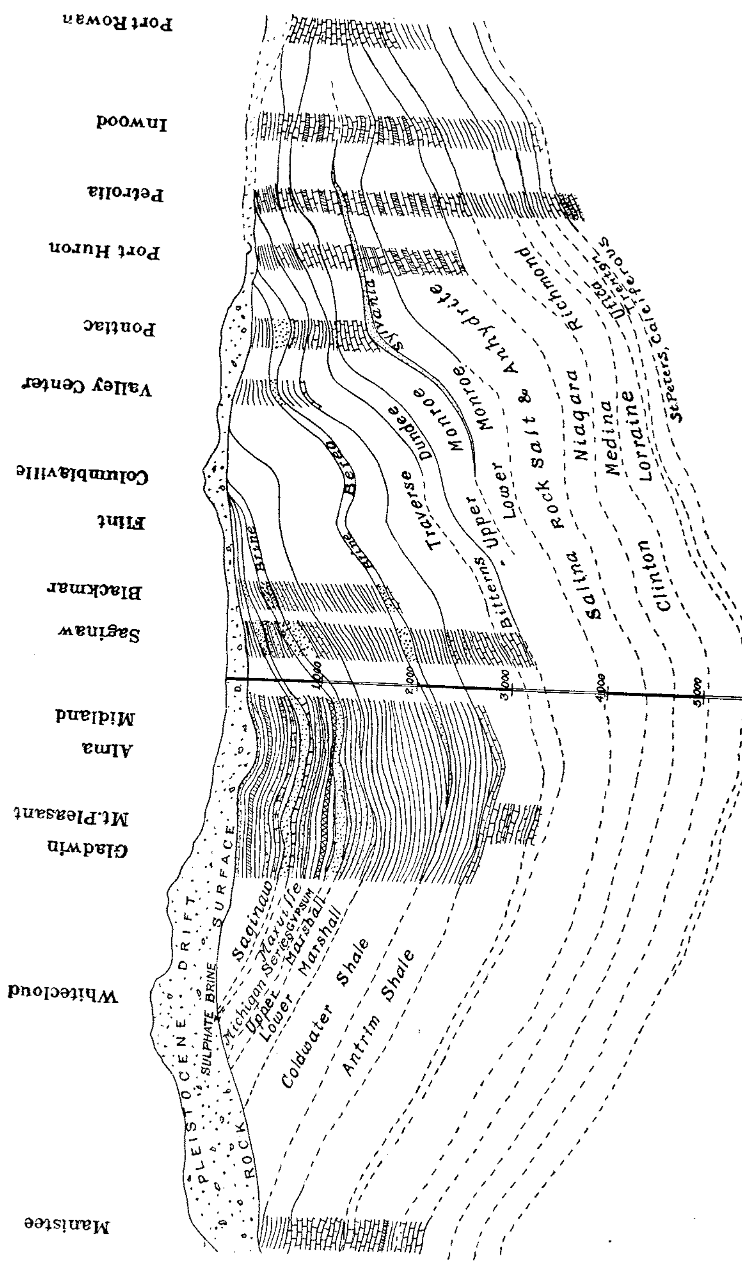

Figure 1. Diagrammatic cross section of the Michigan Basin from Port Rowan, Ontario to Manistee, Michigan.

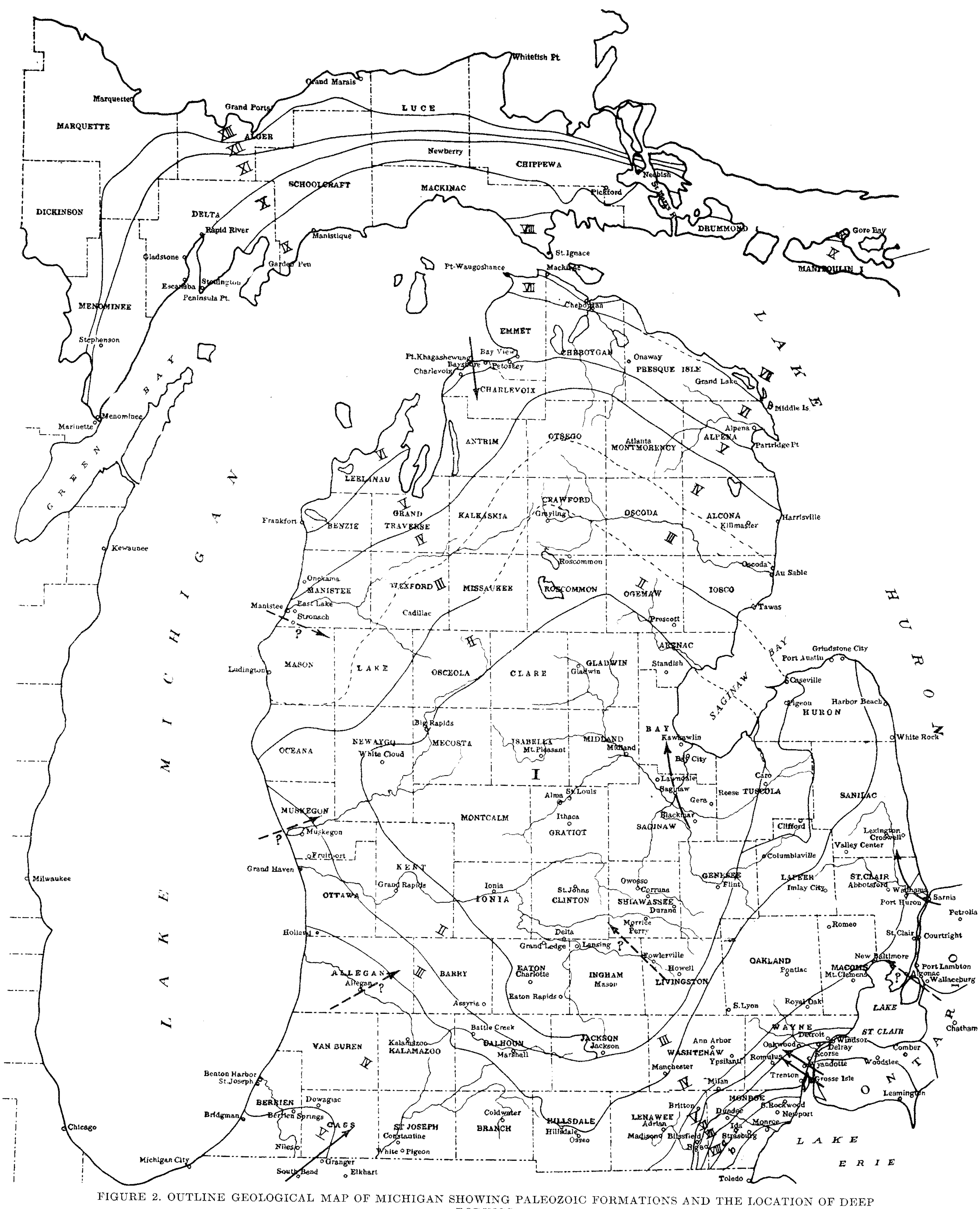

FIGURE 2. OUTLINE GEOLOGICAL MAP OF MICHIGAN SHOWING PALEOZOIC FORMATIONS AND THE LOCATION OF DEEP BORINGS.

PENNSYLVANIAN.

I. *Saginaw Formation* (Upper Pottsville) and *Parma* sandstone (Lower Pottsville).

MISSISSIPPIAN.

II. *Grand Rapids Group: Upper Grand Rapids, Bayport* or *Maxville* limestone (Upper St. Louis), and *Lower Grand Rapids* of *Michigan Series.*

III. *Marshall Formation:* (Kinderhook of Iowa, Black Hand and Logan of Ohio.) *Upper Marshall* or *Napoleon* and *Lower Marshall.*

IV. *Coldwater* shale and *Berea* sandstone.

DEVONIAN.

V. *Antrim* shale.

VI. *Traverse Formation:* (*Hamilton* and *Marcellus* Erian and Delaware of Ohio).

VII. *Dundee limestone:* (*Corniferous* and Schoharie, Ulsterian, and Upper Helderberg).

SILURIAN.

VIII. *Monroe Formation: Upper Monroe* or *Detroit River Series, Middle Monroe* or *Sylvania, and Lower Monroe* or *Bass Island Series.*

IX. *Niagara,* (*Guelph* and *Lockport*), *Rochester* shale, and *Clinton.*

ORDOVICIAN.

X. *Richmond* and overlying *Medina* of the Silurian, *Lorraine* and *Utica.*

XI. *Trenton limestone:* (Galena and Platteville?)

XII. *St. Peters* and *Calciferous* (Lower Magnesian).

CAMBRIAN.

XIII. *Lake Superior* or *Potsdam* sandstone.

ville and Howell, Livingston county. A syncline of considerable length and depth occurs near Berrien Springs and Dowagiac in Berrien county and two or three small ones[1] along Detroit river south of Detroit. Doubtless further drilling will reveal the presence of other anticlines and synclines of which there is now no indication.

In the vicinity of Al egan, there is a sudden change in the general northeastward dip of the strata, indicating the presence of a terrace or structural "bench." Discordant dips have been observed in several places in southeastern Michigan, in Huron, Alpena, and Presque Isle counties, and along the Lake Michigan and Lake Huron shores of the Northern Peninsula.

Numerous faults, generally with a displacement of a few inches to a few feet, have been noted in the Coal Measures. However, the occurrence of two faults with displacements of 50 to 60 feet have been reported, one in the Coal Measures of Saginaw Valley, and the other in the Dundee limestone in Presque Isle county. The Monroe formation in southeastern Michigan and in the Northern Peninsula is characterized by peculiarly brecciated dolomites. Drillings in the Manistee-Ludington salt district and in Presque Isle county indicate a wide spread occurrence of this brecciation, the cause of which may be related to movements due to the ablation of the salt beds as noted in Chapter IX.

THE GEOLOGICAL SECTION.

The rocks of the Michigan Basin represent the Paleozoic succession from the base of the Upper Cambrian to near the top of the Pennsylvanian. Exposures are numerous in many localities, especially along the north and south shores of the Northern Peninsula, but, in areas of large extent in the Southern Peninsula, outcrops are entirely wanting. In the Southern Peninsula, bed rock is exposed in two areas of considerable extent, one in Alpena and Presque Isle counties, and the other in Hillsdale and southern Calhoun and Jackson counties. Scattered outcrops occur in an arcuate belt extending from Arenac county through Huron and Tuscola into Genesee county, and from Jackson county through Calhoun into Ottawa and Kent counties. Limited but important outcrops also occur along the south shore of Little Traverse Bay and in Monroe and Wayne counties. In the greater part of the State, however, the Paleozoic rocks are concealed by a mantle of drift from 100 to 600 feet or more in thickness and the knowledge of the structure, character, distribution, and thickness of the different formations, necessary for making a generalized section, has been derived chiefly from a study of the records of borings.

[1]W. H. Sherzer: The Monroe Formation, Pub. 2, Geol. Ser. 1, p. 57.

CAMBRIAN.

Lake Superior, Eastern or Jacobsville sandstone. The Cambrian, so far as known, is represented in Michigan by the upper member only, called the Lake Superior or Potsdam sandstone. Jacobsville (or "Eastern") is the term applied to a similar sandstone along Keweenaw Bay though it is not certainly the equivalent of the Lake Superior sandstone east of Marquette. The Potsdam sandstone probably underlies the whole of the Michigan Basin. It outcrops at numerous points in the Northern Peninsula, especially along the Lake Superior shore from Marquette eastward to beyond Grand Portal, and it has been penetrated by drill holes in the southern part of the Peninsula. In the Southern Peninsula, it is so deeply buried that no borings have reached it. The formation is composed mainly of fragments of quartz and feldspar and comprises an upper red member, locally mottled and streaked, and a lower one of lighter color. It varies much in thickness, from 1500 feet at Grand Marais to only about 200 and 300 feet at Rapid River and on Neebish Island.

ORDOVICIAN.

Calciferous, Lower Magnesian, (Prairie du Chien), Hermansville Limestone. The Calciferous outcrops in the Northern Peninsula on Calciferous creek, a branch of the Au Train river, and on St. Mary's river near West Neebish Rapids. This formation, or perhaps only the lower part of it, is represented by the Hermansville limestone. It is mainly white sandstone, limestone, and sandy limestone. Its sandy phases resemble the St. Peters and the whiter portions of the Potsdam, hence the three formations are not readily separated in drill samples. Wells along Green Bay indicate a thickness of 200 to 250 feet.

St. Peters. Exposures of the St. Peters sandstone are not known in Michigan. Apparently it is about 75 feet thick at Marinette, (Wis.), absent near Stonington and 18 feet thick at Rapid River, but further east in the Northern Peninsula it has not been recognized. The formation is very irregular in thickness and appears to fill hollows in the eroded surface of the Calciferous. In the Southern Peninsula it has not been penetrated.

Trenton Limestone. The Trenton limestone outcrops at various places on the west side of Green Bay and Little Bay de Noc, along Rapid and Whitefish reivers, and on St. Marys river. Wells have penetrated it at Manistique, Pickford, on Manitoulin island, and in western Ontario. In the Southern Peninsula it has been penetrated only in the southeastern part and at depths of over 1500 feet. It is a widespread formation and probably once extended over the whole

System	Series Name	Formation Name	Columnar Section	Thickness	Character of Rock
QUATERNARY	Pleistocene	Recent Champlain Wisconsin and earlier drift sheets		110—0	Sand, gravel, boulder clay. Lake Superior pink clay. Till=boulder clay, sometimes very sandy, again clayey and dark. A gray and red till may in some places be distinguished, an older and a younger.
POSSIBLY LATER	Conemaugh	Woodville		110—0	Light reddish sandstone and sandy shales.
	Pennsylvanian (Upper Pottsville)	Saginaw		400	White sandstone, coal seams, black and white shales; then bands of limestone and of siderite rare, rarely broken up and found in fragments of the sandstone.
		Parma		170—0	White sandstone and conglomerates, of small white quartz pebbles; brine and sulphates.
CARBONIFEROUS	Mississippian	Bayport or Maxville Upper Grand Rapids Upper St. Louis		255—50	Limestones: light and bluish, cherty; also calcareous sandstones.
		Michigan Lower Gd. Rapids Lower St. Louis Osage or Augusta		300—0	Dark or bluish limestones and dolomites with gypsum and blue or black shales: rarely reddish or greenish shales and dark or red sandstones.
		Napoleon Upper Marshall		560—to	White sandstone: often pyritic, brine or fresh water, sulphates low.
		Lower Marshall		260	White and red sandstones: peanut conglomerates, sandy shales, whetstones, and blur shales, much carbonate of iron, and mica in the formation: generally a red shale at the top and bottom.
		Coldwater Buena Vista		1000—800	Blue shale: with nodules of carbonate of iron especially at the top; sandstone; very subordinate streaks of fine grained limestone, especially on the west side; black shales at the base.
		Sunbury or Berea			
		Berea			White sandstone; brine and salt even near the surface.
DEVONIAN	Neo-Devonian	Bedford Antrim (Senecan)		480—140+	Shale: mainly black and always at the base, with huge round balls of calcite; towards the top, blue and black shales.
	Meso-Devonian	Naples goniatite fauna Traverse Hamilton (Erian) Petosky limestone Acervularia beds		660 to	Bluish limestones, dolomites and shales: base a blue or black shale; top generally limestone and rarely reddish.
		Bell and		50	
		(Marcellus shale)		60	
		Dundee (Ulsterian)		255 to 65—	Limestone: buff and light brown, fiercely effervescent, somewhat cherty.
	Latest Ontarian possibly Eo-Devonian	MONROE: Upper Monroe or Detroit River {Lucas, Amherstburg, Anderdon, Flat Rock}		275 to 0 (a 200, b 20, c 50, d 47)	Dolomites; mainly; the Anderdon formation is limestone; gypsum or anhydrite also occurs, with celestite and sulphur.
		Middle Monroe, Sylvania		410 ? to 30	White sandstone: very pure, passing towards the north into calcareous sand & limestone.
UPPER SILURIAN OR ONTARIAN	Upper Ontarian	Lower Monroe or Bass Island {Raisin River, Put-in-Bay, Tymochtee, Greenfield}		200 ? 100 + 100— 100—	Dolomites: at some levels sandy, at others oölitic, often cherty. At the Tymochtee and other levels shaly; anhydrite abundant in the lower parts of the salt basin; Celestite.
	Middle Ontarian	SALINA ? (3, 2, 1)		960 to 0	Salt, anhydrite, dolomites, calcareous marls: red and green, more rarely blue and black, shales.
	Lower Ontarian (Niagaran or Manitoulin)	Guelph and Niagara		600 to 270	White dolomites: peculiar whiteness characteristic, often cherty, and with a little quartz sand which sometimes occurs in beds; pure limestone rare.
		Rochester Shale		85 to 0	Blue shale.
		Clinton		150 to 0	Reddish limestones and shales or iron ore.
		Medina and		100 to 0	Red shales; sometimes sandy or green shales.
LOWER SILURIAN OR ORDOVICIAN	Upper Ordovician (Cincinnatian) (Hudson River)	Richmond		150 to 0 ?	Shales; red and blue and sandy; gradual transition at base.
		Lorraine		343 t 215	Shales: blue, sometimes in streaks black, especially towards base.
		Utica		00 to 50	Black shales.
	Middle Ordovician	Gelena Trenton Platteville ?		271 to 100 ?	Limestone and dolomite; blue and shaly, or solid shale at base.
OZARKIAN ?	Lower Ordovician	St. Peter Calciferous		18 to 0	White friable sandstone: or represented by red clay, residual top of underlying formation.

FIGURE 3.—GEOLOGICAL COLUMN OF MICHIGAN FROM THE CALCIFEROUS TO THE PLEISTOCENE (BY A. C. LANE).

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of Wisconsin and Michigan, but later was eroded from the present pre-Cambrian areas.

In the Northern Peninsula, it appears to be about 250 feet thick, though across the bay from Escanaba near Stonington it is over 270 feet thick. In the Southern Peninsula, its thickness is unknown.

In the Northern Peninsula the Trenton has three phases, (1) an upper granular, crystalline, dolomitic limestone of alternating blue and brown layers terminating at the base in a dark or black bituminous limestone, (2) a middle portion of cherty layers or lenses alternating with thick beds of limestone and, (3) a basal member of blue shales and limestone, a part of the latter being black or dark. The sandy middle division and the lower blue shaly one appear to have a widespread distribution.

The Trenton limestone is an important oil bearing formation in Ohio. In the outcrops near Rapid and Whitefish rivers in the Northern Peninsula, oil impregnates the rock and asphaltum gum fills fissures and cavities. In Monroe county (Chapter IV) nearly all of the drill holes penetrating this horizon yield a little oil and gas. In Ontario, however, where it has been penetrated at many places, it is apparently barren

Utica Shale. (Eden of Ohio). The Utica shale is very black and bituminous and of fairly uniform thickness which, however, varies from 50 feet in the Northern Peninsula to nearly 200 feet in the southeastern part of the Southern Peninsula. It is easily recognized, but drillers who are not familiar with it are apt to confuse it with the equally black Antrim shales of the Devonian.

Lorraine or *Maysville.* The Utica and Lorraine shales are soft rock, and therefore easily eroded. They occupy low ground extending through Green Bay and Little Bay de Noc and along the north side of the prominent escarpment of the Niagara limestone from Garden Peninsula to Drummond island. The Lorraine shale is generally calcareous and full of fossils. Its color is mainly blue but black streaks occur in it, especially towards its base. The top of the formation is hard to distinguish from the Richmond and the Medina shales above, and its base from the Utica shale below. According to Lane, in the southern part of the state there are above the Trenton about 600 feet of shaly beds of which he ascribes 200 feet to the Utica, 250 feet to the Lorraine, and 150 feet to the Richmond and Medina. In the northern part of the state the Lorraine is more variable in thickness, but it is apparently a very persistent formation throughout the State.

SILURIAN.

Richmond and *Medina.* These formations represent the transition from the blue shale of the Lorraine below to the red dolomitic beds of the Clinton above. They are characterized by the prevalence of soft red shale, sandy in places and mixed here and there with green shale. The Richmond, Medina, and Lorraine cannot be sharply separated. The Richmond and Medina have not been recognized in outcrop anywhere in Michigan and apparently are only sparingly represented in the Northern Peninsula, but in southeastern Michigan and western Ontario, they are much more prominently represented. In Ontario the Medina is largely sandstone and an important oil and gas bearing formation with three productive horizons. In the Southern Peninsula, this formation is practically unexplored and little is known concerning its oil and gas possibilities.

Clinton. The Clinton formation is thin, poorly represented, and not readily separated from the Rochester shale above or the Medina below. In most places, where present at all, it is a clayey dolomite with more or less iron ore and red shale. Its thickness varies from nothing to 130 feet. The presence of water and gas is characteristic of the top of the formation.

Rochester Shale. A blue shale horizon which, though persistent, is never very thick (30 to 80 feet), occurs above the Clinton formation. In many places, it is absent. These blue shales have been correlated with the Rochester formation of New York but they may be a part of the Clinton.

The Niagara Limestone. (*Guelph* and *Lockport.*) In the Upper Peninsula, the Niagara limestone forms an almost continuous belt of outcrops from the southern part of Garden Peninsula along the Lake Michigan and Lake Huron shores to the eastern point of Drummond island. The formation is composed of an upper whiter part called the Guelph dolomite, and a lower less white and uniform one, the Lockport. This formation as a whole is remarkably free from impurities, especially iron and clayey material and is composed dominantly of carbonates of calcium and magnesium with the exception of thin lenses and nodules of chert and occasional sandy beds. Dolomite predominates, though there are heavy beds of very pure limestone in the lower part. According to Lane, the extreme whiteness of the upper part, its occasional grains of sand, and beds of sandstone and chert are characteristic thoughout the State. Its thickness varies from 270 to 350 feet in the southern part of the Southern Peninsula to about 600 feet in the Northern Peninsula. The Niagara is an important producer of oil and gas in Ontario. The formation yields strong flows of fresh water or weak brine at one or more horizons. The mineralized waters or weak brines of the Niagara are characteristically different from the strong sulphate brines of the Monroe formation above.

Salina. The Salina in southeastern Michigan is an extremely variable formation composed of alternating layers of compact brown to drab dolomite, anhydrite (partially converted into gypsum), and salt beds with minor amounts of red, green, and rarely blue and black shales, and dolomitic marls or oozes. It cannot always be separated from the overlying Monroe Formation, because the salt beds are absent in many areas and there is nothing to distinguish the dolomites of the Salina from those of the Monroe. In the absence of salt beds, the top of the first gypsum bed may be taken as the dividing line but as there is more or less gypsum in the Lower Monroe, and even in the Upper Monroe, this is an unsatisfactory basis of division. In the Northern Peninsula and in southwestern Michigan, the Monroe and Salina cannot be differentiated.

In southeastern Michigan and western Ontario, the thickness of the Salina ranges from 370 feet to more than 950 feet, but the average for the Detroit river district is 700 to 800 feet. Rock salt beds have a great development along the flanks of the Cincinnati anticline and, in Michigan, the aggregate thickness of the beds increases down the dip to the northwest, the total thickness being over 609 feet in the Royal Oak well in Oakland county.

South of a line from Muskegon through Kalamazoo to Trenton, no rock salt has been found. In the southwestern and western part of the State, the Salina is much thinner and cannot be separated from the Monroe beds above it. In the Manistee Ludington salt district, the salt beds have an aggregate thickness of only 20 to 40 feet. In Presque Isle and Alpena counties, the Salina apparently is developed to an equal or even greater thickness than in southeastern Michigan. The Salina is apparently over 1100 feet thick in the Onaway well where it includes over 800 feet of rock salt. The Grand Lake well penetrated 428 feet of the Salina, including nearly 325 feet of salt, but did not reach the bottom of the formation. Further drilling may show that the Manistee-Ludington, Alpena-Onaway, and the southeastern Michigan and western Ontario rock salt areas are only portions of a large area.

Signs of oil and gas have been observed in the lower dolomite of the Salina, but in southeastern Michigan this formation has been penetrated at so many places without striking any noteworthy amounts of either oil or gas (aside from hydrogen sulphide gas) that it does not appear to be a promising oil and gas bearing formation.

Monroe Formation. The Monroe formation is divided into three parts—Upper, Middle (Sylvania), and Lower, but these divisions can be clearly recognized only in southeastern Michigan.

Lower Monroe or *Bass Island Series.* The Lower Monroe, or Bass

Island Series, is exposed in eastern Monroe county. It varies from about 365 feet to 440 feet in thickness in southeastern Michigan. Oolite, sandy dolomite, dolomite with anhydrite, and acicular or gashed dolomite are characteristic of the formation in both the Northern and the Southern Peninsulas.

Sylvania. Middle Monroe. In southeastern Michigan the Sylvania sandstone is composed of very white sandstone, (5 to 300 feet thick) and of siliceous limestone or dolomite (30 to 165 feet). This formation is found only along the flanks of the Cincinnati anticline. It is thicker along a line from Milan, Monroe county, northeast to Royal Oak, Oakland county. To the west of this line and also toward the outcrop, where it is between 50 and 100 feet thick, the formation grows thinner. Toward the north, along St. Clair river it grades into sandy dolomite. The Sylvania sandstone is very easily recognized for it is pure white, generally incoherent or little cemented, and resembles granulated sugar. It yields "sulphur" water and much hydrogen sulphide gas.

Upper Monroe or *Detroit River Series.* The Upper Monroe (0—350 ft.) is composed mainly of dolomite interstratified with limestone of great purity, the Anderdon beds. One of the heavy beds of dolomite is bituminous and oily throughout, and oil occurs also in cavities and fissures in this formation. Little or no free oil has been found, however, in the many drill holes which have penetrated this formation along Detroit and St. Clair rivers.

DEVONIAN.

Dundee (Corniferous) limestone. The Dundee limestone underlies most of the Southern Peninsula, and, under other names, western Ontario, and the Ohio and the Mississippi valleys. Its exposures skirt the northern shore of the Lower Peninsula from the northwestern point of Emmet county to the eastern extremity of Presque Isle county, and extend from southeastern Wayne county southwest through Monroe and Lenawee county into Ohio. It has been penetrated in hundreds of drill holes in the Southern Peninsula and Ontario. It is the lowermost formation which has been penetrated in the central part of the Southern Peninsula, having been encountered at depths ranging from 2900 feet at Saginaw and 3270 feet at Bay City to 3667 feet at Mt. Pleasant.

In southeastern Michigan, the Dundee is only about 100 feet thick, but it gradually thickens west and northwest to a maximum of 250 feet throughout an area extending northeast from Barry, Eaton, and Jackson counties into Saginaw and Bay counties. In the southwestern part of the Southern Peninsula, and especially in the western part, it

becomes much thinner. At Allegan it is not over 125 feet thick, perhaps absent at Muskegon, and is only 100 feet thick at Ludington. In Presque Isle and northern Alpena counties, however, the thickness is over 200 feet thick.

In Michigan, the Dundee nearly everywhere is a true limestone, usually light gray to buff in color, very fossiliferous, and locally containing nodules and seams of chert. Some of the beds of limestone are remarkably pure, averaging over 98 per cent calcium carbonate. With dilute acid, the Dundee limestone always gives a vigorous effervescence in marked contrast to the Monroe dolomite below. The formation[2] in many places gives off a strong odor of oil and contains drops of thick black bituminous matter in small cavities. In Ontario, the formation yields oil in considerable quantity, but in Michigan, at Port Huron, Saginaw, and Allegan, it scarcely approaches commercial importance as an oil producer. From the fact that the Dundee usually shows abundant signs of oil and gas wherever penetrated, and that it is easily accessible nearly everywhere in the Southern Peninsula, it appears to be the most promising oil formation of the State.

The Dundee generally yields an abundance of sulphate water or strongly mineralized brines at some distance from the top. So much water was encountered in the top of the formation in the Braun well at Mt. Pleasant as to cause its abandonment.

Traverse (Hamilton and *Marcellus) Formation.* The Traverse formation outcrops along the south side of Little Traverse Bay and at various points across the northern end of the Southern Peninsula into Presque Isle and Alpena counties where it is extensively exposed or is under light drift cover. In southeastern Michigan, it is wholly concealed by drift. The formation is essentially a series of transition limestones, generally hard and fossiliferous, and calcareous shales or soapstones from the Dundee limestones below to the heavy shale of the Antrim above. Wells along Little Traverse Bay indicate that limestone greatly predominates over the shale in that portion of the Southern Peninsula. Some of the limestones are very high grade and are quarried on an extensive scale in Alpena, Charlevoix and Emmet counties. In the northern and eastern parts of the Southern Peninsula, the formation averages about 600 feet thick. In the southern and southeastern parts it is much thinner, being only about 300 feet at Port Huron, 168 feet at Milan, less than 100 feet at Adrian, 55 feet at Jackson and Charlotte, 70 feet at Kalamazoo, and 190 feet at Benton Harbor. A heavy blue or black shale, the Bell (or Marcellus) occurs nearly everywhere at the base and is thus of great stratigraphic importance.

[2]Sherzer: Geology of Wayne county, Pub. 12, Geol. Series 1, p. 201, Michigan Geological and Biological Survey.

In the recent drill holes (see Chapter VI) in the vicinity of Saginaw, an excellent oil was found in a sandy or cherty limestone at the top of the Traverse, but not in commercially important quantities. In one of the wells, three oil bearing horizons were encountered in the Traverse. The oils from the lower horizons were black, much heavier, and of inferior grade. Elsewhere in the State the Traverse has given little promise.

Antrim Shale. (Ohio, Huron, Chagrin, Cleveland, and Bedford of Ohio, Genesee, Portage, and Chemung? of New York). The Antrim black shale is one of the most easily recognized horizons in the Southern Peninsula. It varies from 140 to 480 or more feet in thickness and consists mainly of pyritic shales, nearly everywhere black and bituminous in the lower part and locally blue in the upper part. Spherical to ellipsoidal calcareous concretions from an inch to six feet in diameter are characteristic of the formation in certain localities. Where the Antrim passes into the Berea horizon, elsewhere represented by sandstone, it is generally red, gritty, or interstratified with thin sandstone lenses. In places this formation contains so much bituminous matter that it resembles coal and can be burned. Generally it smells strongly of petroleum and nearly always yields small quantities of gas when penetrated in drill holes. The oil and gas of the Upper Traverse and of the Berea sandstone were possibly largely derived from this bituminous shale. The Devonian formations, especially the Antrim and Dundee, can be traced across southeastern Michigan by a line of ''shale'' or surface gas wells and gas springs.

MISSISSIPPIAN.

Berea Sandstone. This formation was originally defined by Lane[3] as the Richmondville sandstone and was regarded as equivalent of the Berea grit of Ohio. Later he concluded that the ''Richmondville'' is not the exact equivalent of the Berea, ''but a stray sandstone higher up.'' The Berea in Michigan forms the base of the Coldwater, but it cannot always be recognized with certainty on account of the occurrence of sandstone in the lower portion of the Coldwater.

The Berea exists as a sandstone only on the eastern side of the Southern Peninsula, where it is generally white to gray in color and full of pure strong salt brine. In southeastern Michigan, it is a coarse gray sandstone, 100 feet or more in thickness, but, in Saginaw Valley, it is generally very fine grained. Farther north in Iosco and Alcona counties, the Berea is much thinner, and, towards the western side of the State, the formation disappears as a sandstone. At Alma, Mt.

[3]Sherzer: Geology of Wayne county, Pub. 12, Geol. Ser. 9, 1911, p. 191.

Pleasant, and Grayling, it is either represented by red shales, locally sandy, or it is absent.

At Blackmar, Saginaw county, Bay City, and Killmaster, Alcona county, this formation yields very considerable quantities of gas, and, previous to the recent explorations at Saginaw, it was supposed to be one of the most promising gas horizons in Saginaw Valley. Unfortunately, it proved to be so fine grained that it yielded relatively little brine, and only moderate amounts of gas. On the western side of the State, owing to the red shaly character of the rock of the Berea horizon, the possibilities seem to be less promising than on the eastern side.

Coldwater Shale. Part of Waverly, Sunbury or Berea shale together with Cuyahoga and Raccoon(?) and perhaps Black Hand of Ohio. The Coldwater shale is one of the thickest formations in the State. It underlies the surface deposits of a large portion of the Southern Peninsula, but, being a soft formation, has but few exposures. It is composed largely of blue shales with nodules of iron carbonate, especially near the top, and lenses of sandstone and sandy shale with subordinate streaks of limestone, particularly on the western side of the State. A thin, but very persistent black bituminous shale, called the Sunbury or Berea, lies at the base just over the Berea grit. At the top, the Coldwater grades upward into the red shale and sandstone of the Lower Marshall, from which it cannot be sharply separated. The Coldwater and the Lower Marshall are apparently from 1000 to 1200 feet or more in thickness. The shales are soft, nearly everywhere free from water, and afford the easiest of drilling. In some places brine bearing sandstone lenses occur at some distance above the Berea grit and cannot readily be distinguished from it, as in the Bay City, Grand Rapids, Caseville, Tawas City, and Richmondville wells.

Marshall Sandstone. Napoleon or *Upper Marshall* and *Lower Marshall.* (Raccoon, possibly, Black Hand and Logan of Ohio in part, Kinderhook of Illinois.) The Marshall sandstone forms an almost continuous belt around the central portion of the Southern Peninsula and outcrops at many points throughout an arcuate belt from Port Huron southwest into Jackson, Hillsdale, and Calhoun counties and thence northwestward into Ottawa county. It consists of an upper coarse white to gray pyritous and nonfossiliferous sandstone, called the Napoleon sandstone, and a lower white to gray or red micaceous sandstone grading downward into sandy red and blue shales. In Huron county the Lower Marshall is largely sandstone and contains minor amounts of ''peanut'' conglomerate, composed of rounded fragments of quartz, which resemble peanuts, and grindstones and whetstones. In the central part of the Michigan Basin, the sandstone of the Lower Marshall is replaced by a series of red and blue shales, usually sandy. The bottom, and especially the top, is generally marked by a red sandstone or sandy shale popularly called, "paint rock."

The Upper Marshall is nearly nonfossiliferous but the Lower Marshall has several extremely fossiliferous horizons. Strong brine occurs in abundance in the Upper Marshall away from the outcrop and is characterized by its content of bromine, especially toward the centre of the Basin. Near the margin, the Napoleon is an abundant source of fresh water. The thickness of the Marshall formation in Huron county is fully 560 feet, but elsewhere in the State it varies from 260 to 300 feet. Hundreds of drillings for oil, brine, or fresh water have penetrated the Marshall but no signs of either oil or gas have been encountered anywhere.

Michigan Series or *Lower Grand Rapids.* The Michigan Series is a variable formation both in thickness and character. It consists chiefly of dark or bluish limestone or dolomite with blue or black, and, rarely, reddish or greenish shales and dark or red sandstone. Well records indicate that gypsum or anhydrite, associated with dark dolomite and dark blue shale, occurs everywhere near the middle of the formation. In certain areas, gypsum beds are numerous, but most of them are thin, ranging from a fraction of an inch to a foot or more thick. Some of the thicker beds which are being quarried and mined in Kent and Iosco counties, however, are from 6 to 23 feet thick. The sandstones are thin and irregular, and dark limestones occur near the base of the formation.

Near the margin, excepting along the southeastern portion, the formation is apparently about 200 feet in thickness, but toward the center of the Basin it is much thicker, being 330 feet at Midland and 358 feet at Mt. Pleasant. Along the southeastern margin from Tuscola county into Jackson county the formation is absent in whole or in part. The water from the Michigan Series is salty and "bitter," being high in sulphates of calcium and magnesium. The high content of sulphates in these brines readily distinguishes them from those of the Marshall immediately below.

Bay Port Limestone or *Maxville. Upper Grand Rapids,* (Upper St. Louis, Middle Kaskaskia.) The Bay Port, or Maxville, limestone is very irregular in thickness and distribution owing to heavy erosion subsequent to its deposition. The unconformity between the overlying Coal Measures and the Maxville is very pronounced and distinctly marks the division between the Mississippian and Pennsylvanian. Present evidence afforded by drillings and rock exposures indicates that the Maxville exists only

in fragments over much of the Basin. On the southeastern margin from Tuscola into Livingston county, it seems either to have been completely removed by erosion or was never deposited. From Jackson to Grand Rapids, remnants of the Maxville occur and this evidence points to the probability that erosion rather than non-deposition explains the apparent absence of the formation along the southeastern margin. Generally, the formation is not over 50 to 75 feet in thickness, but at Mt. Pleasant it appears to be 235 feet thick. Hard light bluish limestone with chert and white sandstone lenses are characteristic.

PENNSYLVANIAN.

Parma Sandstone or *Conglomerate.* (Pottsville). The Parma is a white sandstone containing local conglomerates with small white quartz pebbles like split peas. It is the basal member of the Pennsylvanian and a very persistent and easily recognized horizon varying from 0 to 170 feet in thickness. It yields an abundance of fresh water around the margin and sulphate brines near the center of the Basin.

Saginaw Formation (Upper Pottsville). The Saginaw formation is the uppermost and youngest of the Paleozoic sediments and underlies the drift in the whole central portion of the Southern Peninsula. Unlike the lower formations, it does not partake of the basin-like structure; its strata, aside from local undulations and small folds, are practically horizontal. The Saginaw formation averages about 400 feet in thickness, and is composed of white shales or so-called fire clays, sandstones, black shales, and coal seams. There are also subordinate amounts of blue shales, thin seams of black band ore (siderite) and, rarely, beds of thin limestone. In general, the strata vary markedly in character and thickness within relatively short distances. Apparently, however, there is a curious persistence of local facies; that is, in one locality the strata may be predominantly sandstone, while in another shales predominate. The same is true of the coal seams, some regions having several seams, generally thin, and other regions none.

Near Fowlerville, a little oil was struck in a sandy shale in the top of the formation. Many drill holes have penetrated this formation and the underlying ones down to the Upper Marshall or Napoleon without striking any noteworthy s gns of oil or gas.

POSSIBLY PERMO-CARBONIFEROUS.

Woodville. (Conemaugh?). Near Jackson, at Woodville, there is a sandstone 79 feet thick, which Winchell separated from the Coal

Measures and called Woodville. Wells at Maple Rapids, St. Johns, Ionia and Gladwin indicate the presence of a reddish sandstone which may be the same as the buff colored Woodville. Being at the top of the Coal Measures, the sandstone apparently has been largely removed by erosion.

PLEISTOCENE.

Nearly the whole state is covered with drift or glacial deposits of sand, gravel and clay varying from a thin veneer to 1000 feet or more in thickness. In most of the eastern half of the Northern Peninsula and in the southern half of the Southern Peninsula the drift is generally less than 200 feet thick, and does not commonly exceed 300 feet, but throughout a broad belt extending from Mason, Oceana, and Newaygo counties northeastward into Otsego, Montmorency, and Alcona counties, the depth to rock varies from 300 to 1000 feet or over and the average depth is probably nearly if not fully 600 feet. From the head of Saginaw Bay southwest to Alma, and thence northwest through Mason and Manistee counties to Lake Michigan, there is an old preglacial rock valley in which the drift is also very deep, especially toward the west, being 400 to 500 feet in Isabella county and 500 to over 700 feet in Manistee county. In Presque Isle and Alpena counties, in eastern Monroe county, and in Hillsdale, Calhoun and Jackson counties the drift is absent, or thin, over areas of considerable extent. In the eastern half of the Northern Peninsula a broad belt along the shores of Lake Michigan and Lake Huron from Little Bay de Noc eastward to Drummond Island, and another north from Little Bay de Noc to Lake Superior are thinly drift covered. Locally, near the lake shore in the Southern Peninsula and around the margin of the Coal Basin, rock is exposed, or but thinly covered with drift.

Nearly everywhere the drift contains thick beds of sand and gravel full of water. Where such beds have a suitable cover of clay and overlie the Devonian formations, especially the Antrim or Dundee, they yield small to considerable quantities of gas. From St. Clair county southwest to Ohio, this surface or ''shale'' gas has been utilized by the farmers for domestic purposes. In the northern part of the Southern Peninsula, where the drift is locally very thick over the Antrim shale, considerable bodies of gas are liable to be encountered in gravel beds. At a depth of about 425 feet, a strong flow of gas with a pressure of about 190 pounds was struck in the drift at Onekama, (Chap. VIII), Manistee county.

CHAPTER II.

GEOLOGICAL FACTORS CONTROLLING THE OCCURRENCE OF OIL AND GAS.

THE ANTICLINAL THEORY.

Very soon after the development of the great oil fields of the country, it was independently observed by different investigators, and by some of the practical oil and gas operators, that the great oil and gas wells in Pennsylvania, Ohio, and West Virginia, were aligned along the crests of anticlines. T. Sterry Hunt[1] was one of the first to recognize the influence of anticlinal folds, in the accumulation of oil in Ontario, and asserted that such structures are absolutely necessary for large accumulations. E. B. Andrews[2] independently reached a similar conclusion in studying the oil and gas wells of the White Oak anticline in the vicinity of Burning Springs, West Virginia, and explained the separation of gas, oil, and water as due to gravity. In a series of articles in 1881, F. W. Minshall of Ohio advocated views similar to those of Andrews concerning the West Virginia ''Oil Break.'' H. Hoefer of Austria, without knowledge of Hunt's and Andrews' publications, recognized that ''rock disturbance'' is a fundamental factor in the accumulation of oil and gas in Pennsylvania and, in 1876, published the elements of the anticlinal theory in a book ''The Petroleum Industry of the United States.''

While the influence of the anticlinal structure was early recognized, no attempt was made to use it in a practical way until 1883, when I. C. White of West Virginia in connection with Wm. A. Earseman, a practical oil operator, made an exhaustive study of the gas fields in the Appalachian district and reached the conclusion that ''rock disturbance caused by anticlinal waves'' is the important factor in the occurrence of both oil and gas. Working upon this hypothesis, the Grapeville, Washington, and other great gas pools were located in the next two years. In 1885, the theory was published by Dr. White[3] in Science, and the essentials of the theory, as first stated by him in connection with the accumulation of gas, is best given in the following paragraphs from this article.

[1]Canadian Naturalist, 1859. Amer. Jour. Sci., Mar. 1863.
[2]Amer. Jour. Sci., May 1861.
[3]Science, June and July, 1885. The Geology of Natural Gas. See also reprint, Geological Survey, West Virginia, Vol. 1, 1899, pages 160-175.

"The first explorers assumed that gas could be obtained at one point as well as at another, provided the earth be penetrated to a depth sufficiently great; and it has required the expenditure of several hundred thousand dollars in useless drilling to convince capitalists of this fallacy, which even yet obtains general credence among those not interested in successful gas companies.

"The writer's study of this subject began in June, 1883, when he was employed by Pittsburg parties to make a general investigation of the natural gas question with the special object of determining whether or not it was possible to predict the presence or absence of gas from geological structure. In the prosecution of this work, I was aided by a suggestion from Mr. William A. Earseman, of Allegheny, Pennsylvania, an oil operator of many years experience, who had noticed that the principal gas wells then known in western Pennsylvania were situated close to where anticlinal axes were drawn on the geological maps. From this, he inferred there must be some connection between the gas wells and the anticlines. After visiting all the great gas wells that had been struck in western Pennsylvania and West Virginia, and carefully examining the geological surroundings of each, I found that every one of them was situated either directly on or near the crown of an anticlinal axis, while wells that had been bored in the synclines on either side furnished little or no gas, but in many cases large quantities of salt water. Further observation showed that the gas wells were confined to a narrow belt, only one-fourth to one mile wide, along the crests of the anticlinal folds. These facts seem to connect gas territory unmistakably with the disturbance in the rocks caused by their upheaval into arches, but the crucial test was yet to be made in the actual location of good gas territory on this theory. During the last two years I have submitted it to all manner of tests, both in locating and condemning gas territory, and the general result has been to confirm the anticlinal theory beyond a reasonable doubt.

"But while we can state with confidence that all great gas wells are found on the anticlinal axis, the converse of this is not true, viz., that great gas wells may be found on all anticlinals. In a theory of this kind, the limitations become quite as important as, or even more so than the theory itself; and hence I have given considerable thought to this side of the question, having formulated them into three or four general rules (which include practically all the limitations known to me, up to the present time, that should be placed on the statement that large gas wells may be obtained on anticlinal folds), viz.:

(a) "The arch in the rocks must be one of considerable magnitude.

(b) "A coarse or porous sandstone of considerable thickness, or, if a fine grained rock, one that would have extensive fissures, and thus in either case rendered capable of acting as a reservoir for gas, must underlie the surface at a depth of several hundred feet (500 to 2,500).

(c) "Probably very few or none of the grand arches along the mountain ranges will be found holding gas in large quantity, since in such cases the disturbance of the stratification has been so profound that all the natural gas generated in the past would long ago ago have escaped into the air through fissures that traverse all the beds.

(d) "Another limitation might possibly be added, which would confine the areas where great gas flows may be obtained to those underlain by a considerable thickness of bituminous shale.

(e) "Very fair gas wells may also be obtained for a considerable distance down the slopes from the crests of the anticlinals provided the dip be sufficiently rapid, and especially if it be irregular or interrupted with slight crumples. And even in regions where there are no well marked anticlinals, if the dip be somewhat rapid and irregular, rather large gas wells may occasionally be found, if all other conditions are favorable.

"The reason why natural gas should collect under the arches of the rocks is sufficiently plain from a consideration of its volatile nature. Then, too, the extensive fissuring of the rock, which appears necessary to form a capacious reservoir for a large gas well, would take place most readily along the anticlinals where the tension in bending would be greatest."

The theory was from the first enthusiastically accepted by many as a complete explanation of both oil and gas accumulations, but was violently attacked and opposed by others. There was such a general attempt on the part of the champions of the theory to explain all accumulations on the anticlinal basis without due regard to White's "limitations" and to other limiting factors not then known or fully recognized that the theory suffered more or less unjust criticism. C. Ashburner, geologist in charge of the Second Pennsylvania Survey, who was a strong opponent of the theory held that the relation between gas wells and anticlinals was merely one of coincidence, and also that large gas wells could be found in synclines. Dr. White's answer to these criticisms is given in the following extract from an article published in Science July 17, 1885.

"In reply to Mr. Ashburner's criticism of the views advanced in my article on natural gas, I would say that the necessary brevity of the paper in question prevented the mention of many facts that might have rendered the conclusions clearer and less open to challenge. One of these is that my communication had especial reference to the natural gas regions proper, i. e., where the gas is unconnected with the oil fields. Most geologists know that natural gas in large quantities exists with and contiguous to every oil pool, apparently as a by-product in the generation of the oil, and of course the rocks are filled with it wherever it can find a reservoir. To gas wells from such sources Mr. Ashburner's criticism may sometimes be found applicable; but, even with these, by far the larger ones will be found on the arches of the rocks.

"The cases that Mr. Ashburner mentions, where large gas wells have been found at the centers of synclines, do not necessarily contradict my conclusions; for no one knows better than he that a subordinate crumple or anticlinal roll often runs along the central line of a syncline.

"My excuse for writing the article on natural gas was that I might be of some service in preventing the waste of capital that has been going on within a radius of fifty miles of Pittsburg by an indiscriminate search for natural gas; and it is a sufficient answer to Mr. Ashburner's criticism to point him to the brilliant lights along the crests of the Waynesburg, Pinhook, Washington, Bull Creek, Bradys Bend, Hickory, Wellsburg, Raccoon, and other anticlinals, and also the darkness that envelops the intervening synclines, in which hundreds of thousands of dollars have been invested without developing a single profitable gas well. The same results has been proven in other portions of the country. The Great Kanawha Valley above Charleston has been honeycombed with borings for salt, and the only gas wells developed were found within a belt a few rods wide, which coincides with the crest of the Brownstown anticlinal, where immense flows were struck. In this connection, I should say that Col Allen, of Charlestown, says he can trace the Brownstown anticlinal by the escaping gas across streams and even mountains, from the Kanawha river to the Big Sandy, where, on its crest, near Warfield, two of the largest gas wells ever known have recently been struck. At Burning Springs, on the Little Kanawha, the only large gas wells were found on the very crest of the great uplift in that region. The gas belt of western Ohio, through Findlay and other towns, follows closely the line of the Cincinnati arch, and the same story is repeated in other localities too numerous to mention.

"Mr. Ashburner can, if he chooses, interpret these facts as mere coincidences, and explain them to himself as having no more bearing on the question of finding gas than "Angell's belt theory" of oil; but the practical gas operator can no longer be deluded by such logic into risking his money in water holes (synclines) where so many thousands have been hopelessly squandered.

"With regard to the anticlinal theory not being a practical basis for successful operations, I deem it a sufficient reply to state that all the successful gas companies of Western Pennsylvania and West Virginia are getting their gas from the crests of anticlinal axes, while those that have confined their operations to synclines have met with uniform financial disaster.

"The statement was distinctly made in my original communication that gas would not be found on all anticlinals, nor at all localities along one that actually produces gas, since other factors have to be considered, as there stated; but, with the facts before us, it would certainly prove a great saving of capital in the search for gas if operations were confined to the crests of anticlinals, and I fail to perceive how Mr. Ashburner's fears for the 'misleading' character of my article can be realized."

In the March number of the Petroleum Age in 1886, Dr. White, in reply to further criticism by Mr. Ashburner, published another paper on the occurrence of gas particularly in western Pennsylvania. In this paper he recognized the importance of the "crowns," "hogsbacks," or domes formed through the intersection of the main anticlines by minor ones, in causing local concentration of the oil and gas at these points. These localizations at the cross arches explain why the course of some anticlines are marked by a *line* of *groups* of productive wells with barren or "lean" territory in the sags or "saddles" between the "crowns" or domes.

"An inspection of the accompanying map will reveal the fact that the main northeast and southwest anticlinals are cut by another set at nearly right angles, which have been termed crosscut anticlinals.

"The principal anticlinal axis of Illinois puts out in Ogle county, in the northern part of the state, and extends in a direction S. 20° E. . . . Along this axis natural gas can be traced in springs and well borings for a distance of 160 miles. *It is however, more prevalent on the crowns of the cross axes.*

"This same story is repeated in Ohio according to the testimony of the eminent state geologist, Professor Orton.

"These cross-cut arches result in carrying the anticlinal structure and a line of disturbance in the rocks directly across the trend of a syncline, and failure to grasp this fact is the principal reason why Mr. Ashburner insists upon his readers believing that a great gas well may be obtained in a syncline; for it is quite certain that no large gas well has ever yet been found in the trend of a syncline, except where the trough itself has been elevated by a long rise which is of course brought about by the crosscut folds.

"These are the geological surroundings of all those wells which Mr. Ashburner cites from northern Pennsylvania and southern New York as occurring in synclines. It is not necessary to show a reversed dip........ in order to demonstrate the existence of one of those crosscut waves, since their crests are often marked by a simple flattening of the rate of dip along the latter. Professor Orton would call such a structure (where there is no reversal of dip, but only a change in rate) a suppressed anticlinal, a very good name, for such it really is.

"It follows, of course, that a synclinal structure may be converted into an anticlinal one by the presence of the crosscut wave, so the reverse may and frequently does happen."

As noted in the foregoing paragraphs, the theory was stated with special reference to the accumulations of gas and the "limitations" given by White were not intended to cover occurrences of oil, or of gas in association with oil.

E. Orton[4] grasped the truth of the principles of the anticlinal theory and used them to explain the accumulations of oil and gas in Ohio where pronounced anticlinals are few, or wanting in many areas. He held that structure is a vital element in the accumulation of either oil or gas and recognized clearly that the principles of the anticlinal theory applied to *any structure* having an anticlinal effect, provided that due regard be given to the "limitations" of the theory, i. e., to the other geologic factors such as water, porosity, size of the pores, and source of hydrocarbons. In brief, he asserted that in a wide area where the rocks are nearly horizontal no marked accumulation can take place until the rocks are tilted considerably so that the small disseminated particles of oil, gas, and water found in nearly all sedimentary rocks can rearrange themselves in the rocks in the order of their specific gravities, assuming the presence of water, a suitable reservoir and an impervious cover to retain the petroliferous products. The gas being lightest is found at the top, the oil next below and the water lowest, filling the rest of the rock reservoir. The ideal conditions for an anticlinal structure are illustrated by figure 4.

The principles of the theory have been widely accepted and applied in the practical development of oil and gas fields in general. Unfortunately at first, the importance of the "limitations" were often ignored, but costly experience has demonstrated the truth of White's statement that they are of as much or even greater importance than the theory itself. Under the anticlinal theory as later developed by

[4]Ohio Geol. Survey, Vol. VI, pp. 89-96.

White, Orton and others, oil and gas may be expected to occur most abundantly on or near the crests of anticlines or *other rock structures*, anticlinal in effect, provided: (1) that a suitable reservoir is present, (2) that the rocks are saturated with water, and (3) that there is an impervious cover over the reservoirs. Orton asserted that the three limiting conditions are more often met together than structure alone, but that they can not produce an accumulation without the aid of a proper structure. Evidently, a large accumulation can not occur without the presence of a stratum not only with a large amount of pore space but also with pores of sufficient size to permit the ready passage of oil and gas in response to gravity or hydrostatic force, nor is oil likely to occur near the crests of anticlines or structures of like

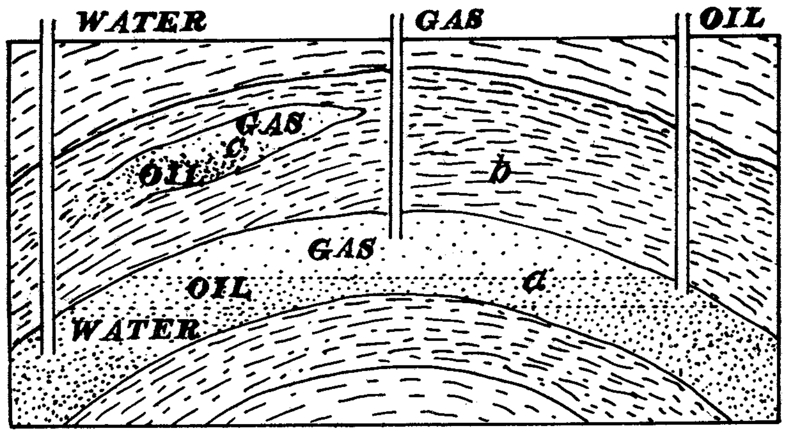

Figure 4. Ideal relations of oil, gas, and water in reservoirs. (a). Sandstone bed interstratified with impervious beds. (c). Sandstone lens wholly sealed in by shales b and not in communication with water.

effect without the rocks are saturated with water which tends to float the oil upward to the highest possible points.

In Pennsylvania and West Virginia, the regional folding has produced a series of pronounced anticlinal and synclinal folds with minor folds, superimposed on the larger ones, all extending in a general northeast southwest direction. As noted on previous pages, the location of all the great gas wells in the latter state, on or near the crests of the pronounced anticlines, was the significant fact which gave rise to the anticlinal theory as stated by White. Since the axes of anticlines do not usually lie in a horizontal position but undulate more or less, resulting in an alternating series of rises or domes and sags, the greatest accumulations generally occur near the crests of the domes while little or no oil and gas is found in the sags, as noted by Orton and White. In many cases, however, considerable bodies of oil and gas are found on the slopes of anticlines, trapped beneath smaller superimposed folds.

Formerly, the opponents of the anticlinal theory made a most convincing argument by pointing to the fact that, in some of the Pennsylvania fields, oil and gas are found anywhere from the bottom of the synclines to the top of the anticlines. Apparently, this proved that there is no relation between the occurrence of the oil and gas and the geologic structure. As previously stated, there are several producing oil sands (Fig. 5) in Pennsylvania, the upper ones of which are saturated and the lower ones dry or only partially saturated. It

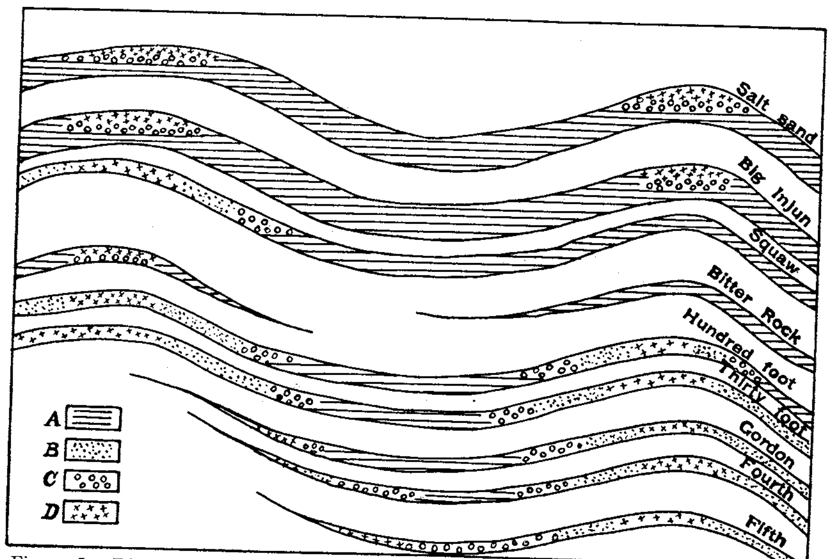

Figure 5. Diagrammatic section of the oil and gas sands in the central Appalachian oil region. (After W. T. Griswold and M. J. Munn).
Adapted from Part I, Bull. 318, U. S. Geological Survey.
A. Oil sand saturated with water.
B. Dry oil sand.
C. Oil accumulation.
D. Gas accumulation.

is this combination of saturated, partially saturated, and dry sands, which at first seemed to prove the theory false and at variance with the facts concerning the occurrence of oil and gas. A study of each sand separately showed that oil and gas in the sands saturated with water are generally found along the crests of anticlines especially in the vicinity of domes and therefore in direct relation to structural conditions. In dry or partially saturated sands, the oil is more apt to be near the bottom of the synclines or part way up the limbs.

Further observations have shown that there are many other structures which serve the same purpose as normal anticlines. In Ohio, the Cincinnati anticlines extends through the state from north to south

but it is so broad and flat that it partakes little of the nature of ordinary anticlines. On the eastern flank of this structure, however, there are a few minor anticlines related in part to the "anticlinal waves" of western Pennsylvania and West Virginia, but, in general, the disturbing force in eastern Ohio produced only marked irregularities in the normal dip. Orton noticed that in many oil and gas fields of Ohio, where anticlines are absent, that the general dip becomes flatter, or even horizontal over a considerable area before the normal dip is again resumed. This gives rise to a structural "bench" or terrace or the *arrested* anticline of Orton. In such cases, the upward migration of the oil and gas is arrested or retarded by the flatter dip, and accumulation occurs beneath the terrace and on the lower slope.

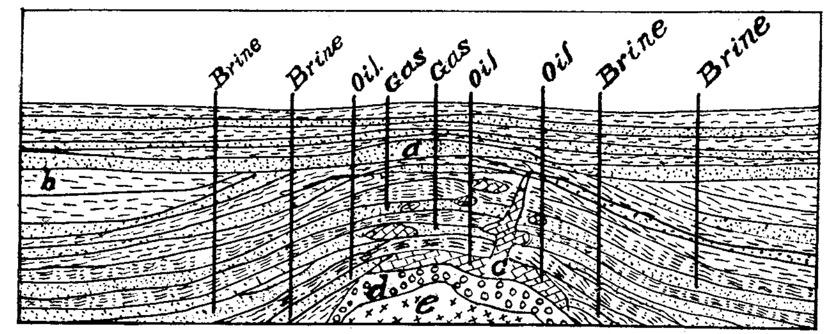

Figure 6. Cross section of the saline dome of the Spindle Top oil field, Texas. (After Jaeger).
(a). Unconsolidated sands and gravels. Great gas reservoirs just above the limestone.
(b). Clays, often of the "gumbo" character.
(c) Cavernous limestone, the chief oil reservoir.
(d). Gypsum.
(e). Rock salt.

This appears to be the case at Allegan where the dip of the strata suddenly changes. (See Fig. 13).

In Texas and Louisiana, the rock strata are locally arched up into domes or quaquaversal anticlines, which appear to be due to dynamic force resulting from the deposition of rock salt and gypsum from ascending waters. These substances always form the inner core of the domes. (See Fig. 6). The greater part of the oil and gas found in such structures occurs in the porous limestone, which forms the capping over the salt, or in porous strata immediately above the limestone. Spindletop is one of the most noted of these oil and gas structures.

While stringers of salt ramify the dolomites for a short distance above the salt beds in Michigan, there is no evidence that the strata have been arched up into domes as in Texas and Louisiana.

In California, Oklahoma and Pennsylvania and other states many

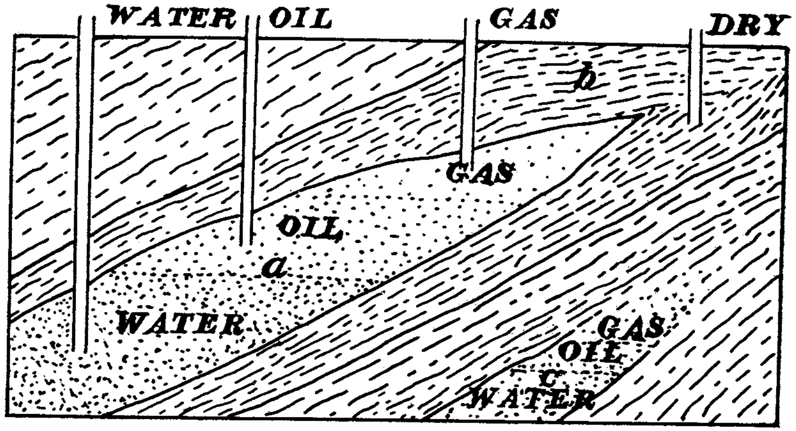

Figure 7. Forms of oil and gas reservoirs.
(a). Inclined lens of sandstone sealed in by shales (b) but somewhere in communication with water under hydrostatic pressure.
(c). Inclined bed of sandstone grading into shales and sealed in by them, but somewhere in connection with water as in (a).

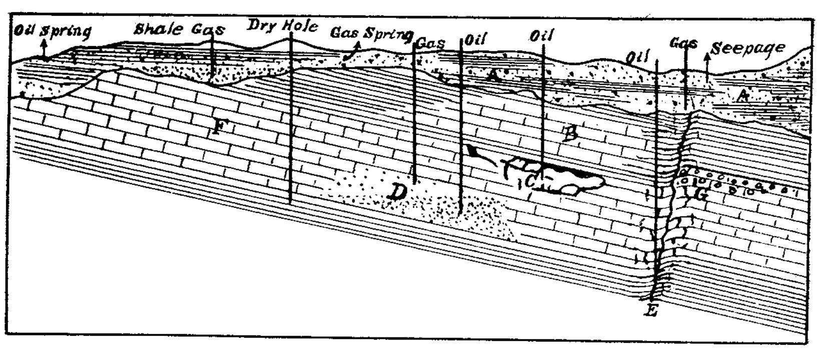

Figure 8. Sketch showing forms of oil reservoirs.
A. Surface sands and clays.
B. Limestone lens in shale.
C. Fissured or cavernous limestone.
D. Sandstone lens in limestone.
E. Fault with fractured or brecciated zone in the limestone, but more or less sealed in the shale.
F. Oil bearing limestone formation.
G. Porous area containing oil and gas not in communication with water.

accumulations of oil and gas occur on unbroken slopes, apparently not related to structure but drillings have shown that generally the accumulations in such cases are contained in porous strata grading up the dip into impervious rock. (Fig. 7). In many instances, the oil reservoir is a porous sandstone lens (c of Fig. 4) hermetically sealed in by impervious shale, in other cases a porous limestone (Fig. 8) surrounded by less porous rock. In the same regions, however, many

of the accumulations and, generally the more important ones, are determined by the anticlines and terraces.

A less common structure is that produced by an unconformity, especially an angular unconformity. In the Coalinga[6] district of California, the oil migrates up the highly inclined strata of the petroliferous Tejon shales into the flat unconformable Vaquereros sandstone above and collects in certain favorable places forming the chief oil accumulations of the district. Similar conditions are illustrated in (Fig. 19), which shows the edge of the inclined Berea sandstone in Alcona county unconformably overlain by the Pleistocene deposits. As shale gas is abundant in the drift along the strike of the oil and gas formations in Michigan, it is proof beyond reasonable doubt that the gas has escaped from the underlying rocks into the overlying sand and gravel beds, as at Killmaster (See Chapter IX), Alcona county.

In eastern Mexico, the accumulations are in the upturned edges of porous strata adjacent to old volcanic necks. This form of occurrence is one of the strongest arguments advanced by the exponents of the inorganic theory of the origin of oil. The oil, however, instead of originating from volcanic emanations from the interior of the earth much more plausibly has been distilled by volcanic heat from the bituminous matter in the intruded sedimentary strata.

In many oil fields, particularly those of the western states, there are numerous faults involving weak or soft strata such as clays and shales. Fractures and faults in such formations are readily healed, preventing the escape of oil and gas from the porous reservoirs below and these products may collect next the ends of the impervious strata, as illustrated in Figure 8. In some oil and gas fields, as in the Niagara limestone of western Ontario, fissured and fractured zones in dense non-porous limestones form the chief oil reservoirs. (Fig. 8). Since the Niagara yields oil only a few miles east of Detroit river, and as the strata are locally disturbed along the river, it is possible that similar fractured zones may exist in the Niagara in southeastern Michigan and prove oil bearing.

From a study of the occurrence of oil and gas in the various fields of the United States, Canada, and Mexico, the following generalizations may be made concerning the application of the anticlinal theory.

1. With a completely saturated oil stratum, the accumulations show a definite relation to the geologic structure.

2. In general, the greatest elongations of the pools are in a direction more or less parallel to and coincident with the axes of the anticlines.

3. With gas, oil, and water present together in the same stratum,

[6] U. S. Geol. Survey, Bulletin 398. Pl. V. B.

they are arranged in the order of their specific gravities, the gas at the top or absorbed in the oil, and the oil next below, but resting on the water which fills the remainder of the reservoir.

4. When water is absent, the oil is apt to occur near the bottom of the synclines but it may be part way up the anticlinal slopes, caught in superimposed synclines or in porous areas.

5. Oil and gas also occur in sealed reservoirs which may be located near the crests of anticlines, on the slopes, or in synclines. Water may or may not be present.

6. Oil and gas may occur on a "structural bench," i. e., where the dip of the strata changes from gentle to steep.

7. Oil and gas occur in other structures, which are not anticlines, but which serve in the same capacity, and the principles of the anticlinal theory (subject to its limitations) apply as in the case of normal anticlines.

8. Gas occurs mainly near the crests of anticlinal folds, but it occurs in greater volume beneath certain upward rises along the crests, called "domes."

9. Due to local changes in dip and porosity, gas occurs also in volume at many other points.

10. Oil in rocks saturated with water is found in the coarse grained porous areas but appears to be wholly excluded from many porous but fine grained areas in the same oil stratum, and this seems to be due in some way to capillary force and viscosity, the effects of which are not well understood.

ROCK PRESSURE IN GAS AND OIL WELLS.

The pressure developed within the casing of a gas or oil well, when the casing valve is closed, is called the "rock" or closed pressure. This pressure, which in general increases with the depth of oil or gas sand, varies from a few pounds up to 1500 or more, but the rock pressure in most of the great gas fields ranges from 300 to 800 pounds. Rock pressure, as observed, is always greatest when a field is first opened.

The open pressure of a well is the pressure exerted by the column of gas escaping with unobstructed flow from the casing. The greater the volume of gas discharged in a given time the greater the open pressure. This pressure which is rarely more than a few pounds is measured by some form of a gauge held in the current of escaping gas, but the open pressure of wells of less capacity than 1,000,000 cubic feet per day cannot be measured by the ordinary high pressure gauges. Resort must be made to the water or mercury column, or the anemometer.

The amount of closed pressure developed by a well is no indication

of its size and value. A small well may develop as great a closed pressure as a large one. A rough estimate of the size of a well, however, can be made by noting the time necessary for it to develop the maximum rock pressure after being closed. In a large well, the full pressure is attained almost instantly, in a few seconds, or in a minute at the longest. Wells of small volume on the contrary require several hours or even days to develop the maximum pressure obtaining in the pool. The time necessary for a well to develop its maximum rock pressure bears such a close relation to its size that generally the volume or value of a gas well is roughly estimated by comparing the amount of pressure developed per minute ("minute pressure") after being closed and the total rock pressure developed. Very accurate determinations are obtained by the use of the improved Pitot tube, which gives the capacity of a gas well in cubic feet.

The reason for the great difference in the volume of gas wells in the same pool lies in the fact that the porosity of the reservoir varies markedly from place to place. In the fine grained portions, the gas and oil escapes into the wells slowly, hence the flows are small. Large wells always indicate very open and porous reservoirs, from which the gas and oil can escape most freely. In general it may be stated that the greater the porosity and the rock pressure in an oil and gas reservoir, the greater is the size of the wells.

Cause of Rock Pressure. The cause of rock pressure in gas and oil wells has been the subject of much speculation and argument, and the controversy is still unsettled. Four theories have been advanced in explanation of rock pressure.

1. Hydrostatic pressure from water.
2. Pressure due to the expansive nature of the gas itself.
3. Pressure as the result of the weight of the overlying rocks.
4. Pressure from gaseous emanations from deep seated rocks.

In most fields, the oil and gas bodies are surrounded by salt water which, when penetrated by the drill, rises in the well to a certain height or even to the surface and above, in response to the pressure of the head of water contained in the rocks. This is the explanation of the artesian well, and E. Orton and I. C. White, and many other early investigators, once held that rock pressure in gas and oil wells similarly is due to direct water pressure acting under artesian conditions. Orton observed that in Ohio the pressure in most of the gas wells from the Trenton limestone was approximately the same as the calculated weight of a column of water of unit cross section reaching from the gas sand to the assumed level of the outcrop of this formation. In the case of oil wells, according to the artesian theory, whenever the elevation of the outcrop of the oil formation is sufficiently high above the mouth of a well to overcome the loss of head through capillary friction, the pressure from the hydrostatic head will force the oil or water, as the case may be, up to or above the surface and the calculated weight of this column should represent the rock pressure. Rock pressure in general increases with depth in about the same proportion as the weight of a column of water extending from the surface to the same depth, but while this is strong evidence that water is generally an important factor in causing rock pressure, it does not follow that it is always a factor, and much less an important one.

The artesian theory assumes a porosity of the oil or gas stratum from well to outcrop, but this assumption in many instances is not warranted by the facts. Many oil sands vary greatly in porosity within short distances. In Oklahoma, California, and other western states some of the oil reservoirs are mere lenses devoid of water and sealed in by impervious strata. The so-called "Saginaw oil sand" (Chap. V) at the top of the Traverse at Saginaw appears to be a thin porous sandy or cherty limestone non-water bearing, of very limited extent, and sealed in by calcareous or bluish shale. Porous lenses appear to be characteristic of this formation, as it yields water only locally, at different levels and with small head in many cases. The deep Gordon and other sands beneath, in Pennsylvania and West Virginia, contain little or no water. Evidently under the conditions cited above water cannot be an important factor in causing rock pressure. Orton in his investigations of the New York gas fields found pressures of 1500 pounds, or much greater than could be accounted for under the artesian theory. In other fields also, rock pressures have been struck at depths much too shallow to be due to any hydrostatic head possible under the conditions. Thus the artesian theory breaks down as an explanation for all cases of oil and gas pressures.

It has been urged also that if artesian water is the cause of rock pressure, this pressure in a given field should remain practically constant instead of showing a more or less gradual decrease. This argument is not conclusive for, admitting that water is the primary factor in causing rock pressure in a gas pool, the pressure always tends to decrease inversely as the number and size of the wells opened. Owing to greater friction, the passage of water through the pores of a rock is much slower than that of gas, hence the invasion of the gas reservoir by water (or oil) may lag behind the escape of the gas, with a consequent fall in the rock pressure. This is especially pronounced in the case of close grained sands tapped by many wells. In open coarse grained rocks offering little resistence to the passage of water, the fall is much less rapid. To determine the maximum rock pressure in a field where artesian conditions prevail, all of the wells must be closed for a period sufficient for the water to invade the gas reservoir and restore the full pressure of the hydrostatic head. The rock pressure in the oil and gas sands of some of the Pennsylvania fields has decreased to zero and in certain pools continuous pumping has tended to develop a vacuum[7] in the sands.

The "expansion hypothesis" advocated by Prof. Lesley many years ago ascribes rock pressure to the expansive nature of the gas itself. Solid and liquid bituminous material in the reservoirs or in the associated rocks are supposed to give rise to gases which occupy many times more space than the liquid or solid sources. The gas tends to expand to fill this space and thus exerts pressure. This theory is apparently the true explanation for the rock pressure observed in sealed reservoirs and sands devoid of water and accounts satisfactorily for the variable pressures found in shale gas pockets.

In sands containing water under artesian conditions, the expansive force of the gas equals that exerted by water. Any increase in pressure by the former will tend to force back the water until equilibrium is again established through the increase in the capacity of the gas reservoir. In close grained sands, however, resistance to the passage of water is very great, hence the expansive pressure of the gas may become much greater than that from any possible hydrostatic head. This may explain the occurrence of exceptional pressures at depths too shallow to be accounted for under the artesian theory. I. C. White also suggests, as a possible explanation for the apparent agreement of rock pressures with the artesian pressure theory, that the long continued escape of small quantities of gas upward to the surface along fissures and joints has reduced the original pressure of expansion within the rock reservoir to that found on opening any new gas field, and in the case of small fissures and joints filled with water, the escape of gas would be arrested as soon as the resistance to the passage of the gas equals the pressure exerted by the head of water.

The third theory ascribes rock pressure to the weight of the overlying sediments. Against this theory, it is urged that oil and gas bearing rocks must be in a crushed state before the weight of the overlying rocks can be effective in reducing pore space and exerting pressure upon the contained liquids and gases. In the original argillaceous and calcareous muds and sands, now shales, limestones, and sandstones, gravity was a very effective force in causing consolidation and a reduction of pore space with a consequent increase of pressure on the liquid and gaseous contents. Rock pressure in the case of sealed reservoirs may be accounted for in part at least in this way,

[7]Bull. 454 U. S. Geol. Surv. 1911.

and it is possible that the pressures obtaining in some of the oil and gas reservoirs of southern Texas and Louisiana fields are due partially to the weight of the overlying and largely unconsolidated Tertiary sediments of the gulf coastal plain. In general, however, the attitude of the rocks and the geological conditions have so changed since the consolidation and cementation of the original sediments that, whatever pressures may have once obtained from the weight of overlying deposits, the existing rock pressures in hard indurated rocks are probably more directly due to other factors.

Under the fourth theory, the cause of rock pressure is referred to the pressure of gaseous emanations from deep seated or magmatic sources. In the zone of anamorphism, or of rock flowage, the pressures and temperatures are so great that gaseous and liquid solutions[8] (chiefly the products of the processes of dehydration and decarbonation, but probably in part the result of emanations from magmatic sources) tend to be squeezed upward into the belt of cementation where lower pressures and tenperatures obtain. The upper part of this belt contains the oil and gas reservoirs, and it is supposed that the gaseous and liquid solutions make their way upward and transmit their higher pressures and temperatures to the oil and gas bodies. While magmatic emanations are probably a factor in causing rock pressure, there is little evidence to indicate that they have been of more than very minor importance in causing the pressures observed in the great oil and gas fields of the continent, and certainly the emanation theory cannot account for the pressures obtaining in sealed reservoirs.

In conclusion it may be said that all four theories contain some elements of truth and that, while most of the existing evidence is inconclusive or contradictory, rock pressure is probably the combined result of the factors as given in the theories. In a given case, one or two factors are generally of much more importance than the others, and present evidence indicates that in most fields the cause of rock pressure can be ascribed chiefly to water acting under artesian conditions and to the expansive force of the gas itself.

SURFACE INDICATIONS.

Oil and gas "signs" in some fields are related to various surface indications. These may be divided into two classes: (1) those common to many fields, (2) those peculiar to certain fields.

In the first class are seepages of oil and gas. The seepages may be far distant from a pool (See fig. 8) and as a general rule the area of seepages is much larger than that of the productive territory. Large

[8] C. R. Van Hise: Mon. XLVII, U. S. Geol. Surv., pp. 1017–1029.

and numerous seepages cannot be regarded as a more favorable sign than few and small ones. Some of the best fields gave little or no surface indications of their presence prior to their discovery. Large seepages may mean a very leaky reservoir and consequently little or no accumulation. Gas seepage is a poor indicator because marsh gas and other gases form so abundantly in many localities from decaying vegetation near the surface.

There are other surface signs peculiar to certain districts which have been taken as favorable indications. Two of these, characteristic of the gulf coastal plain in Texas and Louisiana, are the escape of hydrogen sulphide (H_2S) gas, and the "sour" waters. These phenomena are doubtless related to the formation of the salt bodies below, which in turn cause the formation of favorable structures for trapping the oil and gas in their migration upward.

In Wyoming, and many other western fields, anticlines are frequently discovered from surface observations or from a study of the field relation of the rock outcrops. On the Gulf Coastal Plain, low rises only a few feet in height sometimes indicate the presence of saline domes. More often, the anticlinal conditions are discovered only after considerable drilling.

In Michigan, gas springs, the occurrence of "shale" gas in the drift, a scum of oil on ponds and in wells, and bituminous smelling rock, are most abundant along the strike of the Devonian formations in the southeastern and northern portions of the Southern Peninsula. These signs have led to much fruitless drilling. The belt in which the oil formations outcrop must necessarily be one of leakage rather than accumulation.

The Survey has received many samples of highly bituminous "oil rock" from various parts of the State, especially from the regions mentioned above. Some of the black shales of the Coal Measures, the Sunbury (Berea), Antrim, and the Bell shales, and the Dundee and Trenton limestones give off a strong bituminous odor, especially when struck or heated. Such rocks are a source of oil and gas, but this does not mean that they necessarily contain valuable oil or gas pools, for reasons already given. In Michigan, the configuration of the surface deposits has no relation to the structures in the underlying rocks or to the oil horizons and the conclusions frequently drawn by drillers from the "lay of the land" are therefore of no value whatever. Extensive swamps with an abundance of gas (marsh gas, mainly methane) are also supposed by many to be highly indicative of accumulations of gas or oil in the immediate vicinity.

In many localities, a reddish oily scum with iridescent colors may be observed on the surface of the water, around springs, and in moist places. This nearly always proves to be iron oxide but it is often mistaken for oil.

CHAPTER III.

THE PORT HURON FIELD.

EARLY HISTORY AND DEVELOPMENT.

To Mr. C. H. Gordon[1] we owe a full report concerning oil and gas operations in the vicinity of Port Huron up to 1901. For many years it had been known that oil and gas existed in the underlying rocks in the vicinity of Port Huron, especially in the region to the east in western Ontario. In fact, the occurrence of these products in western Canada is mentioned in the reports of the Geological Survey of Canada nearly seventy-five years ago.

In 1860-61, the small and short lived Oil Springs field was struck, and later the Petrolia field was discovered. The latter, parallel to the Oil Springs pool, extends northwesterly for a distance of 12 miles nearly to the middle of Sarnia township, across the river from Port Huron A third pool was found running parallel to the other two in Euphemia township. It was this pool which led to the sinking of several wells in Port Huron in 1886-7. Even before this, several wells had been drilled along the river for gas. In nearly all of these, gas was found in small or even considerable quantities in the top of the Dundee at a depth of about 500 feet. In 1886, C. A. Bailey drilled a number of wells. Well No. 1 (605 A. T.) was drilled 500 feet N, 1000 feet W, of the S E cor. of sec. 9, T 6 N, R 17 E, and two others appear to have been drilled in the same immediate vicinity. In these wells, the Dundee was struck at 543, 545 and 572 feet respectively. Gas was found in small quantities in the surface deposits just above the Antrim black shale, which is the bed rock in southeastern St. Clair county, and, also, considerable odorless gas was struck near the bottom of the "top lime" of the Traverse at depths varying from about 280 to 320 feet. The first show of oil, accompanied by some gas, occurred in the top of the Dundee at about 520 to 525 feet in all of the three wells.

A year later, F. L. Wells drilled a test well (585 A. T.) 1685 deep on the bank of Black river opposite Kern's brewery. There was a "blow" of odorless gas in the "top lime" of the Traverse, similar to those noted in the Bailey wells, and the usual show of oil and gas

[1]Ann. Report for 1901, pp. 269–290.

in the top of the Dundee which was reached at 515 feet. A pocket of hydrogen sulphide gas under strong pressure was struck in the Upper Monroe beds, and the first conspicuous bed of salt in the Salina seems to have been struck at about 1555 feet.

No further interest was taken in the development of the field until 1898, when Mr. G. B. Stock, an operator from the Canadian fields, organized the Michigan Development Company and drilled a number of wells on what is known as the Goodrich property n the weste n part of the city very close to the old Bailey wells. According to statements of officials of the company, oil in relatively small yet commercially important quantities was struck in all of the wells in the sandy top of the Dundee limestone, which is struck at an average depth of about 520 feet in this part of Port Huron. At first, some of the wells yielded from 2 to 3 barrels per day, but graudally all of them decreased during the first few months until the average yield of each was about one-half barrel per day. With such shallow and cheap drilling the field was considered worthy of further development and new wells have been drilled from time to time until in 1910 there were twenty-one wells ranging in depth from about 500 to 650 feet, with a total production of about 10 barrels per day of 10 hours. The wells are on a tract of about 15 acres and are operated from a central pumping station (Pl. 1) by a 25 horse power gas engine which derives its motive power from gas obtained from the wells themselves. Mr. Stock also drilled a number of test wells north and west of Port Huron near Wadham's Station, at Abbottsford, and in Fort Gratiot township.

The showings of oil nearly everywhere in the district and the energetic example of Mr. Stock incited other men to undertake development work. Drillings were made on the old Sweitzer farm about three miles north of the Stock wells, at Valley Centre, and elsewhere.

A few years ago the Black River Oil Company drilled a number of wells along Black river north of the city. The company was succeeded in 1913 by the Michigan Central Oil Company which has made further exploration, and a number of their wells are reported to yield oil in quantities similar to the Stock wells, and also considerable gas.

While the quantity of oil is small the wells in the Port Huron district are long lived, most of the Stock wells having been pumped from 10 to 15 years without showing any great signs of exhaustion. It is the permanency of production which has caused the firm belief on the part of local prospectors that a large pool must exist somewhere in the vicinity of Port Huron. This permanency of flow seems to be characteristic of the Dundee in Ontario also, as the Petrolia field has been producing oil for over 45 years.

GEOLOGICAL CONDITIONS IN WESTERN ONTARIO.

From the study of the large number of drillings in western Ontario and at Port Huron, much light has been thrown upon the character, thickness and depth of the rock formations and the local geological structures. Early geologists supposed that the great Cincinnati and Nashville anticline, on the flanks and near the crests of which the great oil and gas fields of Ohio occur, extended northeastward from Ohio through the western end of Lake Erie into western Ontario. This now appears to be true only in part. According to E. Coste of the Canadian Survey, it runs from about Point Pelee on Lake Erie through Essex into Kent county and dies out in the northeastern part of the latter county. The Trenton along the supposed axis of the anticline which in Ohio is only 350 feet below sea level at Findlay and 800 feet near Lake Erie, is 1500 feet below sea level in Colchester township, Ontario, 1860 feet at Leamington and 2543 feet at Petrolia. Continuing northeastward from Petrolia the Trenton begins to rise, as it is 2310 feet below sea level near Inwood, 1166 feet at Stratford, 572 feet at Glen Allen, 310 near Alma, and 350 feet in Osprey township, Grey county.

According to the geological section[2] from Hamilton on Lake Ontario southwest to Courtright on St. Clair river, there is a steady dip only very slightly interrupted by minor folds and faults in Lambton county in the vicinity of the Petrolia, Moore and Euphemia pools. The line of section, however, is at an acute angle to the axis of the Cincinnati anticline and passes near the bottom of the sag noted above, hence the present drill holes might not show the presence of a gentle arch such as the Cincinnati anticline probably is, if it exists in Lambton county.

In Ohio, the Cincinnati anticline is very low in comparison with its great breadth. Superimposed upon it, however, are numerous minor anticlines and structural "benches" or terraces under which are found the many oil and gas pools of Ohio. Likewise in Canada there are local folds and undulations which run, not only parallel to the supposed course of the Cincinnati anticline, but also transverse to it. From a study of well records it appears that there are a number of these transverse folds in Ontario, having two principal courses—one practically east and west and the other northwest-southeast. From this, it follows that the structures in general extend toward the Michigan border, and perhaps across it into the state. Apparently this is the case at Port Huron, near Algonac, and at Wyandotte and Stony Island. The anticline at Port Huron seems to be directly in line with those in Enniskillen township, Lambton county, and evidently belongs to the same series.

[2]E. T. Corkill, 14th Rept. Ontario Bull. of Mines, 1905.

The general dip of the formations is westward from Ontario into Michigan, therefore, according to the anticlinal theory, the oil and gas of the Dundee in the eastern part of Michigan would tend to migrate eastward into Ontario and perhaps much of the oil and gas found in the oil fields of Ontario, especially in the western part, has come from the rocks of eastern Michigan.

The Petrolia Field. There are three oil fields in Lambton county—the Petrolia, the Oil Springs and the Moore. The Petrolia was once the largest and most important field in Ontario. Its wells have been uniformly small but surprisingly long lived. Some of the wells have been pumped for nearly forty-five years, but the production has steadily fallen until the average yield per well is only 8 or 9 gallons per day. Through the use of gas engines, utilizing the gas which flows in considerable quantity from many of the oil wells, more than a hundred wells have been operated from a single pumping plant. After the pumps have been withdrawn many of the wells are bailed with fair success.

In the Petrolia field, the oil occurs in a porous horizon, "the lower lime," the Dundee (Corniferous), at about 400 feet, or about 65 feet below the top of the formation; but, in other fields, the oil horizon of the Dundee occurs from 45 to 170 feet from the top. In Michigan, the oil occurs near the top of the formatiom, salt water nearly always being struck when the formation has been penetrated to any considerable depth.

The logs of the wells given below show the general character of the formations in the Petrolia field.

TEST WELL, PETROLIA.

Loc.—Near Imperial Refinery. Record by H. P. H. Brummell, Geol. Survey Can. E. Rawlings, driller.

Elevation 667 ft. A. T.	Thickness, feet.	Depth, feet.
Surface	104	104
Traverse:		
Limestone ("upper lime")	40	144
Shale	130	274
Limestone ("middle lime")	15	289
Shale	43	332
Dundee:		
Limestone ("lower lime")	68	400
Limestone, soft	40	440
Limestone, gray	160	600
Monroe:		
Limestone, hard, white with hard streaks of sandstone from 2 to 5 feet in thickness	500	1100
Gypsum	80	1180
Salina:		
Salt and shale	105	1285
Gypsum	80	1365
Salt and shale	140	1505

The base of the "lower lime" is regarded as the base of the Traverse (Hamilton) by the Canadian geologists, but Michigan geologists draw the line at the base of the overlying shale, because this horizon is very sharply separated from the limestone below and therefore easily recognized in drilling. According to Lane's definition, the Dundee includes all the limestones below the shales down to the dolomites or gypsiferous shales of the Monroe formation. As this well does not reach the Trenton, the record of the Carman well drilled some years later is inserted to show the character, thickness and depth of the rocks down to the Trenton inclusive.

CARMAN WELL, PETROLIA.

Lot 11, Concession 11, Enniskillen, Lambton Co., Ontario, Drilled in 1900.

Elevation 667 ft. A. T.	Thickness, feet.	Depth, feet.
Pleistocene or surface:		
Blue clay	90	90
Traverse (Hamilton)	240	330
Streaks lime and shale. At St. Clair, 775 ft.:		
Dundee (Corniferous) limestone	190	520
Streaks of brown. At St. Clair about 900 ft.:		
Monroe Beds	690	1210
Brown, gray and black dolomite. At St. Clair, about 1630 ft.:		
Salina, gray and black dolomites:		
Salt	65	1275
Dolomite	20	1295
Salt and light streaks dolomite	170	1465
Salt	90	1555
Salt and dolomitic lime	50	1605
Salt	25	1630
Gray dolomite	10	1640
Salt	67	1707
Dolomite and salt	40	1747
Salt	138	1885
Dolomite and lime shale	130	2015
Salt	90	2105
Guelph and Niagara lime	275	2380
Rochester (Niagara) shale (red and dark)	60	2440
Clinton	90	2530
Red Medina	275	2805
Lorraine or Hudson River shale (light)	205	3010
Utica (dark)	165	3175
Trenton (Trenton, Birdseye and Chazy), 1015 ft. 6½ in. casing, no salt water or pressure of any kind found in Trenton, Finished December, 1900	602	3777

Sarnia Township. As the productive oil territory extends northwest into the southeastern part of Sarnia township, and Sarnia lies directly in line of the longer diameter of the Petrolia field, there was more or less exploration in the vicinity of Sarnia.

In the Dicken's well, located in the southern part of the township, no Antrim black shale was found yet, just across the river in Port Huron, it is 82 feet thick in the F. L. Wells drill hole and 183 feet thick in the Junction well in the western part of the city. Evidently the 200 feet of surface in the Sarnia well represents an old pre-glacial channel as the surface materials in Port Huron are only half as thick. The top of the Dundee at Petrolia is 335 feet A. T. and 127 feet A. T.

at Sarnia, and this represents a drop of 208 feet to the westward in about 15 miles, or a dip of 14 feet per mile.

DICKEN'S WELL.

Loc.: Southern part of Sarnia near cor. Rose and Tecumseh streets. H. Mitchel, driller. Record by H. P. H. Brummell.

Elevation 590± ft. A. T.	Thickness, feet.	Depth, feet.
Surface:		
Sand and clay	130	130
Hard pan	55	185
Gravel	15	200
Traverse (Hamilton):		
Limestone	90	290
Shale	100	390
Limestone	5	395
Shale	68	463
Dundee (Corniferous):		
Limestone	77	540

In the King's Gristmill well, Sarnia, one and a half or two miles north of the Dicken's well, the drift is only 120 feet thick and there is 36 feet of the Antrim black shale. No oil was found, but there was a little gas at about 400 feet. The Dundee is 32 feet lower than in south Sarnia, showing a dip of nearly 20 feet per mile toward the north.

KING'S GRISTMILL WELL.

Loc.: One and one-half miles north of Dicken's well, Sarnia. Drilled in 1875 by E. Rawlings. Record by H. P. H. Brummell, Geol. Sur. Can.

Elevation 589 ft. A. T.	Thickness, feet.	Depth, feet.
Surface:		
Sand	9	9
Blue clay	109	118
Hard pan	2	120
Antrim:		
Black shale	36	156
Traverse:		
Limestone	30	186
Shale	263	449
Limestone	5	454
Shale	40	494
Dundee:		
Limestone	60	554
Gray limestone	100	654
Monroe:		
Hard limestone	546	1200
Hard and flinty limestone	200	1400
Limestone with gypsum	105	1505

Courtright. Courtright is about 10 miles south of Sarnia on St. Clair river. In a well at this place, the top of the Dundee was struck at 46 feet A. T. or 81 feet lower than in south Sarnia, the average dip to the south being only about 8 feet per mile. The fact that the Dundee is lower both to the north and south of Sarnia indicates that a fold crosses St. Clair river, probably through the southern part of Sarnia into the southern part of Port Huron. As will be seen later, this low fold appears to turn northwest in Port Huron and run along Black river valley.

COURTRIGHT WELL, ONTARIO.

Record by H. P. H. Brummell, Geol. Surv. Can., E. Rawlings, driller.

Elevation 588 ft. A. T.	Thickness, feet.	Depth, feet.
Pleistocene:		
Surface sand and clay	132	132
Hard pan	28	160
Antrim:		
Shale, black	32	192
Traverse:		
Limestone	40	232
Shale and limestone	310	542
Dundee:		
Limestone, white	50	592
Limestone, gray	100	692
Monroe:		
Limestone, hard, white	370	1062
Sandstone (Dolomite, probably—B), (Sylvania—Lane)	32	1094
Limestone	400	1494
Limestone and gypsum	136	1630
Salt	22	1652
Gypsum	13	1665

EXPLORATIONS IN THE PORT HURON FIELD.

Port Huron. As previously noted, most of the wells in the Port Huron field are in the western part of the city. The G. B. Stock wells on the Goodrich property and the Bailey wells are close together. The former, 21 in number, are owned by the Michigan Development Co. of which E. J. Schoolcraft is president. The output is entirely consumed by the G. B. Stock Xylite Grease and Oil Co. in the manufacture of a superior grade of lubricants, for which the oil is said to be especially adapted. The oil is of a dark and heavy grade and a natural lubricant, being similar to the Petrolia or Lambton county oils which come from the same horizon.

The Bailey and the Stock wells are so close together that the log of only one from each group is given.

Michigan Geological and Biological Survey.

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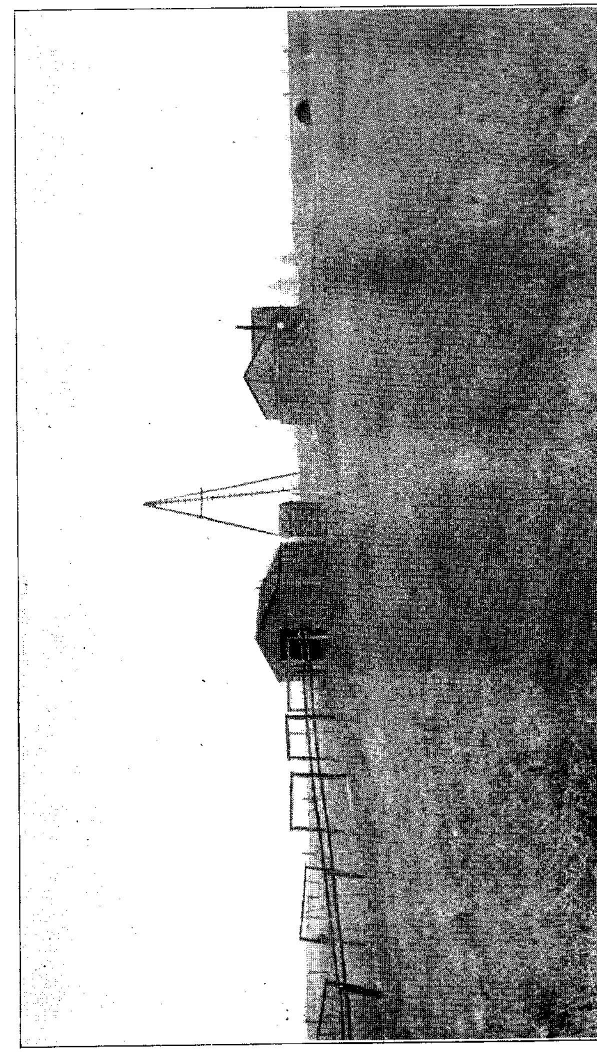

PUMPING PLANT OF THE MICHIGAN DEVELOPMENT COMPANY, PORT HURON.

THE STOCK WELLS.

Loc.: S. ½, N. W. ¼, sec. 9, T. 6 N., R. 17.

Elevation 605 ft. A. T.	Thickness, feet.	Depth, feet.
Surface:		
Blue clay	100	100
Antrim:		
Black shale	87	187
Traverse (Hamilton):		
Limestone ("top lime")	43	230
Soapstone, soft	70	300
Limestone ("middle lime")	15	315
Slate or shale, dark	85	400
Soapstone	120	520
Dundee ("Lower lime"):		
Limestone, sandy, oil bearing	47	567
Limestone	33	600

The oil is found in the first 45 feet of the sandy top of the Dundee. The elevation of the top of the Dundee is 85 feet A. T., or 15 feet higher than in the F. L. Wells well to the eastward, and 23 feet higher than the Bailey No. 1, one-half mile southwest, and 93 feet higher than the Grand Trunk Junction well one and one-half miles southwest. This indicates the presence of a low anticline between the Junction and the Wells drill holes and in the vicinity of the Stock wells.

BAILEY WELL NO. 1.

Loc.: 500 ft. N., 1000 ft. W., sec. 9 T. 6. N., R. 17. About ½ mile southwest of the Stock wells.

Elevation 605 ft. A. T.	Thickness, feet.	Depth, feet.
Surface	100	100
Antrim shale:		
Black shale	100	200
Traverse (Hamilton) formation:		
Streak hard argillaceous limestone with FeS_2	2	202
Soapstone (argillaceous marl)	15	217
Limestone (top) blow of odorless gas at 280 ft	80	297
Soapstone (argillaceous marl)	147	444
Limestone (middle)	9	453
Soapstone with streaks of limestone at 518 and 525 ft	90	543
Dundee (Corniferous) limestone:		
Limestone (lower)	125	668

GRAND TRUNK JUNCTION WELL.

Loc.: At Grand Trunk Junction near the N. E. corner, sec. 18, T. 6 N., R. 17 E.

Elevation 618 ft. A. T.	Thickness, feet.	Depth, feet.
Surface	124	124
Antrim shale:		
Black shale, small amount of gas at 300 ft	183	307
Traverse (Hamilton) formation:		
Limestone (top)	128	435
Soapstone	77	512
Limestone (middle)	8	520
Soapstone	105	625
Dundee (Corniferous) limestone:		
Limestone (lower)	147	772

At 680-685 feet there was "black water," at the bottom of the well, brine, and a show of oil at 710 feet.

The drop of the Dundee from the Stock wells southwest to the Junction well is 92 feet in about a mile.

WELL'S BORE HOLE.

Loc.: On bank of Black River near Seventh St. bridge. Port Huron. F. L. Wells, owner. Drilled in 1886-7. Record from samples.

Elevation 585 ft. A. T.	Thickness, feet.	Depth, feet.
Pleistocene:		
Surface, mostly clay	102	102
Antrim:		
Black slate and shale	83	185
Traverse:		
Limestone (top)	105	290
Soapstone with seams of limestones	225	515
Limestone (middle)	....	....
Soapstone	....	....
Dundee:		
Limestone (lower) cherty at top with show of oil and gas	133	648
Monroe:		
Dolomitic limestone with indications of salt and gypsum	68	716
Marl and marly limestone	54	770
Hard dolomitic limestone	75	845
Bluish black marl with gypsum	58	903
Hard dolomitic limestone with show of brine and oil	42	945
Argillaceous marl with streaks of dolomitic limestone and gypsum	205	1150
Hard gray calcareous sandstone. (Oriskany?)	95	1245
Bluish black argillaceous marl	10	1255
Dolomite and gypsum	300	1555
Alternating beds of salt limestone and shale	130	1685

This drilling is about a mile east and a little north of the Stock wells. The Dundee apparently occurs at 70 feet A. T. in the Wells bore hole, while to the west in the Stock wells it is 85 feet A. T. and 7 feet below tide in the Junction well. This indicates a westward rise of 15 feet to the Stock wells in about a mile, and then a rapid descent of 92 feet to the Grand Trunk Junction well in about a mile and a half. The first salt in the Salina seems to have been struck at

about 1555 feet, which at Petrolia (667 ft. A. T.) in the Carman well (see record on preceding pages) occurs at about 1210 feet. As the distance from the Carman well to the Well's bore hole is about 15 or 16 miles and the difference in elevation is 427 feet, the dip should be about 27 feet per mile to the northwest, or considerably greater than for the upper formations.

The Trenton was struck at 3175 feet or 2508 feet below sea level in the Carman well, and if we assume that the dip is the same for the Trenton as for the top of the Salina, the Trenton at Port Huron should be struck at about 2935 feet below sea level, or 3520 feet below the surface. As many of the deeper formations as the Clinton, Rochester, Medina, and Lorraine are known to vary markedly in the thickness in Ontario, the depth may be considerably more or less than this figure.

The Port Huron Salt Company drilled a deep well to the rock salt beds. The following record made from a complete set of samples is inserted with special reference to the character of the rocks encountered.

PORT HURON SALT CO. WELL.

Elevation about 600 ft. A. T.	Thickness, feet.	Depth, feet.
Pleistocene:		
Glacial drift	110	110
Antrim shale:		
Black bituminous shale; no effervescence	190	300
Traverse (Hamilton) Formation:		
Bluish gray dolomitic limestone; slight eff	15	315
Mixed bluish and gray dolomitic limestone, probably thin bedded; eff. brisk in spots, owing perhaps to fossils	50	365
Bluish calcareous shale somewhat plastic; eff. free	70	435
Even more shaly and plastic; dark rather than blue, yet not as dark as the Antrim	135	570
Dundee (Corniferous) limestone:		
Light brown, limestone sharp, clear fragments; eff. very slow	30	600
Brownish, more granular; eff. fierce	50	650
Similar, with a little darker shaly matter, perhaps accidental	20	670
Same; with a sandy granular character, probably more porous	5	675
Same; eff. fierce	50	725
Almost similar, but a shade darker; no eff	45	70
Similar; slight to slow eff	25	795
Upper Monroe or Detroit River Series:		
Dolomite in light buff chips and white grains of anhydrite	20	815
Dark brown and granular; moderate eff	40	55
Mainly similar to previous samples, but with a few white specks of gypsum as the same is damp, it may have been altered from anhydrite	15	870
Mainly anhydrite	10	880
Dolomite, no eff	5	885
Dolomite; moderate eff	30	915
Dolomitic limestone evidently highly banded, fragments in pieces sometimes nearly 1 cm square x 1 mm thick at 915 ft.; light buff dolomitic limestone, same hue since 885; no eff	30	945
Brown dolomitic limestone; moderate eff.; somegrains of anhy drite?; no quartz	40	985
Light buff dolomite, brisk eff. a moment only	15	1000
Mixed dark brown and brown bituminous dolomitic limestone; some of the grains eff. moderately, others not at all	5	1005
Dark dolomitic limestone; moderate eff	25	1030
Similar	50	1080
Slightly lighter and with some anhydrite; slight eff	35	1115
Dolomite with a little anhydrite	10	1125
Dolomite with anhydrite, and a gassy smell	25	1150
Dolomite; at first brisk and then slight eff	10	1160
Sylvania?:		
Cherty dolomite; blue gray, oxidizes brown; a few grains eff moderately; many grains of chert	5	1165
Largely a white cherty dolomite	20	1185
Lower Monroe or Bass Island Series:		
Apparently a light buff dolomite	25	1210
Darker dolomitic limestone; moderate eff	5	1215
Light dolomitic limestone; moderate eff. with some anhydrite at 1235 ft.	20	1235
Light dolomitic limestone; moderate eff., rather more than at 1235	10	1245
Darker dolomitic limestone; moderate eff., strong gassy smell	20	1265
Dark, evidently thin bedded dolomite; slight eff	20	1285
Lighter dolomite, moderate eff	15	1300
Slate colored dolomitic limestone; moderately brisk eff	5	1305
Bluish slate colored dolomitic limestone; moderately brisk eff	20	1325
Dark bluish gray, and vari-colored dolomitic limestone: moderate eff.; gassy	20	1345
Dark dolomitic limestone, more granular, less slaty; moderate eff	20	1365
Brownish dolomitic limestone; moderate eff	5	1370
Color about like 1370; very moderate eff	25	1395
Yellow; a very sharp change in color; slow eff	13	1408
Dark slate colored dolomite; very slight eff.; like 1395	8	1416
Dark slaty dolomite; very slightly eff.; like 1395	24	1440
Equally dark, but with more of a brown tone, and white specks; with moderate eff. and greenish and reddish specks	20	1460
Dark slate colored anhydrite; very slight eff	33	1493
Salina:		
Brownish salt	3	1496
Dark, slate colored, with impure salt and anhydrite	6	1502
Salt; while this appears impure and brownish, microscopic examination shows that the impurity is in separate particles, probably derived from the overlying bed	4	1506
Blue and brown dolomitic anhydrite; slow eff. The color of the bands is like that of 1345 to 1395	28	1534

PORT HURON SALT WELL CO.—Concluded.

Elevation about 600 ft. A. T.	Thickness, feet.	Depth, feet.
Gray salt	10	1544
Like 1534; slight eff	35	1579
Brown salt at 1574 ft. Buff dolomitic anhydrite; slow eff.; color about like 1408, nearly white to light buff	4	1583
Bluish gray slaty anhydrite, one large piece; no eff	17	1600
Salt, white; anhydrite mixed in from above	15	1615
Brownish salt; mixed with anhydrite	14	1629
Clear white, coarsely crystalline salt	11	1640
White and brown salt	26	1666
Dark gray slate colored anhydrite; color same as at 1345 ft	29	1695
Clear white salt; specks of gray anhydrite probably from the overlying bed	5	1700
Brownish, impure salt	25	1725
Grayish salt with bands of anhydrite	10	1735
Dark gray salt and anhydrite	25	1760
Varicolored dolomite, green, reddish and buff grains, which effervesce slowly	20	1780
Varicolored dolomite; slow eff.; shaly and with anhydrite	25	1805
Buff dolomite; rather a dark buff in thin chips indicating original banding; some dark grains mixed in	20	1825
Slate colored salt and anhydrite	30	1855
Clear white salt	5	1860
Buff dolomite; slow eff.; with large pieces (1 cm) of a green slate with anhydrite	10	1870
Nearly clear salt	5	1875
Mixed green, reddish and colorless salt, anhydrite	10	1885
Gritty clay, plastic when wet, no eff	30	1915
Slate colored anhydrite, about color of 1345; no eff.; some clay	5	1920
Nearly clear white salt; partly gray	62	1982
Salt and anhydrite	....	2013
Gray salt with anhydrite	....	2022
Dark gray anhydrite, color of 1345	....	2027
Gray salt with anhydrite	....	2044
Gray salt with anhydrite	....	2048
Impure dolomite; slow eff. Varicolored	....	2260

There are many typographical errors in the depths as given for the samples from 2012 to 2044 ft.

Marysville. In the Marysville well, four miles south of Port Huron, the top of the Dundee is 73 feet lower than at Port Huron directly north, thus the average dip to the south is over 18 feet per mile. Salt water was struck at 745 feet and mineral water at 817, 970 and 985 feet. The division between the Dundee and the Monroe is not correct as the thickness given for the Dundee is much greater than any observed in Michigan.

MARYSVILLE WELL.

Loc.: Four miles south of Port Huron on the Binic farm. Drilled by Church & Company.

Elevation about 600 ft. A. T.	Thickness, feet.	Depth, feet.
Surface, or Pleistocene:		
Clay	107	107
Gravel (dry)	3	110
Antrim shale:		
Dark blue shale, streaks of black	188	298
Traverse (Hamilton) Formation:		
Gray limestone	97	398
Argillaceous marl thinly laminated and fissile	193	588
Dundee (Corniferous) limestone:		
Sandy limestone, porous, indications of gas	37	625
Limestone, gray (Upper Monroe in part)	390	1015
Monroe Formation:		
Limestone, sandy (Sylvania?)	80	1095
Limestone, dark gray, hard in places	55	1150

Wadham's Station. G. B. Stock drilled a well on the farm of Mr. Fair near Wadham's station, which is four or five miles northwest of Port Huron. The Dundee is 141 feet lower than at Port Huron, and this is equivalent to a dip of about 35 feet per mile. No oil or gas was reported.

THE FAIR WELL.

Loc.: Three-fourths mile southeast of Wadham's station, S. E. ¼, sec. 2, T. 6. N., R. 16 E.

Elevation about 655 ft. A. T.	Thickness, feet.	Depth, feet.
Surface:		
Gravel	4	4
Blue clay	110	114
Antrim:		
Black shale	122	236
Traverse (Hamilton) Formation:		
Limestone (top)	230	466
Soapstone	105	271
Limestone (middle)	45	616
Soapstone	95	711
Dundee (Corniferous) limestone:		
Limestone (lower)	122	833

Abbotsford. A well was drilled by G. B. Stock on the F. A. Beard farm near Abbotsford, which is in Black river valley 10 miles northwest of Port Huron. The top of the Dundee was struck at the depth of 737 feet, or but about 25 feet lower than at the Fair well five or six miles to the southeast. This indicates that the steep northwest dip from Port Huron to Wadham's station becomes almost flat from the latter place to Abbotsford. Only a slight flow of oil was struck and this was 76 feet below the top of the Dundee.

BEARD'S WELL.

Loc.: Abbottsford, near S. E. corner sec. 8, T. 7 N., R. 16 E. F. A. Beard farm. Drilled by G. B. Stock.

Elevation about 655 ft. A. T.	Thickness, feet.	Depth, feet.
Surface:		
Marly clay	30	30
Tough blue clay	86	116
Wash gravel	22	138
Antrim:		
Black shale (heavy flow of mineral water at 140 ft.)	100	238
Traverse (Hamilton) Formation:		
Limestone (top)	217	455
Soapstone	122	577
Limestone (middle)	4	581
Soapstone (brine at 587 ft.)	156	737
Dundee (Corniferous) limestone:		
Limestone (lower); slight flow of oil at 813 ft	96	833

Valley Center. Valley Center is 20 miles northwest from Beard's well and 30 miles from Port Huron. Since the top of the Dundee was not reached at Valley Center, the top of the Traverse must be taken as a basis of comparison. In Beard's well, this is struck at 417 feet A. T. and in the Valley Center at 841 feet, or 423 feet lower. This gives an average dip of about 14 feet per mile to the northwest. The Traverse formation, however, thickens rapidly to the west, increasing from 313 feet in the Stock wells to practically 500 feet at Beard's. This indicates that the Dundee must dip much more than the figure given above. If we assume that the Traverse is 500 feet thick at Valley Center, (probably it is more, as at Saginaw and Bay City it is 600 to 650 feet thick), the top of the Dundee at Valley Center should be struck at a depth of about 1341 feet, (536 feet below sea level) or respectively 454 and 621 feet lower than at Beard's and at Port Huron. This would give an average dip for the Dundee from Port Huron to Valley Center of nearly 21 feet per mile, and nearly 23 feet from Beard's to the latter place.

VALLEY CENTER WELL.

Loc.: S. E. ¼, N. E. ¼, sec. 27, T. 9 N., R. 13 E.

Elevation 805 ft. A. T.	Thickness, feet.	Depth, feet.
Surface:		
Red sand and loam	5	5
Quicksand	90	95
Clay	22	117
Sand and gravel with plenty of pure water	32	149
Coldwater shale:		
Sandstone	5	154
"Conglomerate"	20	174
Sandstone	30	204
(This sandstone and conglomerate may be the Richmondville or another stray sandstone horizon at some distance above the base of the Coldwater.)		
Slate (blue shale)	10	214
Soapstone	175	389
Slate (shale)	150	539
Berea sandstone:		
Limestone	10	549
Sandstone	20	569
Antrim shale:		
Shale changing to soapstone below	272	841
Traverse (Hamilton) Format on:		
Limestone	35	876

Imlay City. Two deep holes respectively 802 and 1020 feet deep were drilled by Walker & Co. at Imlay City, Lapeer county, and the record of the deeper one is given below.

IMLAY CITY WELL.

Walker & Co., owners. Record from driller's notes and from samples.

Elevation 830 ft. A. T.	Thickness, feet.	Depth, feet.
Pleistocene:		
Red sand	11	11
Quicksand (mostly)	60	71
Hardpan	4	75
Gravel	16	91
Lower Marshall? and Coldwater:		
Blue argillaceous shale; quite soft and somewhat calcareous	19	110
Blue shale. (no samples)	80	190
Flow of fresh water at 190 ft.		
Red shale (no sample)	8	198
Light gray argillaceous shale, very sandy. Under microscope about equal parts of somewhat rounded grains of sand and of clay; sand 1-500 in. in diameter	202	400
Light bluish gray argillaceous shale, almost gritless	30	430
Very sandy argillaceous shale, light gray, almost gritless. A few partly rounded grains of sand 1-1000 in in diameter	90	520
Argillaceous shale, light bluish gray, almost gritless. A few partly rounded grains of sand 1-1000 in. in diameter	75	595
Limestone	7	602
Argillaceous shale, light gray; few very minute shale grains at 602 ft.		
Argillaceous shale, light gray	28	630
Argillaceous shale, bluish gray, gritless	20	650
Argillaceous shale, bluish gray	20	670
Argillaceous shale, grayish drab	40	710
Weak brine at 708 ft.		
Argillaceous shale, dark gray	30	740
Argillaceous shale, very dark drab, gritless	15	755
Argillaceous shale, gray	15	770
Argillaceous shale, dark blue	12	782
Argillaceous shale, dark blue, gritless	8	790
Sandstone	10	800
Argillaceous shale, light blue, somewhat sandy	5	805
Argillaceous shale, light blue, gritless	9	814
Argillaceous shale, light blue	51	865
Argillaceous shale, dark bluish drab, somewhat slaty, hard	10	875
Argillaceous shale, light bluish, soft	25	900
Argillaceous shale, light bluish, gritless, soft	15	915
Argillaceous shale, dark blue, gritless soft	10	925
Argillaceous shale, light blue, gritless soft	35	960
Argillaceous shale, gritless, soft	15	975
Argillaceous shale, gritless, soft, light blue	10	985
Argillaceous shale, light blue, gritless, soft	25	1010
Argillaceous shale, dark bluish drab, slaty and rather hard and gritless	5	1015
Reddish shale	5	1020

Fort Gratiot Township. Two wells were drilled on the Sweitzer property, one and a half miles north of the Stock wells. The Dundee is about 33 feet deeper than in the latter wells and this indicates a dip of about 20 feet per mile to the north. A show of oil was reported at 558 feet in the No. 1 well and a small quantity was obtained after shooting it at 568 feet.

SWEITZER WELL.

Loc.: Fort Gratiot Twp., S. W. ¼, sec. 33, T. 7 N., R. 17 E.

Elevation about 610 ft. A. T.	Thickness, feet.	Depth, feet.
Surface:		
Soil and sand	5	5
Clay	100	105
Hard pan and marl	15	120
Antrim shale:		
Black shale	100	220
Traverse Formation:		
Limestone, white with thin strata of soapstone	60	280
Soapstone	278	558
Dundee (Corniferous) limestone:		
Limestone (lower)	62	620

G. B. Stock drilled a well on the farm of Mr. Shaw about six miles north of the Stock wells in Port Huron. In this well, the top of the Dundee occurs at 60 feet above sea level, or practically at the same height as in the Stock wells. To the north of the Shaw well, the formations are known to descend rapidly, as in the Pabst well 3 miles south of Lexington there are more than 252 feet of Antrim shale, including a thin bed of limestone at the top. A showing of oil was said to have been struck at 557 feet in the Shaw well, but this was not tested and the well was abandoned.

The record of the Pabst well above mentioned is faulty or incomplete, hence of little use in correlating horizons or tracing structures.

SHAW WELL.

Loc.: Fort Gratiot Twp., S. E. ¼, sec. 8, T. 7 N., R. 17 E.

Elevation about 600 ft. A. T.	Thickness, feet.	Depth, feet.
Surface:		
Sand and gravel	5	5
Purple clay or mud	30	35
Gravel	3	38
Blue clay	79	117
Antrim shale:		
Black shale	45	162
Traverse (Hamilton) Formation:		
Limestone	203	365
Soapstone	95	460
Limestone (middle)	15	475
Soapstone	65	540
Dundee limestone:		
Limestone (lower)	115	655

THE PORT HURON ANTICLINE.

From the data afforded by the numerous borings in the vicinity of Port Huron, a low fold (Fig. 2) crosses St. Clair river from Sarnia, passes northwestward through the southern and western parts of Port Huron, and, veering to the north, extends along Black river. The anticline pitches very gently along its course, and, on the west, it is bordered by a syncline pitching in the same direction. Since the anticline pitches in a general northwesterly direction, the oil and gas would tend to migrate to the southeast along the crest unless arrested by some cross fold, of which there is no present indication.

THE OIL HORIZONS.

Until a comparatively few years ago, it was supposed that the Dundee was the only oil bearing horizon in Ontario. Prospecting in the deeper formations disclosed the fact that the Guelph or Niagara are locally very ''vesicular'' or fissured and contain oil in great quantities. The porous nature of the reservoirs permitted a ready flow of oil and some of the wells yielded more than 1200 barrels per day. This formation also yielded great quantities of gas in Kent and also in Essex county. The Medina with three ''pays'' was also found to be a great gas producer in the Niagara peninsula. The Onondaga in Kent county, however, has four gas horizons. The wells are very large, one producing 7,000,000 cubic feet per day and 17 averaging two and one-half million cubic feet. The Trenton formation, however, has been a source of disappointment wherever struck in Ontario.

Conclusions. From the foregoing facts, it is reasonable to conclude that, since the Dundee, Niagara, Medina, and Onondaga are oil bearing in western Ontario, the same formations may be productive a few miles to the west in Michigan, especially in the vicinity of favorable structures such as occur at Stony Island, Wyandotte, and Port Huron.

HURON AND SANILAC COUNTIES.

The early salt wells. In the early days of lumbering and salt manufacture, many wells were drilled along the Lake Huron shore from Saginaw bay to Sanilac county. These wells obtained their brines from the Berea grit, or from the Richmondville sandstone. The F. Crawford wells at Caseville were from 1760 to 2270 feet in depth, the Pigeon River Furnace Company (later Lake Huron Iron Co.), 1760 feet, the Port Crescent wells about 1250 feet, Port Austin 1225 feet, Grindstone City 1080 feet, New River 1029 feet, Port Hope Salt Co. 787 feet, Harbor Beach 715 to 1900 feet, and the White Rock wells 700 to 1311 feet.

The brine bearing horizon dips to the westward increasing in depth from 700 to 800 feet at White Rock in the eastern part of Huron county to about 2000 feet in the western part. The Berea in Huron county is a coarse grayish white sandstone full of pure strong brine, but in none of the drill holes was the occurrence of either oil or gas noted.

The Geological Sections. As there are no reliable logs of any of these numerous early salt wells, the following generalized sections showing the probable character and thickness of the formations in Huron and Sanilac counties are inserted.

GEOLOGICAL COLUMN IN HURON COUNTY.

	Thickness, feet.
Surface:	
Lake sands, clays and till	0–50
Saginaw Coal Measures (Present only in extreme southwestern part of county):	
Black, white and blue shales, coal and sandstone	75
Maxville limestone (Present along western shore):	
Sandy yellow limestone, crossbedded sandstone and a little dolomite	50
Michigan Series (Present in western quarter only):	
Light gray shale with gypsum and pyrite; salty bluish shales; argillaceous hydraulic limestones	230
Napoleon or Upper Marshall (Absent from most of eastern half):	
Clean white sandstone, sometimes with an olive tint or brown from specks of pyrite	300
Lower Marshall (Absent along eastern margin of county):	
Flags and sandstones, green weathering red, with beds of blue micaceous shale, white sandstone, nodules of iron carbonate, and thin seams of "peanut" conglomerate	260
Coldwater shales:	
Blue shales with sandy streaks, often ripple-marked, frequently charged with carbonate of iron	896
Sunbury (Berea) shale:	
Black shales	75
Antrim shale:	
Black shales	456
Traverse (Hamilton) Formation:	
Limestones and shales with black Bell (Marcellus) shales at the base	615
Dundee (Corniferous) limestone:	
Limestones locally bituminous; water bearing near the base	120
Monroe (including the Salina):	
Dolomites, anhydrite, shales and salt beds; dolomites heavily water bearing at several horizons	1200 +
Niagara (Guelph and Lockport):	
Dolomites with some limestone and shale and occasional sandstone lenses; water bearing expecially at some distance below the top; yields oil in Ontario	400
Rochester, Clinton, Medina, and Lorraine shales:	
Mainly shales, red green, and black and locally sandy down to the heavy blue shales of the Lorraine	700
Utica shale:	
Black and bituminous shales	50
Trenton limestone:	
Dolomites and limestone with oil horizons near the top and water farther down	300 +

The thicknesses given in the above section are estimated mainly from the records of wells in Huron and Sanilac counties. Since the formations dip to the west, the depth to a given horizon grows progressively greater in that direction.

GENERALIZED SECTION FOR SANILAC COUNTY.

	Thickness, feet.
Pleistocene or glacial drift:	
Sand, clay and till	0–200
Lower Marshall (absent in eastern and southern part of county):	
Sandstone and "grindstones"	60–100
Coldwater shales:	
Blue shales	100–200
Sandstone (Richmondville)	50–80
Blue shales	200–250
Black shales (Sunbury)	50–150
Berea sandstone	30–50
Antrim shale:	
Darker below	100–150
Traverse (Hamilton) Formation:	
Blue calcareous shales and limestones frequently dolomitic	100–150
Dundee limestone	125 +
Monroe Formation including Salina:	
Dolomite, calcareous and argillaceous marls, anhydrite and rock salt	800 +

CHAPTER IV.

THE SOUTHEASTERN DISTRICT.

INTRODUCTORY STATEMENT.

The southeastern district includes that of Port Huron, but for several reasons it has seemed best to discuss the latter as a separate oil field. The southeastern district, lying close to the Toledo oil fields and to two great industrial centers, and including areas in which there are abundant signs of oil and gas, has received a disproportionate amount of attention in the past from oil and gas prospectors. A large number of holes have been drilled from Port Huron to the Ohio line. Many of these were drilled for salt or water and others for oil and gas, but in none of them has there been any but the most meager discoveries of either of the latter products.

ROCK STRUCTURES.

These explorations indicate that all of the formations from the Ohio line to Macomb county dip in general from 20 to 30 feet per mile to the northwest toward the central part of the basin. The only marked disturbances which break the monotony of this northwestward slope appear to be at Stony Island, Wyandotte, and Algonac.

While this general northwest dip of the rocks constitutes a great monocline, a large part of it is included in what is really a very low anticlinal fold extending at least down to the Traverse formation,[1] and pitching gently northwest. The limbs of the fold extend from Adrian to Pontiac, a distance of nearly 70 miles, the axis passing through Ann Arbor. The steepest dip at right angles to the axis appear to be not more than 5 to 7 feet per mile. The actual drop of the Antrim from Ann Arbor to Pontiac is 231 feet in 34 miles, and to Adrian on the other side 195 feet in about the same distance.

Such a structure might reasonably be expected to contain pools of oil and gas, but deep drill holes at Ypsilanti and Ann Arbor encountered no appreciable quantities of either. In explanation of why this structure does not apparently contain these products, Dr. W. H. Sherzer advances the theory, that, since the anticline pitches to the northwest, the oil or gas works its way upward and southeastward along the crest of the anticline to the outcrops of the oil formations in Wayne and Monroe counties, and thus escapes. In this connection, it may be noted that the anticline is so broad, flat, and ill defined that it could have only slight effect on the concentration of oil and gas in bodies of commercial importance.

[1] W. H. Sherzer, Geological Report of Wayne County, Pub. 12, Geol. Ser. 9, 1911.

RELATION OF SURFACE SIGNS TO OIL AND GAS HORIZONS.

Signs of oil and gas abound in the area underlain by the Berea grit and Devonian formations which occur in a belt extending from St. Clair county to the Ohio line. In some places oil accumulates as a scum on ponds, around springs, and in wells, giving a very offensive odor to the water and rendering it unfit for domestic or stock use. Some springs give off gas in amounts sufficient for ignition. Gas is struck in surface wells throughout the belt underlain by the Devonian formations, and nearly a hundred wells in St. Clair, Macomb, Oakland, and Wayne counties yield gas enough for household purposes, many of the wells being utilized by farmers in this way. The pressures vary from a fraction of a pound to nearly 100 pounds, but range ordinarily between 5 and 40 pounds. The life of such wells is generally from 6 to 8 years, but some of them have yielded gas for more than 15 years. Others exhaust themselves in a few weeks or months. The shale gas wells are worth utilizing to a much greater extent than they are at present. One well in Muskegon county, reported to yield 2500 feet per day, is allowed to run to waste. This well would furnish fuel and light for several ordinary families

Similar surface signs are in the northern part of the State where the Devonian formations underlie the drift. The Killmaster and Atlanta gas springs are in the vicinity of the Berea horizon, and the gas well at Onekama (Chap. VIII), Manistee county, struck in January, 1912, is in heavy drift directly over the Antrim black shales.

The Dundee limestone is locally very bituminous and has a strong oily odor. A semi-fluid bituminous or oily matter is sometimes found in cavities of fossils and in crevices and the whole rock is generally more or less impregnated with oil. The Antrim shale is very black and sometimes contains 25 per cent of bituminous matter, smells strongly of petroleum, and nearly always yields small quantities of gas. In places it is so bituminous that it can be burned.

The Traverse formation in the central and northern parts of the state is 600 to 650 feet thick, and is known to produce oil at three different horizons (See Chap. V) at Saginaw. In southeastern Michigan, it is much thinner, being only about 300 feet thick at Port Huron and less than 200 feet thick in the southeastern corner of the State. The bituminous basal (Bell, or Marcellus) shales are not characteristic of the Traverse in the southeastern district, and perhaps this explains why it does not yield more abundant signs of oil and gas in this region.

The Berea sandstone, a coarse gray sandstone full of brine even near its outcrop, is from 100 to 200 feet thick and lies at the base of the Coldwater shales. Its course through Oakland county is apparently marked by a line of brackish or salt wells. It cannot always be recognized in well records that do not go to deeper and more characteristic and recognizable horizons, for, in some localities, stray sandstones very similar in appearance occur in the Coldwater above the Berea horizon. The Berea is generally overlain by a black shale at the base of the Coldwater, known as the Berea or Sunbury shale. Thus the Berea is overlain and underlain by black bituminous formations, giving ample sources for the gas it nearly always contains in considerable quantities and yields to the overlying drift.

THE FOLLOWING TABLE GIVES A NUMBER OF THE SHALE GAS WELLS OF MICHIGAN, THE OWNERS, LOCATIONS AND PRESSURES OF THE WELLS AND THE ROCK FORMATIONS IMMEDIATELY BENEATH THE DRIFT.

Owner.	County.	Township and range.	Depth.	Pressure lbs. per sq. in.	Rock formations below.
C. L. Rowe, Buelah	Benzie	N. E. ¼ of Sec. 28, T. 26 N., R. 15 W.	205	?	Antrim.
Franz Elwart, Warren	Macomb		69	?	Antrim.
Wm. H. Hanekow, Warren	Macomb		72	?	Antrim.
Wm. L. Hartsig, Warren	Macomb		90	72	Antrim.
Otto Jacob, Warren	Macomb	Sec. 20, Warren Twp	60	?	Antrim.
August Mielke, Warren	Macomb		98		Antrim.
A. R. Peters, Warren	Macomb		93	45	Antrim.
Alex. Smith, Warren	Macomb		71	?	Antrim.
Henry Vohs, Warren	Macomb		50	?	Antrim.
Max Wolgast, Warren	Macomb	Sec. 18, Warren Twp	68	25	Antrim.
Jno. Dobberowsky, Grosse Point Farm, Warren	Macomb		?	25	Antrim.
H. W. Leonard, Onekama	Manistee	Sec. 22, Onekama Twp	437	185	Antrim.
Robt. Jackson, Ravenna	Muskegon		?	?	Coldwater.
Louis Granzow, Royal Oak	Oakland		108	39	Antrim.
Frank Grosjean, Southfield	Oakland		105	?	Berea or Sunbury.
Wm. Hilzinger, Royal Oak	Oakland	Sec. 22, Royal Oak Twp	115	39	Antrim.
Edw. Landau, Royal Oak	Oakland		95	?	Antrim.
Henry Langer, Royal Oak	Oakland		102	43	Antrim.
E. McHugh, Redford	Oakland	Southfield Twp	Well exhausted.	20	Berea or Sunbury.
Wm. J. Purdy, Redford	Oakland	Sec. 24, Southfield Twp	105	Weak now.	Berea or Sunbury.
E. A. Starr, Royal Oak	Oakland	N. E. ¼, Sec. 8, T 1 N., R. 8 E.	?	?	Berea.
N. E. Springsteen, Royal Oak	Oakland	Sec. 9, T. 1, N. R. 11 E.	116	Gas with water.	Antrim or Berea.
Frank Parmenter, Royal Oak	Oakland	Royal Oak Twp	108	¼	Antrim.
M. J. & L. J. Harrow, Algonac	St. Clair		300	16	Antrim.
H. E. Harman Willis	Washtenaw	Sec. 26, Augusta	65	10	Antrim.
Irving Becker, Detroit	Wayne	Redford Twp	65	?	Antrim.
Jno. Desgrandchamp, North Detroit	Wayne		122	Exhausted now.	Antrim or Traverse.

MONROE COUNTY.

Monroe county[2] lies close to the oil fields of northwestern Ohio. There is an area in the western part where surface signs of oil and gas are especially abundant. Naturally it received early attention from oil and gas prospectors. About 15 deep wells have been drilled in the county, of which seven penetrate the Trenton.

The Cincinnati anticline extends in a general northeasterly course from the vicinity of Findlay, Ohio, across Lake Erie into Essex and Kent counties of Ontario, where it apparently dies out. On either side of the axis the formations slope away at comparatively flat dips. The general dip northwestward from the crest into Monroe county is only about 30 feet per mile and there are apparently no local disturbances in the general slope. Monroe county is situated well down on the northwest slope of this great anticline, and, therefore, the oil and gas may have been drained to the southeast towards the fields of northern Ohio. Apparently the only hope of finding oil in this part of the State lies in the presence of local anticlines or terraces of which we now have no knowledge, or in porous areas or lenses sealed in by impervious rocks.

The southeastern part of the county is the most promising portion as it is nearest the crest of the Cincinnati anticline and the northern Ohio fields. Of the 15 or more wells drilled for oil, the one farthest southeast, the Potter well, was the most productive, and the ones farthest away from the axis were "dry" holes. The Potter well, is located in N. W. ¼, N. W. ¼, sec. 22, Erie township. It was begun in November and completed December 10, 1899, reaching a depth of 1667 feet, and striking the Trenton at 1555 feet. A little oil and gas were struck. The well has been bailed out several times, once yielding about 10 barrels of oil. The gas, with an original pressure of 25 pounds, was piped to the house and used for cooking and lighting purposes. Most of the other wells made showings of oil and gas, but none as large as the Potter well.

Monroe. At Monroe several wells were drilled, three of them to the Trenton. None yielded more than a trace of oil and a little gas. The record of the Moore well, as revised from Vol. VII, Part I, is given below:

[2] Sherzer: Monroe County, Vol. VII, Part 1, p. 190.

MOORE WELL.

Loc.: Monroe, Monroe County. Record from samples.

Elevation 585 ft. A. T.	Thickness, feet.	Depth, feet.
Surface	40	40
Lower Monroe:		
Bluish shale, with only a small amount of eff. calcareous matter	5	45
Bluish shaly dolomite, with quite a little slowly eff. matter, and a large residue in lower part	35	80
Yellowish limestone, briskly effervescing	230	310
Here and at 35,500 and 650 ft., samples of a white earthy powder of calcite and dolomite, with a trace of gypsum (probably a chemical precipitate from underground water.)		
Water, 3000 gallons per hour between 280 and 297 ft.		
Dolomite at 340 ft.; effervesces slowly when in fine powder; contains much anhydrite of a dark buff color	170	480
Buff dolomite at 450 ft. like the sample above, eff. moderately fast, with an occasional fragment of the green shale, little or no sulphate of lime.		
Light colored dolomite	200	680
Eff. moderately at 500 ft. with much anhydrite.		
Eff. slowly at 500 and 650 ft.; an occasional grain of sand; no anhydrite.		
Light gray dolomite; eff. slowly; reacts for gypsum	20	700
Niagara—Guelph and Lockport:		
Light yellowish to bluish gray dolomite; eff. slowly; quite ferruginous, no gypsum	130	830
White arenaceous dolomite; eff. slowly; with grains of quartz, sand and a very little magnetite	70	900
Gray dolomite, eff. slowly with a trace of quartz. Last limestone before shale	160	1060
Rochester, Medina?		
Greenish and reddish shales, eff. slightly; mostly clay	90	1150
Lorraine or Maysville:		
Bluish gray, somewhat ferruginous shales, slight eff	420	1570
With minute granules of quarts at 1400 ft.		
Green and red ferruginous shales, slightly eff. with a trace of magnetite. (Particles of the drill?)	85	1655
Utica:		
Next above Trenton, black bituminous shale, eff. slightly, fusing with an aromatic odor and intumescence to a blebby enamel; a little finely divided quartz	80	1735
Trenton:		
First screw, buff colored dolomite; hard, with slow eff. At 1742 gas, odorless, with white flame; considerable salt water?		
Third, fourth, fifth and sixth screws in Trenton, buff colored limestones	15	1750

LASALLE* WELL.

Loc.: Gadfry Saul Farm, LaSalle, Monroe county. Owners, Bengood Oil Co., Fostoria Michigan. Drilled in 1914 by Schrier & Kerr, Lancaster, O. Record furnished by Geo. T. Bench, Fostoria, Michigan. Reported by H. L. Osborne.

Elevation between 590 and 600 ft. A. T.	Thickness, feet.	Depth, feet.
Pleistocene:		
Drift	40	40
Drive pipe 40 ft.		
Lower Monroe or Bass Island Series:		
Hard gray lime (dolomite).		
Small stream of water at 50 ft., large at 100 ft	260	300
White lime (dolomite)	60	360
Gray lime (dolomite)	30	390
Niagara (Guelph and Lockport):		
White lime	490	880
Rochester shale and Clinton?		
Blue shale and shells	165	1045
8 inch casing to 885 ft.		
Richmond and Medina:		
Red rock	45	1090
Gray shell	10	1100
Pink rock	50	1150
Lorraine or Maysville shales:		
Gray shell	325	1475
Utica shale:		
Brown shale	160	1635
Trenton rock (Trenton, Birdseye and Chazy?)	850	2485
Little salt water at 2485 ft.		
St. Peters? sandstone:		
White sandstone	31	2516
"Big salt" water at 2510 ft.		

* Record received as this report went to press.

Strasburg. About 1907, a well was put down by the Strasburg Oil Company on the Hansberger farm near Strasburg. It reached the Trenton at 1884 feet, and was shot with 200 quarts of nitroglycerin. From 1950 to 1989 feet there was a very small showing of oil and gas. A small flow of water was struck between 600 and 625 feet, and a larger flow just above 690 feet. A good driller's record and set of samples were obtained from which the following record was compiled by A. C. Lane:

STRASBURG OIL & GAS CO. WELL NO. 1.

Loc.: Hansberger farm, Monroe county. J. P. Harnden, Driller, 1907.

Elevation 625 ft. A. T.	Thickness, feet.	Depth, feet.
Pleistocene drift:		
Soil, sandy loam, light clay and gravel	18	18
Lower Monroe (below Sylvania) Bass Island Series:		
Raisin river and Put-in-Bay dolomites	357	375
300–375, hard with moderate eff.		
Water at 25 ft.		
Water at 45 ft. 10 gallons a minute.		
Flow at 68 ft. 160 gallons a minute.		
Flow at 345 ft. 240 gallons a minute.		
Tymochtee shale horizon:		
Dolomite and gypsum or anhydrite	20	395
375-385, hard, moderate eff. A little anhydrite.		
385-395 with anhydrite and much gypsum. Slow eff.		
Greenfield dolomite. Dolomitic limestone	90	485
395-415, a lutite.		
455-485, the upper samples not so hard; the rest pure, light colored, hard, massive, dolomitic limestone with moderate eff., except the last which contains blue shale and grit as well as dolomite.		
Cased well to 485 feet—no water.		
Anhydrite, hard blue shale and dolomite, a little anhydrite, which may have come from layer below?	55	540
485-510 "Hard" blue shale, almost no eff.		
510-540, "Hard," moderate eff.		
Salina Horizon?		
Anhydrite	20	565
540-565, slow eff., under the microscope mainly anhydrite, light brownish.		
Dolomite mainly, all "hard"	35	600
565-585, slow eff. A little anhydrite which may have dropped in from above.		
Anhydrite	25	625
600-625, moderate eff., "a little water at this depth;" under the microscope, gypsum as well as anhydrite, the former probably produced from the latter by water, as the bed is reported "hard."		
Dolomite (with water)	65	690
625-655, is a brown sandy looking kind of dolomite that often occurs near water course, but there is really only about 1 per cent sand. Compare Morton well, Wyandotte, 230-240, 410. 460, 720 and 780 ft.		
655-690, is also dark and "very hard," more water, filled within 200 ft. of the top, pulled casing, sample of water taken.		
Somewhere from here down should be put the base of the Monroe and Salina and the top of the Niagara or Guelph, the brown sandy looking oily dolomites which occur in this well between 625 ft. and 900 ft. being represented at—		
Wyandotte, between 1235 ft. and 1510 ft.		
Dundee, between 618 ft. and 1193 ft.		
Nogard well, between 569 ft. and 1420 ft.		
Britton, between 1200 and 1550. ft.		
Milan, between 1400 ft to 1540 ft.		
With rock salt at the bottom.		
Monroe, from 500 down.		
Cheboygan, from 1460 down.		
Niagara (Guelph and Lockport):		
Brown dolomite	110	800
690-695, brownish, sandy, "dry, no water," crystalline enough for Guelph.		
695-800, dolomitic limestones with moderate (at 775 ft.) eff. and bluish light colors.		
Light dolomitic limestone	20	820
800-820, is light colored with brisk eff. and under the microscope a clear limestone.		
Brown dolomite	80	900
820-900 are "very hard," brown, sandy looking, almost exclusively carbonate with slow to moderate eff.		
Compare Nogard "oil limestone" at 1269-1420 ft.		
Wyandotte, 1475-1510 ft.		
White dolomitic limestone (Guelph)	200	1100
900-950 "softer," is white, with moderate eff.		
950-1100 is very white, slow eff., the typical "Guelph," western Niagara or Manitoulin dolomite.		

STRASBURG OIL & GAS CO. WELL NO. 1.—Continued.

Elevation about 600 ft. A. T.	Thickness, feet.	Depth, feet.
Compare:		
Monroe, 850-900 ft.		
Dundee, 1208-1343 ft.		
Nogard, 1420-1520 ft.		
Britton, 1550-1643 + ft.		
Riga, 1165-1275 ft.		
Wyandotte, to 1860 ft.		
Kalamazoo, 1730-1875 ft.		
Rochester shale?	70	1170
1100-1140 "no sample saved."		
1140-1170 "was broke or mud."		
1170-1180 is impure mixed with greenish and rusty brownish fragments of limestone; eff. moderate to brisk, with marked iron stain.		
This is properly a part of the Clinton but seems to have some of the overlying shale mixed with it, and an unconformity may well be suspected here.		
Compare:		
Monroe, 1110 ft.		
Wyandotte, 1870 ft.		
Swan, Grosse Isle well, 1400-1500?		
Clinton	130	1300
Ferruginous dolomite and limestone:		
Ferruginous dolomite 10 ft., 1180 ft.		
Described above. Swan, Grosse Isle at 1550 ft., is similar.		
1180-1230, eff. slow to moderate; pink.		
1230-1300, dark, moderate eff.		
1300, white dolomitic limestone, brisk eff.		
"No sample saved, was very red in color and soft shale. We call it 'red rock' in Ohio oil fields, always found just below Clinton lime."		
Clinton Iron Ore, Medina and Richmond Shales	40	1340
This band of red rock marks the base of the Silurian and the top of the Ordovician. As no sample has been preserved it is impossible, and probably would be so anyway to subdivide it, and it is a matter of taste whether it is to be reckoned with the one or the other. It may be correlated with—		
Monroe, 1110 ft.		
Dundee, 1563-1623 ft.		
Nogard, 1640 ft.		
Wyandotte, somewhere between 1890 and 2200 ft., probably about 2100 ft.		
Cheboygan, 2265-2407 ft.		
Lorraine or Maysville shales	320	1660
1340-1660 ft., all the same bluish slightly greenish shale, not eff.		
Utica (Eden) shales	224	1884
1660-1700 ft., slight eff., dark shale.		
1700-1800 ft., similar.		
1800-1884 ft., no eff., yet darker bituminous shales. These Lorraine and Utica shales appear above the Trenton in all the wells cited below.		
Probably the lower part above is the typical Utica of most wells, i. e., Strasburg, 1880-1884 ft., with Pickford 475-525 ft.		
Trenton limestone	105	1989
Limestone:		
1884, "Top of Trenton rock; hard." Moderate eff.		
1884-1890, "Top of Trenton rock; hard." Moderate to brisk eff.		
The dolomitization of the Trenton is confined to the very top.		
1890-1937 ft., all effervesce freely and are a mixed pepper and salt in color. At 1937-1950 ft. is noted "a very light showing of oil and gas." The well was shot with 200 quarts of nitroglycerine.		
The top of the Trenton corresponds well with:		
Monroe, 1734 ft., with 80 ft. of black shale above.		
Dundee, 2133 ft., with 300? ft. of black shale above.		
Nogard, 2150 ft., with 200? ft. of black shale above.		
Wyandotte, 2610 ft.		
Note that it changes to limestone in about 10 feet also at Monroe, and the gas is a few feet down. The black shales also appear above, but the thickness assigned is very irregular.		

Note that it changes to limestone in about 10 feet, also at Monroe, and the gas is a few feet down. The black shales appear also above, but the thickness assigned is very irregular.

Dundee. At Dundee, in the western part of the county and in the old Macon or Christiancy, now Bullock, quarry are two other wells which reached the Trenton. The first was drilled in the quarry then owned by Mr. R. H. Nogard. Owing to the secrecy about the results, the citizens of Dundee inferred that success had been obtained and drilled another well the next year (1888) on the A. Wilkinson farm one mile south of the village. Both wells were failures. The Dundee well penetrated 144 feet of the Trenton formation and a little oil and gas were found, both of which "disappeared." The sandstone, possibly belonging to the Sylvania horizon, yielded some gas from 193 to 205 feet.

Comparing the record of the Potter well with that of the Dundee the top of the Trenton drops 483 feet in about 15 miles. This is equal to a dip of 32 feet per mile to the northwest.

NOGARD WELL.

Loc.: In the Nogard (Macon or Christiancy) quarry, N. W. ¼, N. W. ¼, sec. 8, T. 6 S, R. 7 E.

Elevation 660 ft. A. T.	Thickness, feet.	Depth, feet.
Dundee and Monroe:		
Gray limestone	59	59
Monroe (including Salina) and Lower Dundee?		
Buff and white limestone	100	159
Blue limestone	150	309
Buff and blue limestone	260	569
Oil limestone	100	669
Buff limestone and brown marble	600	1269
Oil limestone	151	1420
Niagara:		
Snow white marble	100	1520
Red, white and blue marble	400	1920
Medina:		
Shale	30	1950
Utica:		
Gray, black and brown slate	200	2150
Trentone limestone:		

DUNDEE WELL.

Loc.: A. Wilkenson farm 1 mile south of village, N. E. ¼, N. E. ¼ sec. 25, T. 6 S. R. 6. E.

Elevation 680 ft. A. T.	Thickness, feet.	Depth, feet.
Pleistocene or surface:		
Quicksand	8	8
Clay	30	38
Dundee and Upper Monroe?:		
Gray oil limestone	65	103
Upper Monroe or Detroit River Series:		
Sulphur limestone	70	173
Dark limestone	20	193
Fine gray sandstone, (Sylvania?) gas	12	205
Blue gray limestone	30	235
Sylvania:		
Gray sandstone	18	253
Fine limestone	105	358
Hard shell limestone	40	398
White sandstone	7	405
Lower Monroe or Bass Island Series:		
Dark limestone	48	453
Hard shell limestone	45	498
White putty limestone	70	568
White putty limestone, very hard	50	618
Buff limestone	220	838
Alternating blue, gray and brown limestone	315	1153
Fine buff limestone	10	1163
Gray limestone	7	1170
Buff limestone	23	1193
Niagara:		
Guelph dolomite—		
Light gray marble	15	1208
Snow white marble	135	1343
Lockport limestone:		
Dark blue marble	80	1423
Red marble	15	1438
Pinkish gray marble	35	1473
Rochester shale:		
Blue slate	30	1503
Clinton:		
Gray limestone (mineral water)	60	1563
Medina:		
Red slate	60	1623
Lorraine (Hudson River) or Maysville:		
Gray slate	100	1723
Blue slate	110	1833
Utica shale:		
Brown slate	300	2133
Trenton limestone	144 +	2277

Milan. About 1900, a well 890 feet deep was drilled at Milan just a few rods south of the Washtenaw-Monroe county line. Later this well was deepened to 1643 feet, penetrating the Niagara. Water was struck at various horizons as in the Dundee, below 298 feet in the Upper Monroe, in the Sylvania below 535 feet, and in the Lower Monroe at 845 and 890 feet. Probably water was also struck in the top of the Upper Monroe.

MILAN WELL.

Loc.: At Milan a few rods south of the Washtenaw-Monroe county line. Depth, 1643 ft.

Elevation 685 ft. A. T.	Thickness, feet.	Depth, feet.
Pleistocene or surface:		
Clay, quicksand about 60 ft. and clay	130	130
Traverse:		
Cherty limestone	30	160
Blue shale	45	205
Blue shaly limestone	65	270
Limestone (fissure?)	28	298
The top of the Dundee cannot be clearly made out owing to the caving. It is surely somewhere between 165 and 298 ft, more probably at or near the latter figure.		
Dundee:		
Limestone quite fine, H_2S water (brecciated and caving)	97	395
Upper Monroe or Detroit River Series:		
Dolomite acicular, caving to 425 ft	30	425
Dolomite sandy	10	435
Dolomite with gypsum	20	455
Gypsum, mainly	80	535
Sylvania or Middle Monroe:		
Sandstones, pebbly at 820	288	823
Lower Monroe or Bass Island Series:		
Various veins of water, calcareous shale	7	830
Dark oily dolomite, more sulphuretted water	15	845
Cherty dolomite	45	890
Blue with mineralized water at 890 ft.		
With some black specks mixed	100	990
Blue clay shale	5	995
(Compare Britton 1015 ft.).		
Dolomite	30	1025
Salina?		
Anhydrite	75	1100
Dolomite	110	1210
Anhydrite	90	1300
Red, then blue shale	100?	1400
Brown, oily dolomite, fine, laminated	75	1475
Dolomite	65	1540
Rock salt	5	1545
Niagara?:		
Dolomite	98	1643

Newport. Northeast of Monroe, a well was drilled on the estate of C. H. Buhl, Berlin township. From samples taken every 20 feet, the following log was compiled.

NEWPORT WELL.

Loc.: N. E. ¼, S. W. ¼, sec. 1, T. 6 S., R. 9 E. Depth 910 ft.

Elevation 585± ft. A. T.	Thickness, feet.	Depth, feet.
Pleistocene or Surface:		
Rusty pebbly clay	3	3
Lower Monroe. (Salina not separated off):		
Drab dolomite, considerable muddy residue. Fragments of calcite, and considerable anhydrite	80	83
Light drab dolomite, with dark shaly fragments. Considerable muddy residue. Anhydrite and sand grains present	10	93
Samples not saved	72	165
Dark dolomite with carbonaceous flakes, which burn with flame. Brisk effervescence. Anhydrite and sand grains present	30	195
Bluish-drab dolomite. Anhydrite is present. Flow of fresh water from 195 to 220 ft.	52	247
Samples wanting	58	305
Bluish gray dolomite, carrying anhydrite and some selenite. Much muddy residue. Further flow of fresh water	10	315
Bluish gray, argillaceous dolomite. Some anhydrite present throughout	57	372
Buff dolomite with much yellow residue. The insoluble portion contains numerous rounded grains of quartz, some horn-blende and some black non-magnetic grains, which are probably some form of titanic iron oxide. Anhydrite	48	420
Bluish dolomite. Drillings are coarse. Lumps of anhydrite with fragments of dolomite	15	435
Quite similar to the bed 372 to 420 ft. Drillings are fine and looser as contrasted with the beds just above and just below. Much anhydrite is present	13	448
Practically identical with bed 420 to 435 ft. A bluish dolomite, drillings coarse. Anhydrite present in lumps	19	467
Bluish, dolomitic shale. Slow eff. Much bluish, muddy sediment. Some anhydrite	33	500
Bluish drab, argillaceous dolomite. Lumps of anhydrite and black flakes	20	520
Bluish, dolomitic shale, essentially similar to that occurring from 467 to 500 ft. Fragments of anhydrite with shale	40	560
Blue and drab dolomite. Drillings fine. Fragments of anhydrite	38	598
Drab to gray dolomite. Anhydrite and some sand grains. Lower portion of bed is more impure	17	615
Drab to gray dolomite, with varying amounts of anhydrite	105	720
The fine samples from this bed are all alike and more buffish than those from above bed. The rock is a dolomite also, containing seams of carbonaceous matter, fragments of anhydrite and scales of selenite. For some reason, the rusty iron grains are exceedingly abundant in all samples. (Rusted fragments of steel from drill?)	95	815
Drillings have a gray color and under the magnifier look much like pure anhydrite. Slow eff. The rusty grains are not quite so abundant, but are numerous	10	825
The drillings from this bed are a purer white than above. Little eff. Much anhydrite	8	833
Gray to drab dolomite with fragments of anhydrite and scales of selenite	11	844
Samples missing	16	860
Bluish gray dolomite. Drillings relatively coarse containing bluish flakes and fragments of anhydrite	50	910

Ida. In 1893, a deep well was drilled at Ida from which a more complete record was obtained than from the Potter well. This is located on the Simeon Van Akin property, N. E. ¼ of N. E. ¼, sec. 3 of Ida township. The altitude of the well is about 640 feet A. T. A pipe was driven 22 feet into the rock before drilling began. Ten feet of "common limerock" was found to overlie 45 feet of Sylvania

sandstone. Gray limestone (dolomite) followed to 320 feet where a light blue shale was struck. After going through this shale a darker limestone than the overlying beds was entered and at about 480 feet gas was struck in considerable quantity, the flow increasing for the next 60 feet. At 700 feet, 100 feet of "light colored rock" was struck. The drilling reached a depth of 1200 feet when work was suddenly stopped.

Riga. About 1899, a well 1700 feet in depth was sunk at Riga, Monroe county, but owing to disputes and legal troubles very little was learned of the record. Dr. Lane examined some of the samples from 1165 to 1275 feet and thought that they appeared to be the white dolomites of the Upper Niagara. Judging from other drillings in the county, it is about the depth at which it should occur.

South Rockwood. There are several other deep wells in the county of which no log, or at best only a part of a record has been obtained. Near South Rockwood the Frey well, N. E. ¼ of N. E. ¼, sec. 33, T. 5 S., R. 10 E., is said to have penetrated 12 feet of salt at about 1200 feet. No mention is made of the occurrence of oil and gas. About 1903 another well, the Lennard, 2430 feet deep was drilled near the swinging bridge over Huron river. The record is very poor and the "sand" in the record may mean only granular limestone or dolomite.

LENNARD WELL.

Loc.: Near swinging bridge over Huron river, South Rockwood.

	Thickness, feet.	Depth, feet.
Surface	30	30
Sylvania?:		
White sand	30	60
Black	30	90
Record missing from 90-950 feet,		
Sand	100	1050
Lime	80	1130
Sand	155	1285
Clinton?		
Red rock (Cf. Strasburg 1300-1340 ft. or 1140-1170, which is 584 ft. above Trenton.)	10	1295
Lorraine and Utica:		
Slate	45	1340
Sand, water	65	1405
Shale	....	2045
Dark at bottom. Smell.		
Trenton at 2430 ft.		

LENAWEE COUNTY.

The belt of rocks over which surface signs are most abundant in southeastern Michigan crosses the northwestern part of Monroe into Lenawee county and consequently exploration has extended westward into the latter county. There are a number of deep wells in this county, chiefly in the eastern half as at Britton, Blissfield, Adrian and Clinton.

Adrian. At Adrian a well 1650 feet in depth was drilled by the Adrian Gas Co. It probably reached the top of the Salina, but does not appear to have encountered any marked signs of either oil or gas. The Berea was present as a gray sandstone and the Antrim as a brown shale. Inasmuch as drillers make no distinction between limestone and dolomite the Dundee cannot be separated in the record. Water or brine was probably struck in the Berea, though not noted in the records; mineral water was encountered at 805 feet, sulphur water at about 940 feet, brine in the Upper Monroe at about 1135 feet, and more brine in the Lower Monroe at 1520 feet.

ADRIAN GAS CO. WELL.

Loc.: Adrian. No samples.

Elevation 810 ft. A. T.	Thickness, feet.	Depth, feet.
Pleistocene:		
Surface	20	20
Quicksand	18	38
Gravel	60	98
Gravel and quicksand	82	180
Coldwater shales:		
Sandstone, light gray	4	184
Soft white "slate" or sandstone	330	514
Sunbury (Berea):		
Brown "slate" (shale)	40	554
Berea:		
Gray sandstone	30	584
Antrim:		
Brown "slate"	80	664
Brown shale	141	805
Traverse (Hamilton) Formation:		
Mineral water at 805 ft.		
Reddish hard limestone. (Mouth of driving pipe 180 ft.; casing to 500, then the second time to 885 ft.)	80	885
Black slate or shale. Regular limestone at 900 ft	15	900
Dundee (Corniferous) and Monroe:		
Limestone, hard, dark drab to gray	750	1650 +
Sulphur water at 940, brine at 1135 and 1520 ft.		
Lorraine:		
Slate rock, white and soft (or anhydrite?)		

Britton. The Britton well, 1700 feet in depth, was drilled about 1900. At 1400 feet and at 1500 feet brown oily dolomites were struck as in many other wells in southeastern Michigan, but no showing of oil was observed.

On the lot of John Wiggin in Britton near the above well, a shallow one 90 feet deep was put down for water and a pocket of gas was struck, the glow of which, when lighted, could be seen in Tecumseh about six miles away. The original pressure increased from 35 to 41 pounds, which would be about equal to the hydrostatic head.

BRITTON WELL.

Elevation 705 ft. A. T. (Approx.)	Thickness, feet.	Depth, feet.
Pleistocene:		
Surface clay and gravel	93	93
Antrim shale:		
Black shales	67	160
Pyritiferous gray shale	15	175
Pyritiferous black shale	35	210
Traverse Group:		
Cherty dolomite	25	235
Green shale	30	265
Cherty dolomite	40	305
Blue calcareous shale	95	400
Dundee (Corniferous, Onondaga) limestone:		
White or brownish crinoidal limestone with water and traces of oil and gas	100	500
Upper Monroe or Detroit River series:		
Gypsiferous dolomite	75	575
Gypsum (Anhydrite)	50	625
Dolomite	50	675
Dolomitic limestone	33	708
Dark cherty dolomite	37	745
The same, bluer	5	750
Sylvania:		
Dolomitic sandstone	25	775
Gypsiferous dolomites	50	825
The same with a little chert and sand	75	900
Dolomitic sandstone, salt water	100	1000
Shale	15	1015
Casing to 1012 or 1015 ft.		
Dolomite, dark blue at 1180 ft	485	1500
Rope black, and H_2S at 1200, where there is a slow very salt seepage. There was said to be 30 ft. of brown oily dolomite at 1400 ft.?		
Dark brown oily dolomite	50	1550
Niagara:		
Light white sugary dolomite, typical Guelph	84	1634
Mineral water at 1600 ft.		

Blissfield. The Blissfield well, one of the deepest in the southeastern district, penetrated the Trenton, but unfortunately only a meager record from memory could be obtained.

BLISSFIELD WELL.

Loc.: Sec. 30, T. 7 S., R. 5 E.

	Thickness, feet.	Depth, feet.
Drift	100	100
Gravel; water rose and filled first 8 inch casing	20	120
First limestone about [to ? dark slate and black water]	300	420
Water in limerock at 1600 ft.		
Struck Trenton at 2342 ft.		
Trenton rock	60	2402

Manchester. Six miles southeast of Manchester a well was drilled about 1904 by the Manchester Oil Co. It is said to have reached only a depth of 690 feet and appears to have stopped in the Traverse shales. There is some doubt as to the exact correlations, but the record as made from well samples by the U. S. Geological Survey is given below.

MANCHESTER WELL.

(U. S. Geological Survey Well No. 25).

Loc.: Six miles southeast of Manchester, Washtenaw county. Manchester Oil Co., owners. C. A. Elliot, driller.

Elevation about 830 ft. A. T.	Thickness, feet.	Depth, feet.
Surface	174	174
Coldwater:		
Blue shale	153	327
Berea:		
Horizon of Berea? Red shale	2	329
This red shale clay might represent a weathered surface, or some other zone of special oxidation. The banding upon it is quite distinct. Compare Bedford shales. Compare Hillsdale at 1030-1033, Osseo 800, Adrian, 514.		
Antrim:		
Usual shale	12	341
Black shale. This looks very much like the Ohio black shale, and would seem to indicate that the horizon of the Berea here is at 327-329	11	352
Bluish shale	48	400
Blue shale	90	490
Brown shale	110	600
Compare Hillsdale 1350, Osseo 1145-1214, Adrian 805, Madison Oil and Gas Co. 665.		
Traverse (Hamilton):		
Gray shale; non-eff	60	660
Gray shale; slightly eff	30	690

"The samples from 600 feet down might quite likely be Traverse or they might be a gray streak in the Antrim. From 327 feet down to 600 feet, or thereabouts, should be Antrim."—Lane.

According to Lane, this well is near and perhaps the same well as that of U. Arnold about two miles from Clinton, sec. 2, T. 4 S., R. 3 E. In the Arnold well, brine was reported at about 1000 feet.

Madison Township. In 1905 the Madison Oil & Gas Co. drilled a well 764 feet in depth on the Snedeker farm, N. E. ¼ of sec. 15, T. 7 S., 3 E. From the character of the water near the bottom of the well Dr. Lane believes that it did not reach the Dundee oil horizon. Water was struck in the black shales of the Antrim from 612 to 618 feet. At this horizon there was a trace of gas also. To have reached the Trenton the well very probably would have had to go 2000 feet below the base of the Antrim.

MADISON OIL AND GAS COMPANY WELL.

Loc.: N. E. ¼ of sec. 15, T. 7 S., R. 3 E.

	Thickness, feet.	Depth, feet.
Pleistocene:		
Sand	20	20
Clay and sand	60	80
"Sand and gravel, dark and light"	115	195
Coldwater:		
Shale, with shaly till? "clay and gravel, dark"	55	250
Blue and light shale, with occasional calcareous streaks	165	415
Gritty shale	15	430
Sunbury shale:		
Black shale	20	450
Berea grit:		
Very fine grained sharp white sandstone or flagstone, salty	50	500
Antrim:		
Bituminous black shale with pyrite	112	612
At 612 to 618 ft. main water, with a trace of illuminating gas. About 14 per cent salts, sulphates low.		
Sandy black shale	53	665
Brown limestone (oily)	15	680
Dark or black shale	20	700
Traverse:		
Brown dolomitic limestone, with white chert	64	764

"The beds in which the well closes are probably not much above those in which is the top of the Wyandotte well, which struck Trenton rock at 2610 feet. The limestone at 665 or 700 feet probably corresponds to that at 420 feet in the Blissfield well, which reached the Trenton at 2342 feet; and to that at 350 to 385 feet beneath South Bend, where the Trenton was reached at 1585 feet. The salt beds along Detroit River thin rapidly to the south and west, but at Adrian from the Devonian black shale or Antrim down to the Trenton is probably not less than 2000 feet. In view of the dolomitic character of the limestone, the strength of the water and its relative freedom from sulphur I do not think this well has yet reached the Dundee, the oil bearing horizon of Port Huron and Canada around Petrolia. Two hundred feet more should go well into it.''—Lane.

HILLSDALE COUNTY.

Hillsdale. Several deep wells have been drilled in Hillsdale county. At Hillsdale two were bored in the courthouse square, respectively 1350 and 1550 feet in depth. The log of the deeper well, given below is a very poor record compiled from hearsay accounts.

HILLSDALE WELL.

	Thick-ness, feet.	Depth, feet.
Drift	?	?
Soft laminated micaceous sandrock	?	20
Mainly bluish shales with arenaceous seams and harder, probably calcareous ledges. The color of the shales became dark, bituminous, in the lower part (Sunbury?)	1100	1120
Hard red rock with much iron pyrite, and strongly saline water	230?	1350?
Fifty feet of white limestone	50?	1400?
Soft calcareous rock to end	150?	1550

Osseo. At Osseo, C. M. DeWitt drilled a well 1430 feet in depth. According to Mr. DeWitt, gas and oil were struck just below black and brown shales (Antrim) from 1219 to 1259 feet, gas again at 1380 feet and oil and gas below 1400 feet. The ''big flow'' of gas came at 1400 feet, and the oil just below 1420 feet. The first oil and gas horizon appears to be in the top of the Traverse, while the lower one is quite probably in the Dundee. *An Atrypa reticularis* from the oil horizon, indicates that it was probab'y that of the ''bastard Trenton'' or Dundee, and certainly not that of the Trenton proper.

The well was filled for about 150 feet with stone and cement and the gas rock above was shot. The gas, originally having a pressure of about 70 pounds, was nearly sufficient to fire the 25 H. P. engine used in pumping the mineral water which was struck in abundance below 1229 feet. The pressure has since decreased to about 38 pounds. According to Mr. DeWitt, the cement filling in the bottom of the well did not set, or only partially, so that a heavy lubricating oil can be obtained after the 1100 foot head of water is pumped off.

OSSEO WELL.

C. M. DeWitt, owner. Lige Curry, driller, Bradner, Ohio.

(Record from a few samples and data furnished by C. M. DeWitt.)

Elevation about 1065 ft. A. T.	Thick-ness, feet.	Depth, feet.
Drift	214	214
Coldwater shale:		
Blue shales	700	914
Berea? (Apparently horizon absent or not recognized.)		
Antrim shale:		
Brown or black shales	231	1145
Stray ''oil sand''	5	1150
Black shale, pyritic, odor of petroleum	64	1214
Traverse (Hamilton) Formation:		
Pepper and salt	5	1219
Dark brown rock, gas	5	1224
Lighter brown rock, more gas	5	1229
Lighter rock. Some oil and more gas. 100 ft. of salt water in well	30	1259
Lighter rock. Water rock very light or hard salt ''sand.'' 400 ft. of mineral water in well	20	1279
Very light hard rock or ''salt sand.'' Fine drilling	25	1304
Light rock becoming darker with bluish cast (shaly?)	21	1325
Rock of a bluish cast (shaly?)	25	1350
More salt water bearing rock	30	1380
Dundee:?		
Brown rock. Heavy flow of water and gas. Water rose to within 330 ft. of the surface	20	1400
The ''Trenton'' (Dundee limestone) with showing of oil and big flow of gas	20	1420
Light brown rock of yellowish cast. Pebble oil rock, very porous	10	1430
Well afterwards filled in with cement and stone for 150 ft. and gas rock shot. ''Lots of oil if head of water is pumped off.'' Gas pressure originally 70 pounds.		

The exact top of the Dundee is not certain from the above record, but it is probably between 1380 and 1400 feet. From this, the dip north-northeast to Jackson would be about 20 feet per mile. Making the comparison for the base of the Antrim in the two wells, the dip is a little over 22 feet per mile.

WAYNE COUNTY.

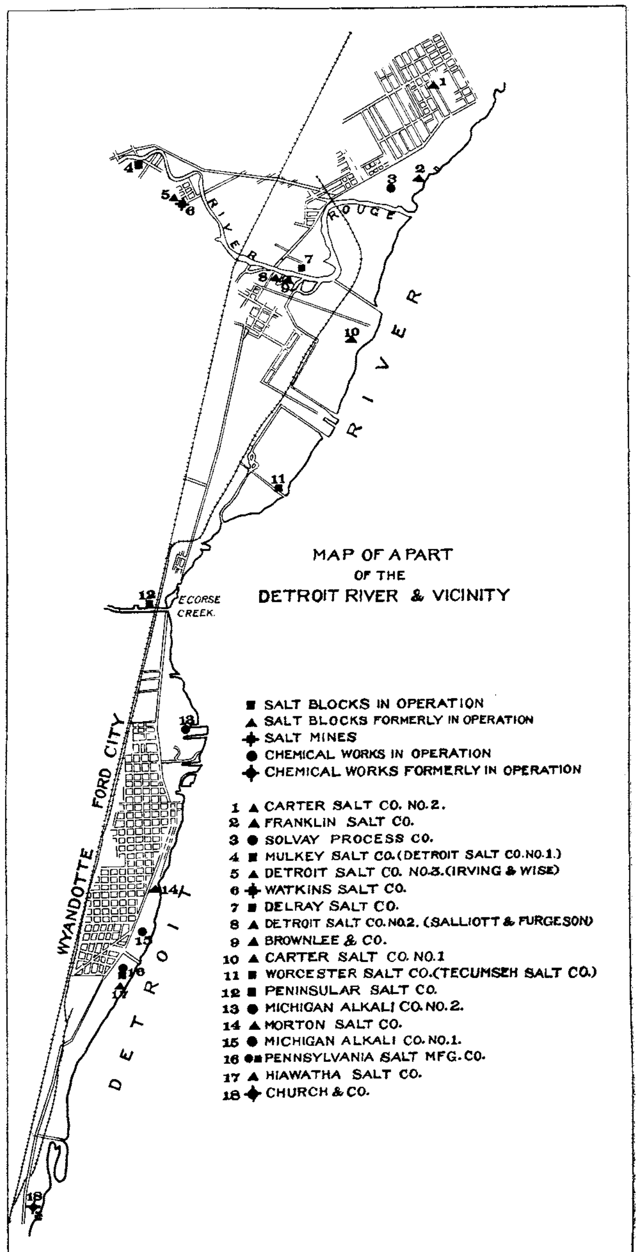

Figure 9. Map showing the location of salt blocks and salt wells in Wayne county (after C. W. Cook).

Trenton. In Wayne county, wells are very numerous, especially along Detroit river where many have been put down for salt (Fig. 9). At Trenton there are six wells of which the record of No. 5 of Church & Company is given below. The well yielded an odor of gas at the bottom.

CHURCH & CO. WELL NO. 5.

Loc.: Church & Co. plant, Trenton.

Elevation about 580 ft. A. T.	Thickness, feet.	Depth, feet.
Surface	75	75
Dundee and Upper Monroe undivided:		
Limestone; moderate to brisk eff	65	140
Limestone; fairly brisk eff.; darker and coarser splinters than beds below; Allegan well 1260+ and St. Clair River 520 ft. resemble the top of the Trenton; light brown limestone	10	150
Limestone fine grained and light buff, moderate to brisk eff	40	190
Samples missing, doubtless limestone	30	210
Genuine limestone, very brisk eff., Amherstburg, Anderdon quarries	10	220
Dark brown limestone, moderate to very brisk eff	20	240
Limestone and dolomite	10	250
Sample missing, probably limestone or dolomite	10	260
Limestone and dolomite with bluish tinge	10	270
Dolomite	10	280
Sylvania or Middle Monroe:		
Fine grained white sandstone	120	400
Dolomite with chert	10	410
Fine white sandstone with white chert	10	420
Sample missing	10	430
Very calcareous sandstone	10	440
Pure white sandstone	10	450
Sandy limestone or dolomite	10	460
Pure white sandstone; water	10	470
Dolomitic sandstone	10	480
Lower Monroe:		
Dolomite with scarcely any sand	10	490
Dolomite, moderate eff. at top, slower toward bottom	110	600
Very fine grained calcareous marl, fairly rapid eff	10	610
Dolomite, with little or no gypsum	60	670
Much white chert with shaly streaks down to 660 ft.		
Dolomite and anhydrite	60	730
Mainly dolomite and anhydrite	70	800
Moderate eff. in places. Dark bluish shales	10	810
Compare Wyandotte at 800-860 ft., Ford No. 23, 700-735 ft.		
Gypsiferous dolomite passing into bluish gypsiferous shales	30	840
Anhydrite with fragments of green shale	30	870
Salina:		
Nearly pure gypsum	20	890
Cream colored dolomite, gypsiferous	40	930
Buff dolomite	20	950
Dark shale	10	960
Blue light yellow and buff dolomite	20	980
Brown dolomite and blue, green and gray shale	10	990
Dark bluish gray shale with buff dolomite and bluish gray gypsiferous beds	10	1000
Bluish shale, gypsiferous at times	170	1170
Light buff or cream colored dolomite	20	1190
Largely bluish shales, gypsiferous	50	1240
Dark dolomitic shales, dolomite, anhydrite at 1280 ft. and bluish to brown dolomites below	50	1290
Buff dolomites	80	1370
Smell of gas at 1310 and 1340 ft.		

No rock salt was struck in this well, but, in the other Church & Co. wells located 200 to 300 feet north, a single bed, varying in the dif-