

THE IRVINE OIL FIELD, ESTILL COUNTY, KENTUCKY.

By EUGENE WESLEY SHAW.

INTRODUCTION.

HISTORY.

Oil and gas were discovered about 65 years ago in borings made for coal 3 to 6 miles northwest of Estill Furnace, 10 miles northeast of Irvine, Ky. Concerning these wells Lesley¹ says:

In this valley [Hardwick's] coal has been bored for—the Devonian black slates having been mistaken for those belonging in the coal measures. In one of the borings the upper portion of the auger was blown out into the air by gas.

Another well was drilled by Samuel T. Vaughn, and Lesley¹ reports that “the auger dropped into a cavity, and when withdrawn salt water was blown out for a short time, which soon gave place to the present flow of rock oil.”

Oil was known to be present at Irvine at least as long ago as 1878, for Davie,² speaking of this locality, says: “Several borings have been made for salt water which have at various depths struck both salt water and petroleum or coal oil of good quality.”

For many years oil with some gas was obtained from a small field known as the Irvine or Ravenna field, which lies from 1 to 3 miles south-southeast of Irvine, in and around Ravenna, and was found to extend southward across Kentucky River into the valley of Little Doe Creek and northward into the hills north of Ravenna. The production and promise of the field became sufficiently great to justify the laying of a pipe line, but the rate of production

¹ Lesley, Joseph, Topographical and geological report of the country along the outcrop base line following the western margin of the eastern coal field of the State of Kentucky from a survey made during the years 1858-59: Kentucky Geol. Survey Fourth Rept., p. 472, 1861.

² Davie, W. J., Kentucky, its resources and present condition: Kentucky Bur. Agr., Hort., and Stat. First Ann. Rept., p. 340, 1878.

gradually decreased, and a good many unsuccessful tests were made about the margin of the pool. Finally the pipe line was taken out, and the wells were abandoned, though some of them were still capable of producing a little oil.

Early in 1915 oil was discovered on Tick Fork, 5 miles northeast of Irvine, in a test well sunk on land held by Mapel & Co. This discovery led to renewed activity, although money was spent with some caution on account of the notion that the pool was likely to be small and short lived. This notion was based on the feeling that a rather large proportion of the test wells in Kentucky were unsuccessful, or at most light and short-lived producers. As a matter of fact the proportion of unsuccessful wildcat wells does not seem to be much higher than in other States, but a good many prospectors seem to have drilled first a well of light capacity and then several dry wells, whereupon they have quit the State in disgust. The experience of oil men in the Irvine field seems to have redeemed the State's reputation, which may have declined because expectations were too high. One company is said to have obtained 118 successful wells out of 123 drilled. Although Kentucky may never be so productive of oil as Pennsylvania, yet it doubtless contains many undiscovered pools, and some of them will, like the Irvine pool, yield their oil at little cost, for they lie not far below the surface. On the other hand, there is danger that expectations will be raised too high and that money will be spent foolishly. On account of the fact that compared with the pools in West Virginia and Pennsylvania the Kentucky pools may be small and far apart, a wildcat well should be located only after a careful attempt to determine the most promising spot.

The field grew very slowly in 1915, particularly in the spring and summer. Under date of December 25, 1915, a correspondent of the *Oil and Gas Journal*¹ states that there are 50 producing wells and adds:

These wells are capable of producing from 5 to 200 barrels per day. This statement would seem out of reason in view of the little that has been said about the field, were the facts not verified by actual gages. Some of the wells have been standing many months, as it has been but recently that any provisions have been made for taking care of the production. The field would have been much further advanced than it is at present, were it not for the fact that, as usual, everybody was skeptical, and the pipe line refused to make any preparations for handling the product. Consequently, those who had faith in the merits of the field had to go on investing their money without receiving any returns until recently. The Cumberland Pipe Line Co. laid a line into the field from the railroad at Irvine and installed a loading rack, together with storage tanks, and the first oil was run through its lines last week. * * *

¹ Irvine field becomes interesting: *Oil and Gas Jour.*, vol. 14, No. 30, pp. 20-24, 1915.

There has not been a single failure scored within defined limits, although during the two years that operations have been going on about a dozen dry holes have been drilled in territory surrounding the present field. These were mostly drilled during the early stages of developments and have served as a guidepost along the highway for the fellows who came after and were valuable in helping to establish the present defined limits of the field. Another unusual feature of the development in this field has been the lack of publicity received from the press of the country. Since the beginning of developments, more than two years ago, scarcely any mention of the field has been made. * * *

The pay is found in the top of the sand, although most of the wells are generally drilled 15 to 17 feet into the formation. The wells produce but little gas, but if drilled too deep there is danger of striking salt water. The oil itself is of 33° gravity and has a paraffin base. It is rather low in gasoline and other volatile substances, but otherwise it is a very fair grade of oil. * * *

This, however, is not the first experience Irvine has had in the oil business. About 10 or 12 years ago local parties, operating under the name of the Estill County Oil & Gas Co., opened a shallow pool just northeast of town and lying between Irvine and the present field. At one time they were operating 63 wells and sold several thousand barrels of oil to the Cumberland Pipe Line Co. The property changed hands two or three times and, after being in operation for some five or six years, eventually fell into the hands of junk dealers at Marietta, Ohio, who pulled the wells out and abandoned them.

The field grew much more rapidly in 1916, especially after about the middle of the year, when the pipe line to Campton was completed.

In the Irvine field nearly a thousand wells have now been drilled, and on the whole the decline of each has been comparatively slow. A well a third of a mile south of the discovery well, known as Hillis & Co. No. 1, Dan Rawlins, has now been pumped over two years, and its capacity is said to be nearly as great as at first.

In November, 1916, the field was producing about 5,000 barrels a day, from about 550 wells, or considerably more oil per day than all the rest of the State, which probably yielded less than 500,000 barrels in 1916. The Oil Trade Journal¹ makes the following statement concerning the field on February 20, 1917: "On a close estimate if all the wells could be pumped to their full capacity the production would be 30,000 barrels daily."

If this statement is correct and the capacity were to remain the same for a year, the field could produce in that time 10,950,000 barrels, or more than all the remainder of Kentucky has produced in the entire half century during which the oil industry has existed in that State. The field is still being vigorously developed, and its capacity for oil production is increasing. The quantity actually marketed in 1917 will probably be about 1,600,000 barrels.

In this report the continuous area underlain by oil and gas to the northeast of Irvine will be called the Irvine field, and that to the southeast the Ravenna field. Oil and gas have also been found to

¹ Development is active in Kentucky: Oil Trade Jour., vol. 8, No. 3, p. 107, 1917.

the southwest, in the vicinity of Station Camp, and this area will be spoken of as the Station Camp field. The bodies of oil and gas under these areas are called, respectively, the Irvine pool, the Ravenna pool, and the Station Camp pool. The report is, however, intended as a description of the Irvine field and pool, and the others will be referred to only incidentally. As oil is the main product of the field, it will be called the Irvine oil field. Other fields in the same region are shown on Plate XI.

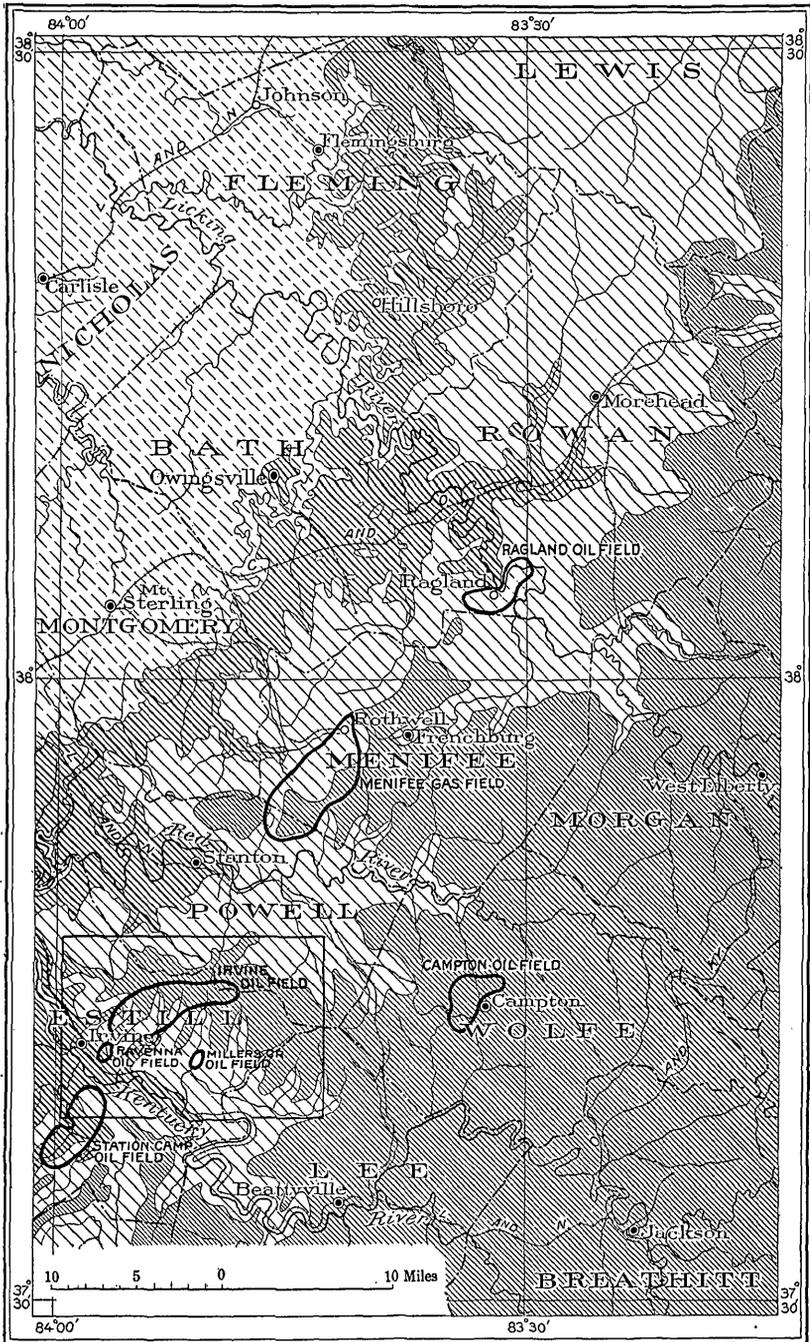
GENERAL FEATURES OF THE RAVENNA OIL FIELD.

The Ravenna or, as Hoeing called it, the Irvine oil field, is described by him¹ as follows:

Estill County field.—In the field near Irvine the majority of the wells start below the Waverly in the black shale itself and strike the oil rock at depths of from 70 to 90 feet. The white shale (white fire clay of the drillers) shows in places near the base of the black shale and above the oil rock, as at Ragland, and in other parts of the field is cut out. The oil rock is the Corniferous and shows in outcrop about a mile west of the oil field, along the railroad and in the town of Irvine, underlain by the Niagara shales in considerable thickness, probably 75 to 85 feet of the latter showing in a drain between the railroad depot and Irvine. In the wells a white limestone carrying fresh water is reported directly under the oil rock. An examination of the outcrop proved this to be the bottom ledge of the Corniferous. (As explained on a preceding page, by Corniferous here is meant the whole limestone formation from the top of the Niagara shale to the base of the black shale. The lower two or three ledges may belong to the "water lime" of Ohio and the Niagara limestone, below the Corniferous proper.)

This Estill County field illustrates very nicely the anticlinal theory of the storage of oil in the rocks. Just at the edge of Irvine on the east is the top of what was an anticlinal fold but one which broke at the top. Between the railroad bridge over the river and the crossing at Main Street the Corniferous is exposed in the railroad cuts with the black shale over it and the Niagara shale under it. Near the bridge a fault brings the black shale down close to the river; between the bridge and town several small faults show, but the rocks are nearly horizontal; at the Main Street crossing the Corniferous shows in a cut on the west side and a fault or uplift shows very plainly at the same place. This fault brings the top of the Niagara shale on the east side of Main Street above the level of the top of the Corniferous on the west side of the street. From this point the rocks seem to rise very slightly to the east for a short distance, then bend and fall rapidly to the east (the Corniferous being below the river at the oil field) and form a long monocline with its axis just east of Irvine and the oil field still farther east and down the slope. Wells drilled on this monocline show, near the axis, dry holes; farther down the dip, oil; still farther down, oil underlain by fresh water; and still farther down the slope, salt water alone. The fresh water has evidently come in from the river, and the contents of the rocks have arranged themselves in order of their specific gravity, the salt water below and the oil above, the latter rising up the

¹ Hoeing, J. B., Oil and gas sands of Kentucky: Kentucky Geol. Survey Bull. 1, pp. 53-54, 1905.



Carboniferous



Pennsylvanian ("Coal Measures") Mississippian Devonian and Silurian Ordovician

GEOLOGIC SKETCH MAP OF A PART OF NORTHEASTERN KENTUCKY.

dip only far enough to keep ahead of the water, and wells above that point giving no oil.

In 1912 M. J. Munn made a brief examination of the Ravenna field, and his unpublished notes contain the following description, which is of special value because the field is now abandoned, and any information other than scattered and more or less unrelated facts concerning it is difficult to obtain:

The Ravenna field is on the western border of the eastern Kentucky coal field. The outcropping rocks extend from the Pennsylvanian series, which cap some of the higher hills and ridges, to rocks of Ordovician age exposed along Kentucky River and some of the principal tributaries. In the northern part of Estill County the general dip of the rocks to the east appears to be modified by a broad, low syncline whose axis trends almost due east. No geologic work was done to determine the exact form of this syncline, but its presence is clearly shown by the depth to the top of the "Corniferous" limestone, which is the oil and gas bearing bed in the Ravenna field, as well as in the gas field of Menifee County and the Ragland oil pool to the north.

Considerable drilling has been done in Estill County in search for oil and gas but has resulted in the development of only a single small pool in the "Corniferous" limestone and the finding of small quantities of gas in several wildcat wells at horizons below the "Corniferous."

The Ravenna field is from 1 to 3 miles southeast of Irvine, in the valley of Kentucky River and on adjacent hillsides. In this pool the "Corniferous" limestone is reached at a depth of 70 to 90 feet, the wells starting in the Chattanooga shale in the valleys. The first well was drilled in this field in 1901, and the pool was rapidly developed after that time. In 1910 it consisted of about 60 wells, none of which was producing more than a few barrels a day. In December, 1911, the pool was exhausted and completely abandoned. In this pool the "Corniferous" limestone, in which oil was found, averages about 20 feet in thickness, and the oil comes from a pay streak near the top. The pay streak is underlain by a light-colored limestone in which fresh or salt water is usually found. The "Corniferous" limestone is exposed at the top of the river bank in the town of Irvine, where certain portions show considerable traces of oil. This section of the "Corniferous" has been studied by a number of geologists, among them Kindle,¹ who has pointed out that there is an unconformity here between this limestone and the Chattanooga shale above. Kindle has shown in his paper that the Chattanooga shale at many places appears to lie conformably upon the "Corniferous," but at many other places the limestone appears to have been considerably eroded before the deposition of the Chattanooga shale.

FIELD WORK.

The investigation on which this report is based was of a reconnaissance nature, being part of a broader study of the oil and gas of the southern half of the Appalachian region, on which a general report is planned. Ten days—October 27 to November 5, 1916, inclusive—was spent in the field proper, and about five days additional in surrounding territory.

¹ Kindle, E. M., The unconformity at the base of the Chattanooga shale in Kentucky: *Am. Jour. Sci.*, 4th ser., vol. 33, pp. 120-136, 1912.

One of the principal objects of the field work was to determine the structure or lay of the oil-bearing stratum, for such studies throw much light on the causes of accumulation of oil pools and lead to a reduction in the percentage of unsuccessful tests through making it possible to point out promising and unpromising places to drill.

The structure of the Irvine oil sand could have been determined by running a spirit-level line to each of the hundreds of wells which furnish data concerning depth to the sand or by running level lines along the outcrops of single beds of rock that lie more or less closely parallel to the oil sand, or by taking observations of dip and strike at many places throughout the field. The first two methods would have required more time and funds than were available. The third does not yield precise results, for exact altitudes are not obtained and the strata are so nearly horizontal that it is not possible to observe strikes and dips with precision. However, the outcrops of some of the harder beds are conspicuous, and when the field work was done many of the forest leaves had fallen, and from numerous points it was possible to see a single bed for a quarter of a mile or more. The country being rugged, these outcrops curve in and out among the mountains, and by using a hand transit it is possible to determine approximately how the beds slope from place to place. The best key rock for this purpose is the Maxville(?) limestone, known to drillers as the big lime or "Mississippi lime." Another good bed is the "Corniferous" limestone, the oil sand itself, which crops out not far from the northwestern margin of the field. (See Pl. XIII, p. 166.)

Thus the field work consisted largely in making a rough survey of the outcropping beds and in obtaining from the oil operators data concerning the wells and their output. It included the determination of the general lay of the rocks in an area surrounding the field—a determination which would have been impossible from well data and spirit-level lines alone, for, although a considerable number of dry holes have been drilled outside of the field, they are scarcely sufficient to throw much light on the structure, especially as data concerning many of them can not be obtained. When an oil prospector makes an unsuccessful test he seems inclined to forget all about it as soon as possible; but data concerning such tests are of great value to both the geologist and the prospector.

From a reconnaissance topographic map of the region, made by the United States Geological Survey 26 years ago, and data concerning the altitude of the railway tracks it was possible to determine approximate altitudes throughout the field.

The main basis of the structure map (Pl. XIV, in pocket) is a series of dip observations made at points along the cliff of Maxville(?) limestone. The observations at each point consisted in sighting with

the hand transit to all other cliffs of this limestone in sight and determining the apparent directions of dip. The amount of dip, if any, was estimated, and the result was plotted on that portion of the map representing the particular area covered by the observation. A large number of such observations bring to light the general form of the structure and thus fill the most essential purpose of a structure map in oil prospecting, but they do not yield data as to the exact altitude of any bed at any point.

ACKNOWLEDGMENTS.

The results of earlier work in the region by Lesley,¹ Campbell,² Foerste,³ Hoeing,⁴ Munn,⁵ Gardner,⁶ and others constituted an excellent foundation upon which to base the geologic studies. Mr. J. B. Hoeing, State geologist, and Prof. A. M. Miller, of the State University of Kentucky, also gave valuable data and suggestions. Prof. Miller very kindly furnished a sketch map showing faults which he had observed in the region. Special thanks are due to the many oil operators, who gladly put at the disposal of the Survey all the data in their possession bearing on the geology of the district and expressed a willingness to collect additional data.

GEOGRAPHY OF THE REGION.

The Irvine oil field, like the Menifee, Campton, and Ragland fields, lies in the mountainous country that borders the eastern edge of the blue-grass region of Kentucky. (See Pl. XI.) Kentucky River, which flows northwest past Beattyville and Irvine, and Licking River, which flows northwest through the Ragland field, are the main drainage lines of the region. Red River, a large tributary of the Kentucky, flows west between the Irvine and Menifee fields. The valleys of Kentucky River below Irvine, of Red River below Stanton, and of Licking River below Ragland are 2 or 3 miles wide, but upstream from these places the valleys are gorgelike and 400 to 600 feet deep.

¹ Lesley, Joseph, Kentucky Geol. Survey Fourth Rept., pp. 439-494, 1861.

² Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Richmond folio (No. 46), 1898.

³ Foerste, A. F., The Silurian, Devonian, and Irvine formations of east-central Kentucky: Kentucky Geol. Survey Bull. 7, pp. 1-206, 1906.

⁴ Hoeing, J. B., Kentucky Geol. Survey Bull. 1, 1905; Kentucky Geol. Survey, 4th ser., vol. 1, pt. 1, 1913.

⁵ Munn, M. J., The Campton oil pool, Ky.: U. S. Geol. Survey Bull. 471, pp. 9-17, 1912; The Menifee gas field and the Ragland oil field, Ky.: U. S. Geol. Survey Bull. 531, pp. 1-20, 1913.

⁶ Gardner, J. H., A stratigraphic disturbance through the Ohio Valley, running from the Appalachian Plateau in Pennsylvania to the Ozark Mountains in Missouri: Geol. Soc. America Bull., vol. 26, pp. 477-483, 1915.

GEOGRAPHY OF THE IRVINE FIELD.

LOCATION AND AREA.

The limits of the Irvine field as now developed may be described as extending from a point $1\frac{1}{2}$ miles northeast of the Irvine station, in a north-northeasterly direction 5 miles to Union Hall; thence east 5 miles to a point beyond Estill Furnace; thence curving sharply southward and southwestward around to Fitchburg, a distance of about 3 miles; thence west-southwest 6 miles down the north side of Cow Creek valley and northwest a mile or so to the starting point. The length of the field is about 9 miles and its maximum width 2 miles. The farms now producing oil have an aggregate area of about 15 square miles, exclusive of scattered outside farms under which has been found oil that is not known to be connected with the Irvine pool. The field proper is now being developed most rapidly to the east.

DRAINAGE.

Most of the surface drainage of the Irvine oil field takes a south-westward course into Kentucky River by way of Cow Creek and its tributaries, Campbell Fork, Cottage Fork, and Rockhouse Fork. A small stream known as Sweet Lick Branch flows along part of the northwest border of the field, and a larger stream, Whiteoak Creek, which is about 6 miles long, has a parallel course a mile to the northwest. In a few places the northern limit of the field has been pushed across the divide and into the drainage basin of Red River.

RELIEF.

The altitude of the surface in and near the Irvine field ranges from about 600 feet in the channel of the river at Irvine, or 633 feet at the railway station, to nearly 1,500 feet at several places along the divide that runs close to the northwestern and northern boundary of the field, and a little more than 1,500 feet at High Rock, 3 miles to the northeast. This divide, like many others in the region, has a rather even crest, though in places it is as low as 1,250 feet above the sea. The ridges are strikingly uniform in height, without regard to the underlying formation, and from this it is evident that the region was once a plain and that the mountains have been made by the uplift of the region and the gradual deepening of all valleys by stream erosion.

The surface is so rugged and rocky that the shape and arrangement of the valleys and ridges are of prime importance to the oil operator, who must transport heavy machinery and pipe to all parts of the field. The valley sides are so steep that almost nowhere except on the roads can any hauling be done.

ROADS AND TOWNS.

The roads of this part of Kentucky are comparatively poor. Partly through the efforts of the oil men some of the roads in and around the Irvine field have been improved to a moderate extent, but almost no macadamizing or other dressing has been done, though limestone is abundant in all parts of the district. In Irvine some of the streets are now being surfaced with gravel and hard black shale of the Ohio (Chattanooga) formation. There is much complaint among oil operators concerning the roads, and it is said that they have offered to pay half the cost of macadamizing some of the more important roads but that such offers have not been accepted.

The main roads follow either divides or valley bottoms, and there are only a few connecting roads. The best and most traveled road of the field runs from Irvine southeast for 2 miles and thence northeast up the valley of Cow Creek. From this road branches run up the valleys of tributaries; a poor one runs up Sweet Lick Branch and a somewhat better one up Whiteoak Creek, a mile to the northwest. On the divide that forms the north and northwest boundary of the Cow Creek drainage basin there is a fairly good road, branches of which extend out along the crests of branch divides and inter-finger with the roads in the valley bottoms between.

Irvine had a population of 272 in 1910, but must have several hundred more now. The Irvine magisterial district, one of six such districts in Estill County, had a population of 3,615. Ravenna, the downtown portion of which is nearly 2 miles southeast of the corresponding part of Irvine, is also growing rapidly, and the two towns are now practically one. Small stores, some of them with post offices, are fairly numerous in the country.

The Louisville & Nashville Railroad has lines connecting Irvine with Winchester, Richmond, and Beattyville and more distant points in each direction.

GEOLOGY.

STRATIGRAPHY.

GENERAL FEATURES.

The Irvine oil field is situated on the western edge of the Appalachian bituminous coal basin, just a few miles east of the eastern border of the broad area of Ordovician limestones known as the Blue Grass region of Kentucky. A southeastward dip carries the Ordovician rocks of the Blue Grass region beneath successively younger rocks of Silurian and Devonian age which crop out immediately west of Irvine. To the east these younger rocks are in turn overlain by still younger rocks of Carboniferous age (Missis-

sippian and Pennsylvanian). The Pennsylvanian rocks are at the surface in the great Appalachian coal basin, east of which, in the western part of Virginia and Maryland and the eastern part of West Virginia, the older Ordovician, Silurian, and Devonian rocks are again brought to the surface in areas that have been subjected to intense folding and faulting.

As a general rule the formations thicken toward the east. For example, the top of the Mississippian series in the western part of the Irvine field averages about 640 feet above the oil sand or "Corniferous" limestone, whereas in the eastern part of the field it is about 700 feet above; in the Campton field, 20 miles to the east, it is about 850 feet; and in the east end of Wolfe County nearly 1,000 feet. This gradual eastward divergence of the Maxville (?) and "Corniferous" limestones is illustrated in figure 22 (p. 168).

UNEXPOSED ROCKS.

NEED OF INFORMATION.

A question which arises sooner or later in every oil field, and which is just now beginning to arise in the Irvine field, is: What chance is there of finding oil reservoirs below the present productive "sand"? Because of this question, information concerning the Ordovician and Silurian strata that underlie the oil-bearing rock becomes of great importance. Beds which may form oil reservoirs are of course of particular interest, but others for which casing must be prepared, or special drilling plans made, must also be considered. As many of the limestones of Kentucky are porous, and in places cavernous, some of them may act as oil reservoirs. Knowledge concerning these underlying beds is not very abundant. One of the best sources of information is the Richmond folio of the Geologic Atlas of the United States, which covers an area just west of Irvine. This folio, however, like many other geologic reports, discusses only the exposed rocks and hence does not describe some of the lower Ordovician strata.

SECTION IN THE BLUE GRASS REGION.

Matson's description of the rocks underlying the Blue Grass region,¹ just west of Irvine, affords much information concerning the nature of the deep-lying rocks, and the following generalized section for that region is based on his report. The comments concerning water in the several formations throw light on their possibilities as oil reservoirs.

¹ Matson, G. C., Water resources of the Blue Grass region, Ky.: U. S. Geol. Survey Water-Supply Paper 233, pp. 14-17, 1909.

Section of hard rocks in Blue Grass region.

	Feet.
Carboniferous system:	
Waverly shale. Contains beds of greenish sandstone, which, where near the surface, yield excellent soft water. "The shale furnishes no water"-----	300
Devonian system:	
Ohio shale. In shallow wells it "yields an abundance of highly mineralized water. The most common mineral waters are sulphur, chalybeate, and alum"-----	150
"Corniferous limestone" [oil sand at Irvine]. "Usually a cherty magnesian limestone with some shale beds." In deep wells yields moderate quantities of magnesian water-----	30
Silurian system:	
"Blue shales and yellow limestones in places containing chert. Locally includes some sandstone." In deep wells "the limestones furnish considerable water in some localities"-----	60
Ordovician system:	
Richmond formation:	
Upper division, heavy-bedded gray or blue arenaceous limestones, with about 10 feet of dense calcareous shale in lower part. Locally an impure sandstone. Sandy portions yield a little water in some places-----	60
Middle division, blue shale, with some blue or dove-colored limestone. Rarely yields water-----	125
Lower division, interbedded blue limestone and shale. May occasionally yield some sulphur, brackish, or salt water-----	80
Maysville formation. Interbedded blue limestones and shales, the alternate layers usually thin and nodular. Most of the beds thin. "Seldom yields water at depths greater than 150 feet." Water is "apt to be brackish and contain hydrogen sulphide"-----	230
Eden shale. Mainly bluish shale, but upper part is commonly sandy (Garrard sandstone), and the most sandy portions generally yield water-----	200+
Winchester limestone. Generally yields moderate amounts of strong brines with more or less hydrogen sulphide-----	60+
Lexington limestone:	
Upper division, gray, crystalline and cherty (Flanagan chert). Commonly yields much salt or saline-sulphur water-----	75
Middle division, light-drab argillaceous limestone, with shale beds. Uppermost part, 20 to 60 feet thick, is commonly sandstone, with some phosphatic limestone. Yields some strongly mineralized water, "usually salt or salt-sulphur"-----	194
Lower division, heavy bedded, coarse grained, crystalline, and cherty. Yields a little salt-sulphur water-----	30

Ordovician system—Continued.

Highbridge limestone. Mainly limestone, with shale lenses here and there. Little or no sandstone. Yields moderate amounts of salt and salt-sulphur water, especially from beds near top-----	400
Unidentified limestone, similar to Highbridge limestone -----	100
St. Peter sandstone. A siliceous limestone yielding large quantities of salt-sulphur water. Thickness unknown.	

SECTION IN THE RICHMOND QUADRANGLE.

Campbell's section for the Richmond quadrangle¹ is, with slight revision, as follows:

Generalized section for the Richmond quadrangle.

Carboniferous system:

[Pottsville formation.]

Corbin conglomerate lentil. Coarse pink sandstone or conglomerate-----	Feet. 90
Lee formation. Shale and sandstone, with some coal seams. The outcrop of the coal is of minor extent...	250-300
Rockcastle conglomerate lentil. Coarse conglomerate...	0-175
Pennington shale [Chester group?]. Red and green shale and thin beds of limestone-----	0-90
Newman limestone [St. Louis and Ste. Genevieve limestones?]. Blue limestone, slightly cherty near the base-----	100-200
Waverly formation. Green calcareous and argillaceous sandstone. Fine green clay shale with iron concretions-----	350-420

Devonian system:

Chattanooga shale. Black carbonaceous shale----- 110-150

Devonian and Silurian systems:

Panola formation. Brown limestone, in places cherty, at the top; light-blue clay shale below; and coarse yellow sandstone or brown siliceous limestone at the base----- 1-70

Silurian system:

Richmond formation. Blue calcareous shale with thin beds of limestone-----	300
Garrard sandstone. Brown calcareous sandstone----	70-100
Winchester limestone. Thin-bedded blue crystalline limestone with bands of calcareous shale-----	200-230
Flanagan chert. Thin-bedded gray limestone and calcareous shale, containing nodules and bands of chert-----	0-40
Lexington limestone. Thin-bedded gray limestone, containing nodules of chert at the base-----	140-160
Highbridge limestone. White limestone, grading downward into gray limestone and calcareous shale...	190

¹ Campbell, M. R., U. S. Geol. Survey Geol. Atlas, Richmond folio (No. 46), 1898.

DEEP-WELL SECTIONS NEAR IRVINE.

Hoeing¹ gives the following valuable discussion of exposed rocks and interpretation of records of shallow and deep wells drilled prior to 1904 in the Irvine field:

Estill County wells.

West farm, Irvine field.

[Thickness in feet.]

	1	2	3	4	5	6
Clay.....	14	3	25	45	4	22
Black shale (Devonian).....	49	69	50	17	91	52
Oil sand (Corniferous).....	20	20	18	13	16	13
	* 83	92	93	75	111	87

No. 7, West farm.

	Thick- ness.	Depth.	Geologic formation.
	<i>Fect.</i>	<i>Fect.</i>	
Clay.....	45	45	
Black shale.....	24	69	Devonian shale.
Hard gray lime.....	25	94	} Corniferous limestone—Estill sand (Ragland sand).
Light gray lime.....	36	130	
Gray soapstone.....	145	275	Niagara shale.
Hard gray lime.....	30	305	
Soapstone.....	10	315	} Clinton.
Gray lime.....	8	323	
Red lime.....	10	333	
Bastard gray lime.....	17	350	} Lower Silurian (Ordovician) limestones, Hudson and Trenton groups.
Bastard brown lime.....	40	390	
Bastard gray lime.....	839	1,229	

Of the above records, the first six were taken at random from a number of records of wells drilled into the oil sand. The seventh was drilled deeper; it shows an unusual thickness of Corniferous (the limestones on outcrop about a mile west are only 25 to 30 feet thick) and also shows 145 feet of Niagara shales under the oil sand. The 30 feet of limestones under the Niagara shale are nearly all Clinton, but the upper layers may belong to the Niagara. The well went probably 250 feet in the Trenton rocks, or about to the top of the Birdseye.

A combined section made from the log of the above well (No. 7), the log of a well now being drilled on Whiteoak Creek, and a detailed section of the St. Louis, etc., given in volume 4 of the Owen reports would show the rocks from near the top of the conglomerate measures down to probably within 100 feet of the base of the Chazy limestones. The well on Whiteoak started near the top of the black shale and is down over 1,900 feet.² The record was not kept in the upper part but begins at 1,260 feet, which would be just about where the record of No. 7 ends. The following is the section combined as above:

¹ Hoeing, J. B., Oil and gas sands of Kentucky: Kentucky Geol. Survey Bull. 1, pp. 69, 70, 1905.

² This well has since been drilled deeper, striking high-pressure gas in the Calciferous [St. Peter?] at about 1,940 feet.

Combined section in Estill County.

[The column showing depth has been recalculated to conform with other sections.]

	Thick- ness.	Depth.	Geologic formation.	
	<i>Feet.</i>	<i>Feet.</i>		
Heavy sandstone.....	196	196	Conglomerate measures.	
Shales and shaly sandstone.....	50	246		
Black slate.....	4	250		
Coal.....	1	251		
Gray shales.....	4	255		
Coal.....	1	256		
Shales.....	15	271		
Buff earthy limestones.....	8	279		
Archimedes limestone.....	2	281		
Gray limestone.....	13	294		
Calcareous shales.....	10	304		
Oolitic limestone.....	10	314		
Buff limestone.....	11	325		
Semioolitic limestone.....	22	347		
Gray limestones.....	12	359		
Earthy buff limestone.....	5	364	St. Louis, 150 feet.	
Thin gray cherty limestones.....	24	388		
Massive limestone.....	22	410		
Blue limestone and shale.....	38	448		
Earthy yellow limestone.....	6	454		
Sandstones and shales.....	490	944		Waverly, 490 feet.
Black shale.....	125	1,069		
Devonian shales, 125 feet.		1,069		Corniferous, 25 feet.
Estill County oil sand.....	25	1,094		
Blue and gray shales.....	145	1,239		Niagara, 150 feet.
Gray lime.....	5	1,244		
Gray lime.....	25	1,269		
Gray shale.....	10	1,279	Clinton, 53 feet.	
Gray lime.....	8	1,287		
Red lime.....	10	1,297		
Gray lime.....	17	1,314		
Brown lime.....	40	1,354		
Gray lime.....	839	2,193		
Greenish-white friable shaly sandstone	10	2,203		Lower Silurian [Ordovician], Hudson and Trenton groups, 1,476 feet.
Hard fine-grained limestone, dark dove-color, with occasional bands of dark-blue hard limestone.	425	2,628		
Hard gray limestone.....	145	2,773		
White fine-grained sand and lime.....	15	2,788	Calcliferous [St. Peter?].	
Bottom of Whiteoak well.				

The first 15 feet are Calciferous; the next 570 feet Chazy and Birdseye, with about 10 feet of fine light-green sand marking the top of the latter. Of the 839 feet of limestones above that, the lowest 200 to 250 feet constitute the Trenton limestones, and the rest, up to about 1,500, belong to the Hudson.

In another place¹ Hoeing makes the following remarks concerning what he calls the White Oak sand:

THE CALCIFEROUS [ST. PETER SANDSTONE?].

White Oak sand of Estill County.

The Calciferous until quite recently has not been known as a gas or oil bearing rock, it generally producing strong brines and mineral waters where drilled into. A well recently drilled at Elizabethtown, in Hardin County, has produced some gas from this formation at a depth of 2,300 feet. There is a flow of Blue Lick water also in this well. Another well, on Whiteoak Creek, in Estill County, has dry gas from the same formation at a depth of about 1,940 feet. The gas from this well has quite a high rock pressure, and a reported measurement by a Pitot's tube gave a volume of a little over 300,000 cubic feet per day. A second well, just completed, on Whiteoak Creek, struck a strong show of oil

¹ Hoeing, J. B., op. cit., p. 58.

in the Calciferous at a little greater depth than the gas in the first well. The drilling was carried a little deeper and a strong flow of salt water encountered.

ORDOVICIAN SYSTEM.

The Ordovician system, which includes the strata from about 300 feet to about 2,000 feet below the surface at Irvine, consists largely of limestone, most of which is probably too compact to serve as an oil reservoir. Near the top, however, and also at the base there are sandy strata. The sandstone near the top is limy and on the whole hard and compact, but here and there it probably has connecting pores of sufficient size to form an oil reservoir. The sandstone at the base is probably equivalent to the extensive and widely known St. Peter sandstone of the upper part of the Mississippi Basin. It is generally calcareous and is probably the formation called Calciferous in eastern Kentucky.

Throughout most of its extent the St. Peter sandstone yields either an abundance of good, fresh water or a small quantity of highly mineralized water, but not the ordinary salt water of oil fields. "Blue Lick," or sulphur water, is commonly reported, and shows of oil and gas are found here and there. Two deep tests near Ragland seem to have reached the St. Peter sandstone at depths of 2,558 and 2,599 feet. The strata from 400 to 600 feet below the top of the system are commonly shaly or consist of alternating shale and limestone. In Kentucky the Ordovician system is exposed throughout an area over 100 miles across, extending from points a few miles west of the Irvine field north and northwest to Ohio River and west nearly to Louisville.

EXPOSED ROCKS.

OCCURRENCE.

Very good outcrops of many of the formations immediately underlying the surface in and around Irvine are found in the vicinity of Rock House Knob. In this hill the portion of the Maxville (?) limestone represented is about 80 feet thick, the "Waverly" about 400 feet, the Ohio shale about 90 feet, and the oil sand about 10 feet.

In his third report Owen¹ gives a similar section of rocks exposed "between low water of the Kentucky River and the top of Rock House Knob, capped with sub-Carboniferous limestone."

Overlying and younger rocks cap the hills in the eastern part of the Irvine field, and older strata appear in the valley bottoms to the northwest.

¹ Owen, D. D., Kentucky Geol. Survey Third Rept., pt. 1, p. 138, 1857.

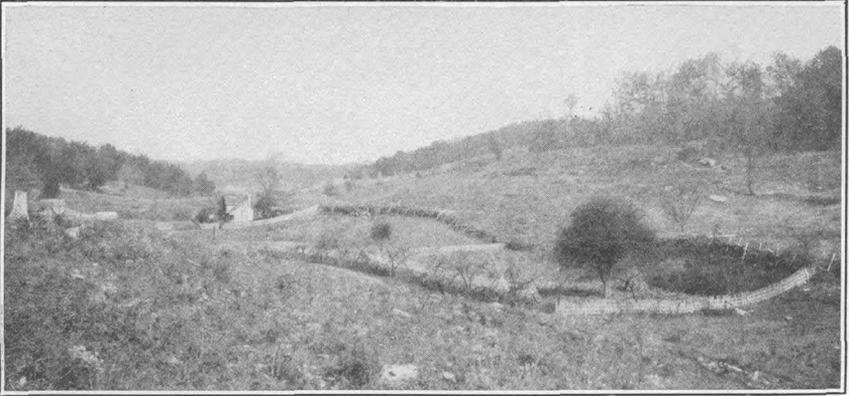
SILURIAN SYSTEM.

In the region around Irvine the Silurian system is about 300 feet thick and consists mostly of shale. It includes almost all the strata between the oil sand of the Irvine field ("Corniferous" limestone) and the top of the great limestone mass of the Ordovician system and is exposed north and northwest of Irvine. The lowermost 50 or 60 feet consists of alternating beds of impure and semicrystalline limestone and shale, which grade down into the sandy uppermost portion of the Ordovician. The central portion of the Silurian is mainly gray shale, which here and there shows tints of red, purple, and pink. In the upper part of this central portion there are alternating beds of limestone and shale. The uppermost third of the system is mainly gray shale but includes a few beds of limestone. The stratum of principal importance to the oil operator is a sandstone near the top, which is lacking in many parts of the area. Owing to an unconformity, its position below the oil sand of the Irvine field is also irregular. The sandstone is commonly 20 to 30 feet thick and would furnish a good reservoir for oil or gas. Most of the limestones of the Silurian appear too compact for oil or gas accumulations.

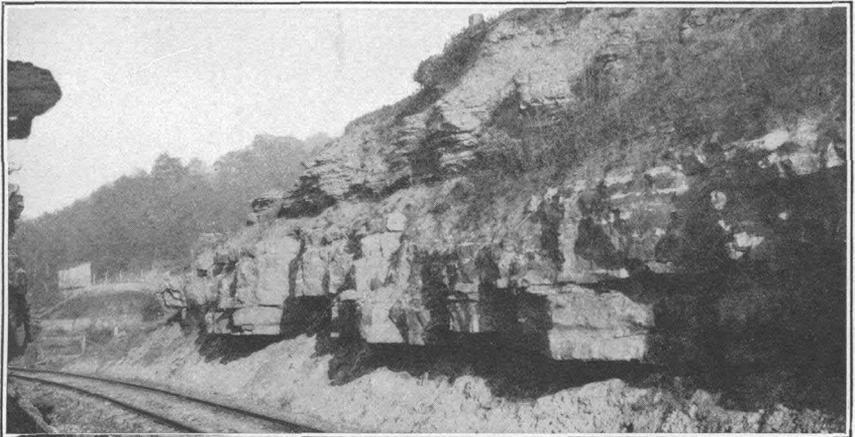
Foerste,¹ who studied the succession of rocks in this region with considerable care, divides the exposed portion of the Silurian into the Brassfield (Clinton) limestone, about 15 feet thick, at the base, and the Crab Orchard division above; the Crab Orchard he further divides into the Indian Fields and Alger formations. The lower part of the Brassfield limestone is thick bedded and the upper thin bedded, with a few clay layers. Foerste's Indian Fields formation is described as consisting of 10 or 12 feet of limestone overlying 4 or 5 feet of clay and his Alger formation as consisting of about 100 feet of clay with a bed of limestone 1 to 2 feet thick 12 to 15 feet above the base. Foerste calls the lower clay member of his Alger formation the Lulbegrud clay, the upper member the Estill clay, and the limestone between the Waco limestone. All three are very well exposed on the lower slopes of hills along the lower 2 or 3 miles of Whiteoak Creek, from 1 to 3 miles north of Irvine. These divisions can be readily identified and followed in the outcrops around Irvine and can be fairly readily recognized in drilling.

The layers that would seem most likely to contain oil where the structure and other conditions are favorable are the 20 to 30 foot sandstone lying, where present, 50 feet or less below the top, a limestone lying about 100 feet from the top and one or two limestones near the base. The Waco limestone of Foerste, lying about 60 feet below the top (or base of the oil sand of the Irvine field) is not

¹ Foerste, A. F., Kentucky Geol. Survey Bull. 7, pp. 10-58, 1906.



A. COMPARATIVELY GENTLE BUT ROCKY SLOPES WITH SINK HOLES DEVELOPED ON STRATA ABOVE MAXVILLE (?) LIMESTONE, 2 MILES WEST-SOUTHWEST OF FITCHBURG.



B. CHARACTERISTIC APPEARANCE OF "CORNIFEROUS" LIMESTONE IN RAILWAY CUT JUST NORTH OF IRVINE.



C. QUARRY IN BLACK OHIO SHALE, IRVINE.

COMMON SURFACE EXPRESSION OF DIFFERENT STRATA IN IRVINE OIL FIELD, KY.

promising as an oil-bearing stratum, for it is both thin and compact and is inclosed in thick beds of noncarbonaceous clay. This limestone, however, is magnesian and porous, at least in places.

The uppermost Silurian rocks may be seen at the surface in railroad cuts and the bottoms of gullies in and around Irvine. One of the best exposures is in a railroad cut a mile north of Irvine. The middle and lower portions appear down the river to the northeast, and the whole system is exposed on the valley sides a little below the mouth of Red River.

DEVONIAN SYSTEM.

"CORNIFEROUS" LIMESTONE (BOYLE LIMESTONE OF FOERSTE).

The lowest and oldest Devonian formation of the Irvine oil field is the oil sand itself, which is really a magnesian limestone or dolomite. It has been variously known as the Corniferous limestone, Devonian limestone, Boyle limestone, Columbus limestone, and, incorrectly by drillers, Clinton limestone. It is of about the same age as the Columbus and Delaware limestones of central Ohio. Its fossils are said by Butts¹ to resemble those of the Delaware limestone more than those of the Columbus, and it may be that the representative of the Columbus is missing, for there is an unconformity at or near the base of the limestone.

In thickness this limestone shows a wide range. In railroad cuts in Irvine and in hillside exposures from 1 to 4 miles north of Irvine it is less than 15 feet thick. (See Pl. XII, *B*.) To the east, however, logs of oil wells show 30 or 40 feet or even more. Elsewhere in Kentucky its thickness is as low as 1 foot, and in places it may be lacking. On the whole, it thins toward the south and west and thickens toward the north and east. Not far south of Irvine it is cut out by an unconformity at the base of the overlying black shale. In the Campton field it is probably 200 feet thick. A limestone about 780 feet thick on Lick Creek, about 5 miles northwest of Gallup, in Lawrence County, is believed to belong to this formation.

The limestone generally has a porous sandy texture and contains many small cavities, some of them lined with crystals. It is rather heavy bedded and is much jointed, so that on weathering it falls into somewhat rectangular blocks a few feet across. At some places, particularly a mile or two northwest of Irvine, it is very cherty but at others it contains little chert. Several metallic and other minerals were observed along joint cracks and in cavities associated with faults. Marcasite, a sulphide of iron, is a common constituent.

¹ Butts, Charles, oral communication.

Galena and sphalerite, lead and zinc sulphides, were found a mile northwest of Irvine, and barite was seen at several places. Peter¹ states that the first copper ore found in Kentucky was obtained at Irvine. The metallic minerals yield glittering grains in drill cuttings. For example, samples of the oil sand from a well 850 feet deep on a farm owned by Frank B. Russell, three-fourths of a mile south of Furnace post office, contain many fragments of marcasite and a few of sphalerite.

This limestone is easily recognized in well drilling, for it is overlain and underlain by soft whitish clay shale and is the first limestone below the hard Ohio black shale. It constitutes the oil sand of many fields in eastern Kentucky. It has sometimes been called Clinton sand, but the position of the true Clinton sand is considerably lower. In some parts of the region around the Irvine oil field the limestone is said to be wanting, and in drilling in such places a lower limestone may be identified as "Corniferous" by mistake, for the clay shales above and below the "Corniferous" are very similar. The "Corniferous" is perhaps more likely to be confused with the Waco limestone of Foerste than with any other bed, but where the two are exposed on the same hillside great differences are generally apparent.

The limestone is in only a few places petroliferous throughout its thickness, and these places are, so far as known, where it is comparatively thin. The oil and gas bearing portion, or "the pay," as it is called, varies considerably in position and thickness from well to well. On the whole it seems thicker and farther below the top of the formation in the eastern part of the Irvine field than in the western part, but in the extreme eastern portion two "pays" are reported. In color the "pay" is one shade or another of brownish gray. The oil-bearing portion of the rock is firmly cemented, commonly showing much recrystallization, though it is full of minute cavities, most of which are intercommunicating. In this respect it contrasts with some other limestones of the southern Appalachian region, which carry small quantities of oil in large cavities and fissures. Some portions, however, are fine grained. The coarse-grained crystalline limestone commonly shows a strong pinkish tinge, but most of the limestone is light gray and acquires a brown stain on weathering.

The chemical composition of a somewhat argillaceous and very cherty portion of the oil sand is indicated by the analyses given in the following quotation from a report by Peter:²

¹ Peter, Robert, Second chemical report on the ores, rocks, soils, coals, mineral waters, etc., of Kentucky: Kentucky Geol. Survey Second Rept., p. 162, 1857.

² Peter, Robert, A summary of the chemical analyses of ores, rocks, soils, clays, marls, iron furnace products, mineral waters, etc., of Kentucky: Kentucky Geol. Survey Fourth Rept. for 1858-59, pp. 141-142, 1861.

No. 951. Limestone (hydraulic?), labeled "Hydraulic limestone? 2 miles west of Red River Iron Works, Estill County, Ky. (Devonian)." A brownish-black or dark umber-colored fine-granular rock; easily broken; does not adhere to the tongue. Powder of a light umber color.

Composition of three limestones, dried at 212° F.

	No. 949 (argilla- ceous lime- stone).	No. 950 (lime- stone shale).	No. 951 (hydrau- lic lime- stone).
Carbonate of lime.....	27.980	37.480	36.580
Carbonate of magnesia.....	19.022	22.927	19.792
Alumina and oxides of iron and manganese.....	9.660	6.160	6.200
Phosphoric acid.....	.246	.182	.079
Sulphuric acid.....	.544	1.363	1.561
Potash.....	.618	.695	.482
Soda.....	.296	.372	.231
Silex and insoluble silicates.....	38.480	28.580	28.240
Water and loss.....	3.154	2.236	α 6.775
	100.000	100.000	100.000
Moisture loss at 212° F.....	.700	.700	.740

α This includes some bituminous matters.

Although these limestones contain more siliceous and aluminous matters than the best water limes, they are worthy of trial as hydraulic cement.

A sample of the oil sand from a well in the eastern part of the field was submitted to George Steiger, of the United States Geological Survey, to determine the magnesium and calcium carbonates. The sample was made up from drill cuttings obtained by the writer at the well immediately after it was finished, and as the finer fragments of rock that were washed out of the samples in bailing are probably of the same composition as the coarser fragments, the figures are believed to represent the composition of the oil sand at this well and are also believed to be in a general way representative for the field. The portion insoluble in hydrochloric acid, however, may consist partly of fragments of overlying shale that had fallen to the bottom of the well. In any case the analysis shows that the oil sand at this place, at least, is practically a dolomite and not limestone in the ordinary sense. The pure mineral dolomite consists of calcium carbonate, 54.35 per cent, and magnesium carbonate, 45.65 per cent. Roughly, dolomite has almost five-sixths as much magnesium carbonate as calcium carbonate, whereas the oil sand of the Irvine field seems to have only about three-fourths as much.

Partial analysis of composite sample of oil sand from Huff gas well, near Estill Furnace, Ky.

[George Steiger, analyst.]

Insoluble in HCl.....	24.7
FeO.....	2.4
CaO.....	22.3
MgO.....	14.3
CO ₂	34.8

Probable combinations.

Insoluble in HCl.....	24.7
CaCO ₃	40
MgCO ₃	30.2
FeCO ₃	2.3
FeO.....	.9

Throughout most of its extent in and around the Irvine oil field the oil sand probably contains at least 15 to 20 per cent of magnesium carbonate, and its porosity and consequent suitability as an oil reservoir are probably due to the process by which the magnesium carbonate was introduced, for magnesian limestones are commonly porous and sandy in texture.

OHIO (CHATTANOOGA) SHALE AND OLENTANGY (?) SHALE.

The next formation above the "Corniferous" limestone is the peculiar hard black fissile shale, from 125 to 150 feet in thickness, which is well known to drillers because of its striking nature, particularly its color and brittleness. It is well exposed at the bases of the mountains around Irvine and in a belt 5 to 10 miles wide extending many miles northeast and southwest of Irvine; in fact, a belt surrounding the great area of Ordovician rocks above described extends nearly to Louisville and far beyond Cincinnati.

Generally the "Corniferous" limestone is immediately overlain by a bed of soft light-gray or bluish-gray clay shale 5 to 10 feet thick, and this in turn is overlain by 5 to 10 feet of hard sandy light-colored mudstone. In some places the hard mudstone is lacking, and in a few places the black shale rests directly upon the limestone, both light-colored beds being lacking. Here and there, as 4 miles northwest of Irvine, the basal part of the black shale is interstratified with two or three of the upper beds of limestone, with lenses of light-colored clay shale. On the whole the clay shale is persistent and probably performs an important function in sealing in the oil of the limestone below. It seems to be indistinguishable from a bed under the black shale in central Ohio known as the Olentangy shale, and, as Foerste¹ has suggested, the two are probably equivalent. They resemble each other in color, hardness, and stratigraphic relations and in carrying locally rather large crystals of marcasite. Well records indicate that eastward from Irvine this clay shale gradually increases in thickness.

The great overlying mass of black shale is perhaps the most striking formation in a region where all the formations are rather impressive. It is remarkably uniform in make-up and appearance and is found in every well that penetrates to its horizon throughout the broad region of its occurrence, a region that covers thousands of

¹ Foerste, A. F., The Silurian, Devonian, and Irvine formations of east-central Kentucky: Kentucky Geol. Survey Bull. 7, p. 288, 1906.

square miles in the Appalachian and other oil fields. Some of the wells in the Irvine field report variations in the color and hardness of the shale, and some departures from uniformity were observed in outcrops, but such differences are slight and of small extent. (See Pl. XII, C.)

In eastern Tennessee and Kentucky and adjoining territory, where this formation is generally 5 to 125 feet thick, it has been named the Chattanooga shale, from a typical exposure at Chattanooga, Tenn. In Ohio and Pennsylvania, in some parts of which this shale is thousands of feet thick and has several distinct subdivisions, it is known as the Ohio shale. The region of transition from the northern to the southern phase is in northeastern Kentucky.

Although the Ohio (Chattanooga) shale is here classed as Devonian, some geologists¹ believe that the uppermost part is Carboniferous.

The opposing view that the black shale is altogether Devonian is set forth by several writers, among whom should be mentioned particularly Kindle,² who describes in considerable detail some features of the strata that crop out around Irvine.

Gas and oil showings in the black shale are often reported. Hoeing³ says:

The black shale, wherever tested under cover, carries a large percentage of oil disseminated through it and furnishes the oil for numerous oil springs along its outcrop. When drilled through, it often gives shows of oil and gas all the way through it, especially at points where a hard layer in the shale forms a cap or shell. In other States it has been found to be a reservoir for low-pressure gas in moderate quantities, but in Kentucky it has so far, with but one notable exception, given neither gas nor oil in large amounts. The structure of the shale itself is not favorable for the accumulation of oil in reservoirs unless somewhere a sandstone should be found embedded in it.

The exception above referred to is the well-known Meade County field, where gas was found in the black shale and piped to Louisville.

CARBONIFEROUS SYSTEM.

Mississippian series.

"WAVERLY" FORMATION.

Overlying the black Ohio shale is from 400 to 450 feet of soft olive-colored, drab, or bluish shale which contains many sandy layers

¹ Williams, H. S., On the southern Devonian formations: *Am. Jour. Sci.*, 4th ser., vol. 3, p. 398, 1897.

Grabau, A. W., Types of sedimentary overlap: *Geol. Soc. America Bull.*, vol. 17, p. 609, 1906.

Morse, W. C., and Foerste, A. F., The Waverly formations of east-central Kentucky: *Jour. Geology*, vol. 17, p. 176, 1909.

Ulrich, E. O., The Chattanooga series with special reference to the Ohio shale problem: *Am. Jour. Sci.*, 4th ser., vol. 34, pp. 157-183, 1912.

² Kindle, E. M., The unconformity at the base of the Chattanooga shale in Kentucky: *Am. Jour. Sci.*, 4th ser., vol. 33, pp. 120-136, 1912.

³ Hoeing, J. B., The oil and gas sands of Kentucky: *Kentucky Geol. Survey Bull.* 1, p. 50, 1905.

and a few lenses of fairly clean sandstone and thin beds of limestone. This shale is equivalent to the "Waverly group" of Ohio and probably to the Pocono formation of Pennsylvania, which includes the famous Big Injun oil sand.

In some places immediately above the Ohio black shale is a thin porous limestone which is commonly sandy. This is probably equivalent to the Beaver Creek "sand," an oil-bearing limestone of southern Kentucky. In the Irvine field it seems to contain no oil or gas, but it may be found productive to the east, farther from its outcrop.

The central part of the formation is largely olive-colored or light-green clay shale containing many clay ironstone concretions, commonly called boulders by drillers, ranging from an inch or two to 3 feet in diameter. Many of them when broken show the yellowish metallic glitter of marcasite. Such concretions are especially abundant in Rockhouse Fork. A 2-foot layer of purplish clay shale is exposed near the mouth of this fork.

In places the uppermost part of the "Waverly" is more or less calcareous, and just northeast of the field it contains considerable shaly and fossiliferous limestone having the approximate stratigraphic position and general aspect of the Keokuk limestone of Illinois, Missouri, and other States. A collection of fossils was made and submitted to George H. Girty, with the request that he determine, if possible, whether or not they indicate that the strata are of Keokuk age, and he reports as follows:

Fossils collected 40 feet below base of cliff of St. Louis (?) limestone $1\frac{1}{2}$ miles south of High Rock and 5 miles south of Filson, Ky.:

Batostomella sp.
Cystodictya lineata?
Orthotetes sp.
Chonetes illinoisensis?
Productus ovatus.
Spirifer aff. *S. grimesi*.
Athyris lamellosa.

This lot appears to be of the age of the Keokuk limestone. In lithology the beds from which the fossils were obtained are more like the "Waverly group" of Ohio, and I think that they probably belong somewhere in the upper "Waverly," but the fauna is more like that of the typical Keokuk.

In Ohio the "Waverly" has been subdivided by Prosser¹ into the Logan formation, Black Hand formation, Cuyahoga formation, Sunbury shale, Berea grit, and Bedford formation, named from the top down. The Berea is a famous oil-bearing bed, named from Berea, Ohio, where it crops out and in places is quarried for grindstones.

¹ Prosser, C. S., The classification of the Waverly series of central Ohio: Jour. Geology, vol. 9, pp. 214, 215, 1901.

Morse and Foerste¹ give the following statement and section:

Here [at Irvine] the Bedford-Berea is 1 foot 6 inches in thickness and fossiliferous, while the Sunbury is only 3 feet. This very gradual decrease in the Sunbury should be noted, although it is much less marked than the thinning of the Bedford-Berea.

Section of Minerva Mountain, Irvine.

	Ft.	in.	Feet.
6. Sub-Carboniferous limestone: Yellowish sandy-like limestone, lying at the extreme top of the hill-----			1
5. Upper Waverly series, not divided-----			344
Covered interval-----	60	6	
Thin-bedded buff argillaceous sandstones; which weather to thin shaly pieces; <i>Taonurus</i> -----	17	0	
Layers of massive buff argillaceous sandstone; <i>Taonurus</i> abundant-----	24	0	
Buff argillaceous sandstones, weathering to shales; <i>Taonurus</i> -----	17	0	
Covered interval-----	225	6	
4. Cuyahoga formation, top not determined-----			144
Brownish ferruginous and calcareous nodular layer of sandstone-----	6		
Indurated bluish to pinkish argillaceous shales with ferruginous nodular layers--	69	6	
Soft bluish argillaceous shale with ferruginous nodular layers, slightly covered (top of Linietta clay)-----	63	6	
Layer of brownish argillaceous sandstone, which breaks up into shaly layers-----	2	0	
Soft bluish to pinkish argillaceous shales with small phosphatic nodules-----	8	6	
3. Sunbury shale: Black fissile carbonaceous shales-----			3
2. Bedford-Berea-----			1½
Argillaceous shales with phosphatic nodules	2		
Black fissile carbonaceous shales-----	3		
Dark argillaceous shales, with some carbonaceous material-----	6		
Gray calcareous and argillaceous shales, slightly fossiliferous-----	2		
Yellowish calcareous and argillaceous shales, the upper part very fossiliferous--	5		
1. Ohio shale: Black fissile carbonaceous shales, with an occasional softer argillaceous layer. Practically all exposed to the highway-----			94½

The "Waverly" formation underlies the surface of valley sides and hill slopes throughout the Irvine field and much surrounding

¹ Morse, W. C., and Foerste, A. F., The Waverly formations of east-central Kentucky: Jour. Geology, vol. 17, pp. 172-173, 1909. See also Kentucky Geol. Survey Bull. 16, serial No. 19, pp. 46-47, 1912. Also Foerste, A. F., The Bedford fauna at Indian Fields and Irvine, Ky.: Ohio Naturalist, vol. 9, pp. 515-523, 1909.

territory. It is readily identified by its light olive or greenish-gray color, together with its dominant soft shaly nature, great thickness, and position between the black shale below and the "Mississippi lime" or big lime above. The lower part of it and the upper part of the underlying black shale are well exposed at the mouth of Cow Creek and around the base of the mountain immediately to the east. Other parts are more or less well exposed at many places throughout the field and surrounding country but nowhere on mountain tops and in valley bottoms except in the eastern part. Compared with other formations, however, it is, because of its softness and weak nature, poorly exposed.

The upper part of the formation is more or less sandy, and the amount of sand seems, on the whole, to increase upward to the top. This sandy portion is approximately if not exactly the same as the Big Injun sand of the drillers of West Virginia, Ohio, and Pennsylvania.

Hoeing¹ and Morse and Foerste² have discussed the possibility of finding oil in the "Waverly" of Kentucky, but as the formation is mostly above drainage level in and around the Irvine field, it probably contains no oil here.

MAXVILLE (?) LIMESTONE.

At the top of the Mississippian series is 50 to 175 feet of limestone, with here and there a bed of hard bluish or drab shale and generally soft sandstone of varying fineness of grain. This limestone is probably the same as the Maxville limestone or Big lime of West Virginia and adjacent oil regions, and the Newman limestone of the Richmond folio of the Geologic Atlas of the United States and other reports on neighboring areas to the west. It seems to be the sole representative in the Irvine field of several formations in the oil region of Illinois, including the St. Louis and Ste. Genevieve limestones, and the overlying beds of the Chester group. (See Pl. XII, A, p. 156.)

In other regions where it is known to occur the St. Louis limestone is almost everywhere cherty and jointed, carries *Lithostrotion canadense*, commonly gives rise to sink holes, and is comparatively resistant to erosion, so that it stands forth in bold cliffs. A member of the Maxville (?) limestone at Irvine, lying at or near the base and including about 50 feet of heavy-bedded limestone, so closely resembles the St. Louis elsewhere that it is provisionally regarded as equivalent to that formation. It is more or less cherty and jointed; the characteristic fossil referred to was found in it at several places,

¹ Hoeing, J. B., Oil and gas sands of Kentucky: Kentucky Geol. Survey Bull. 1, pp. 32, 46, 1905.

² Morse, W. C., and Foerste, A. F., Preliminary report on the Waverlian formations of east-central Kentucky and their economic values: Kentucky Geol. Survey Bull. 16, p. 73, 1912.

as, for example, on the Whiteoak Creek road, $1\frac{1}{2}$ miles southwest of Union Hall; sink holes are fairly common where the limestone is not buried under the sandstone and shale of the overlying Pottsville formation, as, for example, in the vicinity of Estill Furnace and a mile north of High Rock; and it forms so continuous an escarpment at its outcrop that it is widely used as a farm boundary. Perhaps for a fourth or a third of the length of its outcrop this escarpment is a vertical cliff which may be seen for miles, and hence, as there is scarcely a square mile in or near the field where it does not occur, it is of great value in structural studies. (See Pl. XV, A, B, p. 172.)

Above the cliff-making limestone is from 1 foot to 100 feet of limestone that consists on the whole of purer lime carbonate and contains much less silica, though it includes lenses of both shale and sandstone. The principal reason for the marked variation in thickness is an unconformity at the top. No doubt this limestone was originally at least 75 feet thick, but before the overlying strata were laid down it was exposed to the weather and extensively eroded. Its lower part is either coarsely crystalline or oolitic, resembling fish eggs. Some of it, however, is argillaceous. Like the "Corniferous" limestone it contains many button-like or beadlike sections of stems of crinoids, or sea lilies. The upper part is less pure and contains the lenses of sandstone and shale.

So far as known the lower part of this member may be equivalent to the Ste. Genevieve limestone of Missouri, which is generally oolitic and which in the Illinois oil fields is known as the McClosky sand, and the upper part to the overlying beds of the Chester group of Illinois, which consists of much sandstone, including, in Illinois, many of the producing sands, and greenish calcareous shale. Reddish and purplish tints are also common in the Chester and are to be seen at some places east of Irvine.

A collection of fossils obtained from the limestone was submitted to George H. Girty, with the request that he determine whether or not they are of Ste. Genevieve age, and he reports as follows:

Fossils collected 4 miles northeast of Irvine, Ky., on crest of ridge south of Whiteoak Creek:

- Eupachyrinus?* sp.
- Fenestella* sp.
- Rhombopora* sp.
- Streblotrypa nicklesi*.
- Productus ovatus*.
- Girtyella indianensis*.
- Spirifer pellensis*.
- Composita trinuclea*.
- Cliothyridina sublamellosa*.
- Leptodesma* sp.
- Deltopecten monroensis*.
- Aviculipecten talboti*.

Conocardium sp.

Eotrochus sp.

Griffithides sp.

This collection almost certainly belongs at the horizon of the Ste. Genevieve limestone.

Pennsylvanian series.

POTTSVILLE FORMATION.

The ridges in and around the Irvine field, particularly to the east and south, are for the most part capped with sandy strata having an aggregate thickness of 1 foot to 200 feet and belonging in the widely known Pottsville formation. The type locality of this formation is in the anthracite region of eastern Pennsylvania, but it is readily recognized in western Pennsylvania, West Virginia, Ohio, Indiana, Illinois, Kentucky, Tennessee, and other States. In the Irvine field much of it has been eroded, and what remains is mostly sandstone. Conglomerate lenses with pebbles from one-eighth to one-half inch in diameter appear here and there, as for example just south of Union Hall, and gray to black hard to soft shale occurs at many places. Here and there, as for example at High Rock, there is a bed of coal as much as 2 feet in thickness.

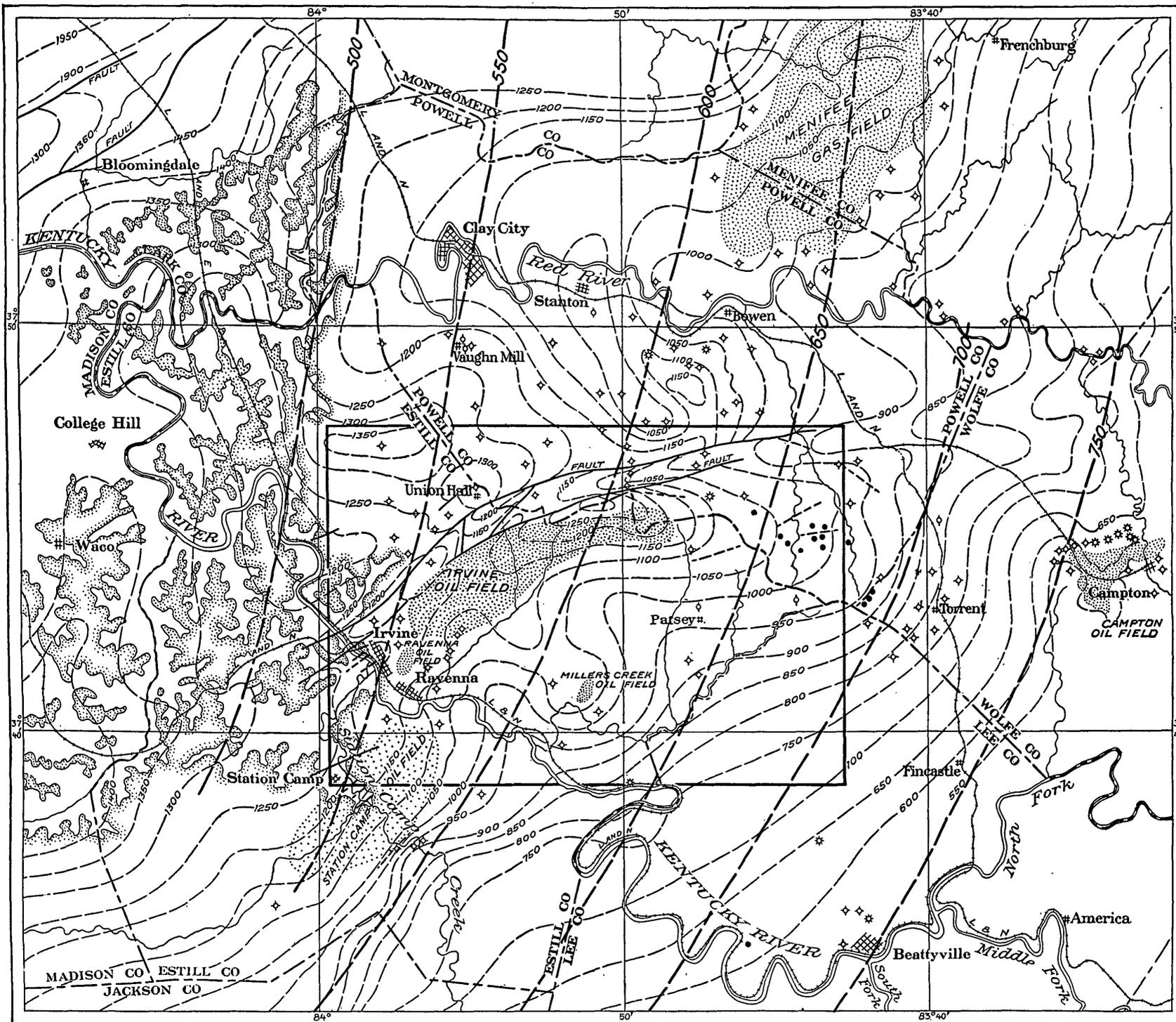
The Pottsville in the Richmond region, to the west, is said to be naturally divisible into an upper and a lower member of conglomerate and a middle one of shale. In the Irvine field sandstone is far more abundant than conglomerate, and the central shaly part of the formation, or what is left of it, is largely sandstone.

The Pottsville sandstone differs from other sandstones of the region in being on the whole more massively bedded, coarser grained, more commonly pebbly, and more generally cross-bedded, and in containing coal seams. The black carbonaceous Ohio shale 500 or 600 feet below has often been searched for coal but always in vain.

STRUCTURE.

ACCURACY OF STRUCTURE CONTOURS.

The general structure of the region is shown on the sketch map (Pl. XIII) with a contour interval of 50 feet. The contours are based on approximate dips and altitudes of various recognizable strata, the altitudes being generally taken from topographic maps. These maps, however, are of a reconnaissance character and have a rather small scale and a contour interval of 100 feet, and therefore each altitude figure may be 50 feet or more in error. Nevertheless, as these errors are not cumulative and the dips are considerable, it is believed that Plate XIII shows the general slopes and wrinkles of the strata with fair reliability.



EXPLANATION

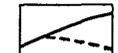


Outcrop of "Corniferous" limestone, the oil and gas bearing sand which underlies entire area on dotted side of line

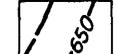


Structure contours showing approximate form of top of cliff-making member of Maxville(?) limestone
Interval 50 feet
Datum is sea level

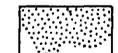
As the structure shown is based on observed slopes of outcropping beds and as no level lines were run, altitudes may be considerably in error and some details of structure not shown



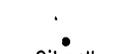
Faults



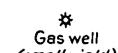
Convergence lines showing approximate distance between top of cliff-making member of Maxville(?) limestone and top of oil sand ("Corniferous" limestone)



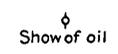
Oil or gas field



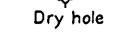
Oil well



Gas well (small yield)



Show of oil



Dry hole

Base from U.S.G.S. topographic maps

Scale 250000
0 1 2 3 4 5 6 7 8 9 10 MILES

SKETCH MAP SHOWING THE GENERAL GEOLOGIC STRUCTURE IN THE IRVINE OIL FIELD AND VICINITY, KENTUCKY.

The 25-foot contours shown on the larger-scale structure map (Pl. XIV, in pocket) also are not presumed to show accurately the altitude of the stratum of Maxville (?) limestone on which they are drawn, for no level lines were run to aid in the delineation, but it is believed that they show the general slopes of that limestone and also of the oil sand below, as the two are more or less nearly parallel. Although the oil prospector may desire to know the altitude of some particular point, the general form of the strata is of greater interest to him, for in Kentucky, as in many other regions, oil is found in areas where the rocks are higher than they are in adjacent territory in at least two directions, or where there is a more or less sharp change in dip.

One possible source of error in making such a structure map is the fact that two different cliff-making strata may be regarded as one and the same bed. Different parts of the Maxville (?) limestone are exposed in cliffs at different places, and here and there the overlying Pottsville sandstone makes cliffs which at a distance of a mile or more are in some places difficult to distinguish from the limestone cliffs. The structure maps of this report are believed to contain no errors from this source.

GENERAL SOUTHEASTWARD DIP.

The dominant structural feature of the region around the Irvine oil field is the general southeastward dip, which averages about 35 feet to the mile. This dip, together with its broader variations, is illustrated in Plate XIII. It carries the conspicuous cliff-making member of the Maxville (?) limestone from an altitude of about 1,330 feet 6 miles north of Irvine down to the river channel at about 635 feet 14 miles southeast of Irvine, 2 miles below the mouth of Sturgeon Creek. It carries the oil sand from an altitude of 630 feet above sea level at the Irvine Station to about 150 feet below sea level in the Campton oil field, a slope in an easterly direction, not directly down the dip, of 780 feet in 24 miles, or $32\frac{1}{2}$ feet to the mile. In the Menifee gas field the sand has an average altitude of 400 feet above sea level, and as Campton, 15 miles to the southeast, is almost directly down the general dip, the sand thus slopes down between these two fields 550 feet in 15 miles, or approximately 37 feet to the mile.

The general strike of the beds, or the direction in which they do not vary in altitude, is evidently less than 45° east of north, for the Irvine, Menifee, and Ragland fields lie almost along a line trending N. 45° E., and the altitude of the sand above the sea decreases about 10 feet to the mile in that direction. From the Ragland field the southward slope toward the Campton field is about 20 feet to the mile, the total descent being about 440 feet in 22 miles.

In discussing the structure of this region Munn¹ says: "From the Menifee gas field due east to the wells on Toms Run, 5 miles north of Paintsville, in the central part of Johnson County, a distance of approximately 50 miles, the dip of the 'Corniferous' limestone is about 1,400 feet, or an average of about 28 feet per mile." He infers that directly down the dip the beds slope 40 feet to the mile.

This general eastward dip was observed as long ago as 1838 by Mather,² who describes it as follows:

As the strata of rock dips slightly to the east-southeast, in ascending the Kentucky River from Irvine to the forks we pass in succession over the rocks that overlie each other and which are seen in the hills at Irvine. At about 12 or 14 miles above Irvine we pass over the slate rock, which has plunged below the bed of the river, although at Irvine it formed the mass of the hills for 200 to 400 feet high. Limestone then succeeds in high cliffs along the banks, but this in its turn also sinks below the stream, after ascending to the rock shoals, about 3 miles below the mouth of the South Fork, and disappears from the banks of the Kentucky and its tributaries.

The lay of the rocks between Irvine and Campton, the lithologic character and thickness of various formations, and the general form and altitude of the surface are illustrated in figure 22.

A northeast-southwest profile of the oil sand is given in figure 23.

LOCUST BRANCH ANTICLINE.

Next to the general southeastward dip the most prominent structural feature of the region is the gradual change in dip from nearly east to nearly south in the general vicinity of Locust Branch and

the point where Madison, Estill, and Jackson counties meet. The general structure southwest of Irvine is thus that of a southeastward-

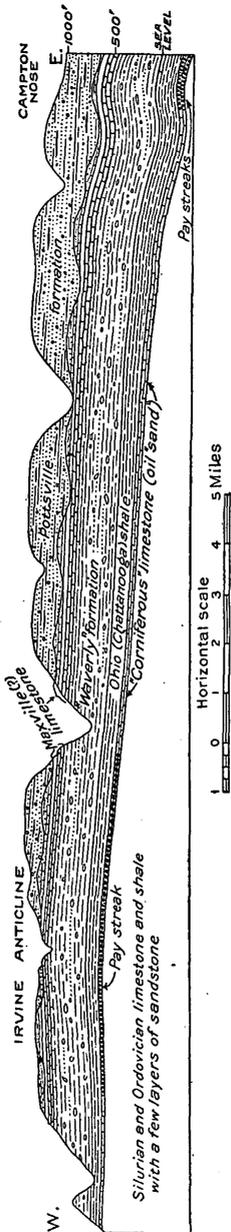


FIGURE 22.—Cross section from Irvine to Campton, Ky., showing the dip and thickening of formations in that direction, the structural features on which the oil pools are found, and the general altitude of the surface.

¹ Munn, M. J., U. S. Geol. Survey Bull. 531, p. 19, 1913.
² Mather, W. W., Report on the geological reconnaissance of Kentucky made in 1838, p. 13, 1839.

dipping monocline modified by a broad anticline that plunges rather steeply southeast. As indicated by the contours in Plate XIII, the change in direction of dip is not smooth and gradual but irregular, and as the map is only a sketch map it is probable that the irregularity is much greater than is shown. The change in dip is so irregular in detail that it is made evident only by considering in a broad way the structure of all three counties and some adjoining territory. In a district lying 2 to 10 miles west of Irvine the general dip is almost due east and about 25 feet to the mile. In the vicinity of Combs, Locust Branch, and Alcorn the general dip is nearly southeast and about 30 or 35 feet to the mile. A few miles to the west the general dip is almost due south and 40 or 50 feet to the mile. Farther west, around Berea, the dip is irregular but averages nearly south and about 30 feet to the mile. A northeast-southwest section through Locust Branch would therefore show that the beds have a general but irregular slope in each direction, though the greatest slope or true general dip would be shown by sections running from Locust Branch about east-southeast and south-southeast.

GENERAL STRUCTURAL FEATURES AROUND IRVINE.

The general eastward dip of the northeast flank of the Locust Branch anticline, for a distance of 30 miles north of its axis, is not at all regular but swings toward the north and south and in some places is almost completely reversed or in some westerly direction. (See Pl. XIV, in pocket.) In particular along a line extending 10 miles south and 20 miles north of Irvine the average dip is a little south of east, but this dip is modified by three prominent features and many smaller ones. The larger features are an asymmetric anticline, the axis of which trends northeast from Irvine; a fault zone from half a mile to 1½ miles wide parallel to the axis of the anticline and a mile

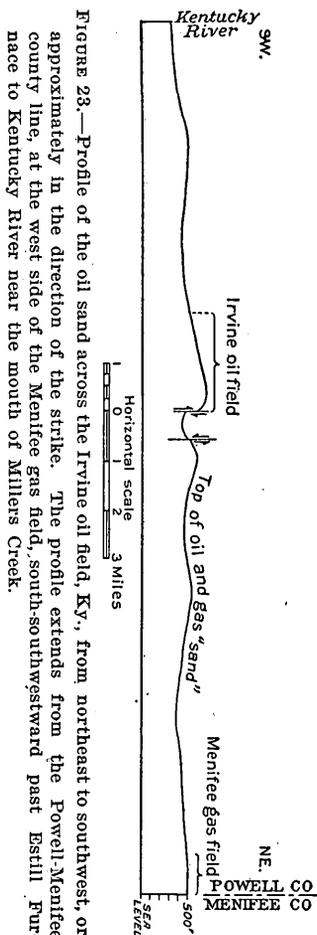


Figure 23.—Profile of the oil sand across the Irvine oil field, Ky., from northeast to southwest, or approximately in the direction of the strike. The profile extends from the Powell-Menifee county line, at the west side of the Menifee gas field, south-southwestward past Estill. Face to Kentucky River near the mouth of Millers Creek.

or two to the northwest of it; and a broad, shallow syncline under Clay City. For the first two the names Irvine anticline and Irvine fault zone seem appropriate, and for the third the name Stanton syncline or basin. Several secondary features are also worthy of mention, though the exact form and extent of none of them have been determined.

IRVINE ANTICLINE.

Although Munn made no survey of the country around Irvine, he suspected the existence of an anticline running east from that place, as indicated by the following statement,¹ made before the present Irvine oil field was discovered:

The Irvine [Ravenna] and Campton fields are probably on the same anticline, which may prove to be the westward extension of a fairly definite anticline observed at a number of places in Morgan County. If careful geologic work in this area should show this to be a fact, there is a strong possibility that some of the territory along the axis of this fold between the Irvine and Campton fields will furnish small though valuable fields of oil or gas.

The axis of the Irvine anticline seems to trend almost due northeast through the downtown portion of Irvine, but 2 or 3 miles to the northeast it curves gradually to a course nearly east. It crosses the headwaters of Campbell Fork and continues across the central portion of Tick Fork. Thence, curving slightly, it crosses the divide between Cottage Fork and Rockhouse Fork, near their headwaters. Up to this point the difference in altitude of beds on the crest and the same beds at the border of the fault zone on the northwest is only 20 or 30 feet, but from this point eastward the height of the anticline seems to increase to about 50 feet, measured on the north flank, and the decline on the south flank north of Fitchburg Furnace seems to be more than 200 feet. The height of the crest above sea level also increases toward the east, although the regional dip is in that direction.

The top of the cliff-making St. Louis (?) limestone, which is represented by contours on the map (Pl. XIV), is 1,200 to 1,250 feet above sea level at Irvine, about 1,150 feet 3 to 5 miles to the northeast, and 1,300 feet in the vicinity of Estill Furnace, though its highest point is somewhat west of that place. In the next 10 miles to the east the anticline seems to broaden and gradually disappear. The northwest limb seems to be short and rather steep; the southeast limb long and somewhat irregular, sloping from 25 to 100 feet to the mile and gradually merging into a general southeast dip.

¹ Munn, M. J., The Menifee gas field and the Ragland oil field, Ky.: U. S. Geol. Survey Bull. 531, pp. 25-26, 1913.

These features are conspicuous in and near Irvine. At Wagers station, 3 miles southeast of Irvine, the top of the Ohio shale is about at track level. To the southeast it has a medium dip, but to the northwest it rises gently for three-fourths of a mile to the mouth of Cow Creek, where it is about 15 feet above track level, or 650 feet above the sea. From this point northwestward it rises to a position of 800 feet above the sea near the downtown portion of Irvine and then declines to somewhat less than 700 feet at the schoolhouse on Sweet Lick Branch.

IRVINE FAULT ZONE.

A curious fault zone borders the crest of the Irvine anticline on the northwest. On the whole, the effect of the faulting is to drop a block of the earth's crust, from half a mile to 2 miles wide and probably more than 20 miles long, 25 to 200 feet.

The faulting was apparently first noticed by Lesley¹ in 1858. He found a fault just northwest of Estill Furnace and concluded that it had a throw of 160 feet. Former State Geologist C. J. Norwood, Prof. A. M. Miller, State Geologist J. B. Hoeing, and others have made observations at many places along its course. Gardner² places it on a long line of disturbance extending from the Ozarks to north-central Pennsylvania.

Along the north border of the Irvine oil field the fault zone is conspicuous at several places, though between these places are stretches through which it has not been traced continuously.

The persistent and almost unique character of the "Corniferous" limestone or oil sand makes faulting and other structural features along its outcrop easy to discern. Southeast of the Irvine station this formation is below track level and dips rather steeply to the southeast. To the northwest it rises irregularly and with slight faulting here and there (see Pl. XV, *C*), but on the whole the rise is gentle to and a little beyond the courthouse, where the limestone is 30 or 40 feet above the track. In the next half mile or so along the railway the limestone declines, with several faults of 5 to 15 feet throw, to a position only about 5 feet above the railway near the main wagon-road crossing. Here there is a much greater fault, having a downthrow on the north of perhaps 100 feet. In the next half mile the central part of the black shale crops out almost continuously at track level. A few hundred feet southeast of the mouth of Whiteoak Creek the limestone is thrown up again

¹ Lesley, Joseph, Topographical and geological report made during the years 1858-59: Kentucky Geol. Survey Fourth Rept., pp. 469-470, 1861.

² Gardner, J. H., A stratigraphic disturbance through the Ohio Valley running from the Appalachian Plateau in Pennsylvania to the Ozark Mountains in Missouri: Geol. Soc. America Bull., vol. 26, pp. 477-483, 1915.

above track level, and thence it rises to the northwest about 100 feet in a quarter of a mile.

This steep rise is conspicuous also a mile to the northeast along the road north of the Estill Springs Hotel. Here the northward rise is shown by comparing a roadside exposure of an inclined bed of limestone at an altitude of less than 650 feet and exposures of the same bed on hillsides a mile to the north and northwest, where the bed is about 700 feet above the sea. Two miles still farther north-northwest the bed lies at about 640 feet.

Another place where the fault zone and associated deformation are conspicuous is in the upper end of the valley of Tick Fork. From a point about 2 miles southwest of Union Hall a view to the southeast shows the St. Louis (?) limestone much lower on the southeast side of this narrow valley than on the northwest.

A good view of the fault zone is also to be had from the opposite or south side of it 2 miles west-southwest of Estill Furnace. Here the observer may stand on the cliff-making limestone and, looking northwest, see two ridges in which the limestone is more than 100 feet below his position, but 2 or 3 miles to the northwest it is as high as on the south side of the fault zone.

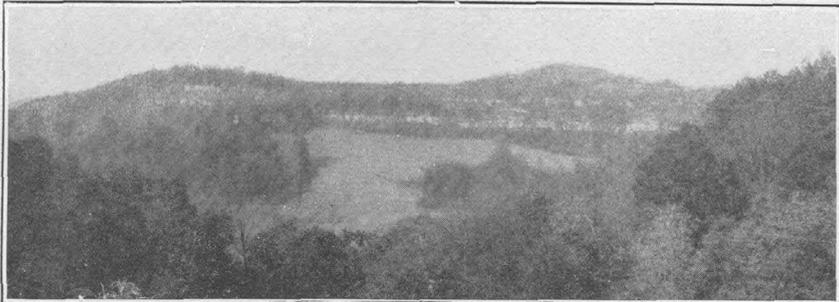
The displacement is striking also on the road leading north from Estill Furnace and 3 or 4 miles farther east, on the south side of High Rock. According to Prof. A. M. Miller,¹ it is well shown 3 miles east-southeast of High Rock, or just below the mouth of Barker Branch, and also 3 miles east of this point, near Glen Cairn. Prof. Miller calls the fault on the south side of the zone at Irvine the Sweet Lick fault and that on the north side the Estill Springs fault, the one immediately north of Estill Furnace the Estill Furnace fault, and the one at Glen Cairn the Glen Cairn fault.

The Irvine fault zone is nearly parallel to the axis of the Irvine anticline, and for most of their courses they are close together. The fault zone runs northeast from Irvine, curves gradually to an east or slightly north of east course from Estill Furnace to High Rock, and then, according to Prof. Miller, bends slightly south of east, and at Glen Cairn resumes an eastward course.

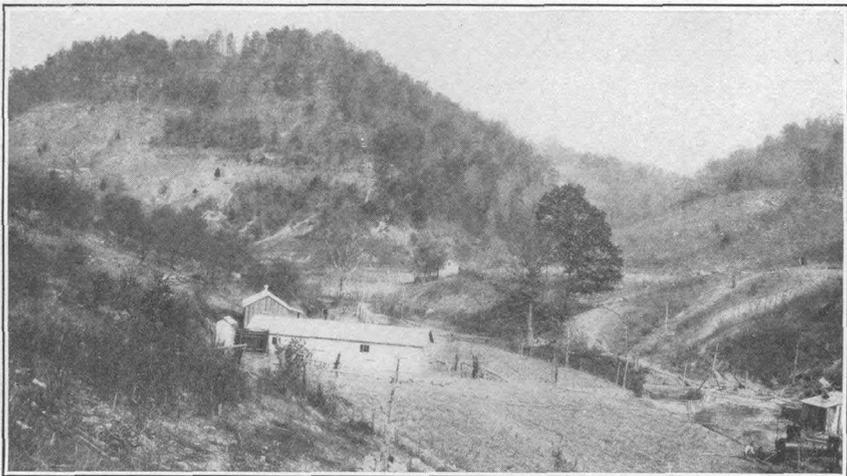
Apparently the zone includes two major faults, with numerous minor faults on each side. Some of the minor faults are parallel to the principal ones, and some make various angles with them. Southeast of Union Hall and along the lower course of Sweet Lick Branch there is some evidence of a fault crossing the zone diagonally.

Within the fault zone the beds are generally not far from horizontal. On the whole they seem to have a synclinal structure, the middle being lower than the sides. In some places, however, as for

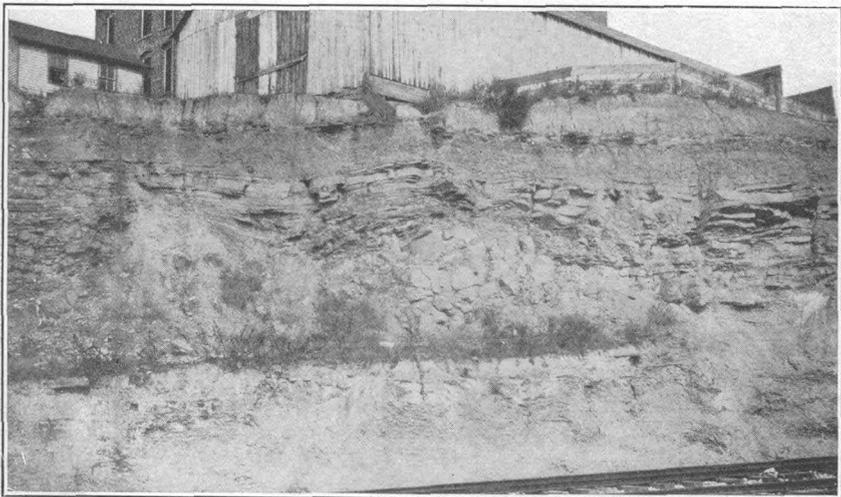
¹ Oral communication.



A. SOUTHEASTWARD DIP OF LOWER MEMBER OF MAXVILLE (?) LIMESTONE AND POTTSVILLE SANDSTONE 1½ MILES EAST OF IRVINE.



B. SOUTHEASTWARD DIP OF LOWER MEMBER OF MAXVILLE (?) LIMESTONE SHOWN BY LIMESTONE CLIFF 5 MILES EAST OF IRVINE.



C. SMALL FAULTS AND BRECCIATION OF "CORNFEROUS" LIMESTONE AT IRVINE.
STRUCTURAL FEATURES IN IRVINE OIL FIELD, KY., APPARENT
WITHOUT INSTRUMENTAL DETERMINATION.

example from $1\frac{1}{2}$ to 2 miles above the mouth of Sweet Lick Branch, there are rather strong dips. Here along the bed of the creek the black shale dips from 10° to 20° in a direction somewhat west of north. This strong dip seems to indicate a monocline, which replaces the fault in part of its course. In an unsuccessful test at the schoolhouse on Sweet Lick Branch near the base of the monocline, the top of the sand was found at 148 feet below the surface and the bottom at 178 feet. Outcrops and logs of wells to the south show that the strata rise in that direction apparently without faulting.

STANTON SYNCLINE.

Although little was determined regarding the exact position, form, and extent of the Stanton syncline, the evidence that was gathered indicates its existence beyond question. This evidence consists largely in scattered observations on the geographic position and altitude of outcropping beds. In his report on the Menifee and Ragland fields Munn¹ expresses the belief that such a syncline exists, saying: "The general dip toward the southeast in the Menifee, if continued to Campton, would bring this limestone to a depth several hundred feet below that at which it is found."

Apparently this syncline plunges to the east and is terminated on the west by a north-south anticline or terrace, 8 to 10 miles west of Stanton.

MINOR STRUCTURAL FEATURES.

Slight anticlinal structure seems to be generally developed along the northwest side of the Irvine fault zone. The anticline is highest 2 or 3 miles northwest of Irvine, where it is well displayed by the outcrop of the "Corniferous" limestone and in part by the lower-lying Waco limestone of Foerste.

From a point 3 or 4 miles north of Irvine a syncline seems to extend westward 2 or 3 miles and then northward. This syncline is apparently bordered on the northeast by an irregular anticline 50 to 100 feet in height, which trends northwest from Union Hall for 5 or 6 miles and thence north along the upper end of the Stanton syncline.

Southeast of Union Hall and on the opposite side of the Irvine fault zone and anticline there seem to be two cross anticlines which converge toward the one just referred to. Indeed, if no great error has been made in their delineation, the three may be regarded as constituting a major structural feature crossing the Irvine anticline at right angles.

¹Munn, M. J., U. S. Geol. Survey Bull. 531, p. 14, 1913.

There seems to be a small asymmetric dome 2 miles north-northwest of High Rock or 4 miles south-southwest of Filson.

A terrace from 2 to 3 miles wide apparently extends south-southwest 10 miles from the mouth of Cottage Fork to the mouth of Jones Branch.

CONVERGENCE.

The structure map (Pl. XIV, in pocket) falls short of showing the attitude of the oil sand, not only because of the reconnaissance nature of the survey but also because it represents, as nearly as possible at the present time, the structure of a bed lying several hundred feet above the oil sand, and the two beds are not parallel. The principal departure from parallelism is due to a general westward thinning of many of the formations, as noted on page 150 and shown in figure 22 (p. 168). The precise nature of the westward convergence of the beds is not known, but apparently the distance between the top of the St. Louis(?) limestone and the "Corniferous" limestone in the Campton field is fully 750 feet, whereas at Irvine, 25 miles to the west, it is only 530 feet.

The broader structural features of the oil sand, however, are believed to be similar to those of the St. Louis(?) limestone as represented on the map. The principal difference is that all the eastward dips of the oil sand are a little greater and all the westward dips more gentle.

JOINTS.

Joints are prominent in this region, particularly in the Ohio shale and the St. Louis(?) limestone. In softer and more plastic beds, such as most of those composing the "Waverly," the joints are obscure or lacking.

Observations on joints are of interest in connection with the study of an oil pool, principally because joints may form channels for oil and gas migration and because they may throw some light on the forces that warped the rocks and produced the structural features in which the oil is found.

In the Irvine oil field most of the joints trend between north and east. Very few trending between east and south were noticed. Most of them are nearly vertical, but a few depart 30° to 50° from verticality.

OIL AND GAS.

CHARACTER OF THE "PAY."

The "pay," or oil-bearing portion of the oil "sand," differs from the remainder of the limestone or dolomite in having larger pores and in being softer or less indurated. In places it is reported to be

cavernous. As this character is a product of recrystallization, it differs from similar features found in true sandstones in that it does not follow the bedding and is extremely irregular in development. After penetrating the soft, more or less sticky clay shale that overlies the oil sand the drill commonly enters a rather hard limestone or cap rock, which here and there yields water and which ranges from a few inches to several feet in thickness. Below this rock is the soft brown sandy-textured magnesian limestone which constitutes the oil reservoir. In the eastern part of the field, where the whole "sand" is thicker, oil-bearing strata are said to be found at more than one horizon.

The average thickness of the "pay" is difficult to estimate, because of its great irregularity and the fact that to avoid penetrating water-bearing rock many wells have not been deepened to the bottom of the "pay." The average thickness of "sand" penetrated, including both the oil-bearing portion and the overlying water-bearing or apparently dry rock, is probably between 20 and 25 feet. On the Isaac Henry tract, at the west end of the field, the bottoms of the wells are said to be about 20 feet below the top of the "sand," and on the Bud Rawlins tract, near by, 16 to 30 feet. On the A. M. Pasley farm, in the central part of the field, the bottoms of several wells are said to be 16, 26, 35, 23, 28, 19, 26, 23, 23, and 22 feet below the top of the "sand." Well No. 4 on this farm was carried to a depth of 80 feet below the top of the "sand" because of the poor showing of oil. These figures seem to be fairly representative of the field. Some wells have been extended 30 feet or more below the top of the "sand" and a few less than 15 feet. On the whole the "pay" is said to be farther below the top of the limestone in the eastern part of the field than in the western part, some wells penetrating 25 or 30 feet of the formation before oil in paying quantities is found.

GAS.

More or less gas has been found in a good many wells in the Irvine oil field, particularly along the northern border. A gas well about 3 miles west-southwest of Estill Furnace yielded no oil in the first week of its history, which ended at the time field work for this report was completed. It was allowed to blow off gas in the hope that oil would appear in the well in a short time. To judge by the sound of rushing gas in the casing, which is 6 inches in diameter, the well was producing 100,000 cubic feet or more of gas daily. It would not be surprising if enough gas were found in the vicinity of Estill Furnace to be worth marketing, for the Irvine anticline seems to be higher and sharper there than to the east or west.

To allow a well in an oil field to blow off gas is wasteful of gas and reduces the pressure and the ultimate yield of oil, but under

present customs to close such a well imposes a hardship upon the owner without due recompense. Many such wells produce oil and become valuable assets after blowing off gas for a while. In the later part of the life of an oil field air might be pumped into some wells to take the place of gas in making the oil extraction more complete.

Most of the wells in the Irvine field yield little or no gas.

WATER.

Salt water is probably present in the lower part of the oil sand throughout much of the field, particularly the southern half, and many wells just outside the field have yielded considerable quantities of water. Along the northern border, however, wells that fail to produce oil are commonly reported altogether dry. For example, a well at the schoolhouse $2\frac{1}{2}$ miles above the mouth of Sweet Lick Branch is reported to have yielded nothing at all. This well was on the north side of the fault and sharp monocline which borders the field on the north, though the difference in altitude between the oil sand here and at a producing well one-eighth of a mile to the southeast is not much over 40 feet. A fault of 30-foot throw would probably be sufficient to seal off the oil-bearing sand from the same bed on the opposite side of the fault, for the oil sand is scarcely 30 feet thick in this part of the field, and immediately above and below it are beds of relatively impervious clay shale of similar or greater thickness.

A pervious rock that is penetrated in a well and fails to yield water, oil, or gas is commonly said to be dry, but such a bed may contain much water. If the bed is lens-shaped and surrounded by impervious clay, so that no water can enter it to take the place of any that would otherwise flow out into the well, it may seem to be dry or it may yield its water very slowly. On the other hand, if the bed is not far below the surface it may be above the level of ground water and thus be really dry or rather have its pores filled with air and a very little water instead of almost nothing but water. In some places an essentially dry sandstone may lie between two beds that contain water, the upper water-bearing bed being due to perched ground water—that is, water whose natural downward movement is prevented or checked by an impervious layer. It seems probable that many if not all the deep-lying so-called dry sands in the Irvine field really contain much water, but either they are so sealed in that they can not give up their water or else they have a good outlet at a lower altitude and the hydraulic head of the water forces it to flow down the sand layer to this outlet instead of out into the well. Conditions are easily imagined under which a sand that is actually quite

full of water, if the water is in motion, may take up water that is poured into a well for drilling.

Thus the failure of a well to yield water does not prove that the sand contains little or none, or even that it is not saturated, for if a layer or mass of porous rock within the earth is saturated with water but sealed off from other layers containing water, oil, or gas which can flow in to take its place its water would probably not flow out into a well. It is conceivable that if the well penetrates a great thickness of the porous bed air might flow from the well into the upper part of the bed while water flows out from the lower part, but the process would be slow because of the very low differential pressure.

The composition of the water associated with the oil at Irvine is unknown, except that it contains much sodium chloride or common salt. The water in the noted mineral springs at Irvine may come from the limestone that constitutes the oil sand, but it is certainly very different in quality from the salt water of this and other oil fields. Perhaps this difference is due to a fault between the springs and the oil-producing area and some circulation in the water of the limestone in the vicinity of the springs. The facts that mineral springs, particularly sulphur springs, are fairly common along the outcrop of the basal portion of the Ohio shale in Kentucky and Ohio and that the shale is relatively impervious, marcasitic, and commonly jointed seem to indicate that the spring water generally comes from the underlying limestone through a fissure in the shale, probably on the whole traveling far and at a comparatively slow rate, and that it gets some of its mineral matter from the limestone and some from the shale. The nature of possible oil-sand water from springs in the fault zone is indicated in analyses made by Peter,¹ who comments upon them as follows:

The carbonates of lime, magnesia, and iron are held in solution by the free carbonic acid; or, in other words, exist in the waters as bicarbonates. The soda is also in the form of bicarbonate, which salt is not incompatible with the sulphate of magnesia present in the same water.

The chalybeate water owes its name and peculiar virtues to its bicarbonate of iron, of which the red sulphur water, most distant from the house, contains traces (as doubtless the other also), and the "black sulphur" even more than the chalybeate (as tested at the laboratory). The latter contains a small portion of sulphate of alumina (alum). The change of the dissolved bicarbonate of protoxide of iron to insoluble hydrated peroxide of iron, which always takes place when these waters are exposed to the air, is the cause of the formation of the brownish deposit and their loss of virtues when they are carried any distance from the spring.

¹Peter, Robert, A summary of the chemical analyses of ores, rocks, soils, clays, marls, iron furnace products, mineral waters, etc., of Kentucky: Kentucky Geol. Survey Fourth Rept., for 1858-59, p. 143, 1861.

It should be borne in mind that the water may come up from a lower rock, along a fault or joint, but the facts that the salinity of the spring water is low compared with that of oil-field water in general, that in this region all the deeper wells find strong salt water, that the oil "sand" is underlain by relatively soft shale such as would be likely to seal up any fissure, and finally that springs of this sort are common near the outcrop of the "Corniferous" limestone and the basal part of the Ohio shale make it seem probable that the water really comes from the oil sand. Perhaps the fact that in all such springs the flow is copious is a further indication that the water does not come from a deep-seated source.

Some of the analyses are quoted by Chase Palmer¹ in a modified form, with further comment.

The red sulphur water deposits ferric hydrate, the color of which has given the name to the water. Black ferrous sulphide is deposited from the black sulphur water, and from the white sulphur water a white deposit of sulphur is formed.

Composition of Estill Springs waters.^a

[Parts per million.^b Analyst, Dr. Robert Peter.]

	Red sulphur.	White sulphur.	Black sulphur.	Chalybeate.
Silica (SiO ₂).....	6.8	4.0	13	32
Iron (Fe).....			48	15
Aluminum (Al).....		8.5	3.6	
Calcium (Ca).....	81	121	45	148
Magnesium (Mg).....	26	25	11	47
Sodium (Na).....	99	52	26	7.4
Potassium (K).....	42	32	7.6	4.9
Carbonate radicle (CO ₃).....	197	24	108	72
Sulphate radicle (SO ₄).....	176	152	67	350
Phosphate radicle (PO ₄).....		Trace		
Chlorine (Cl).....	5	5.5	22	5.5
Organic and volatile matter.....	40	50	59	141
	715	696	410	896
Free carbon dioxide (CO ₂).....	325	360	263	269
Free hydrogen sulphide (H ₂ S).....	4.5	3	35	0

^a Kentucky Geol. Survey Fourth Rept., for 1858-59, p. 143, 1861.

^b Obtained by computation to ionic form; results originally stated in hypothetical combinations.

Salt water in the vicinity of the Irvine field has been known at least as long as 60 years. Owen² says: "Borings for salt have been made on Millers Creek a few miles above its mouth and some salt water obtained."

In another report³ Owen makes the general statement: "In the second or more ancient of these sandstones (Potsdam or Cambrian?) the water is also generally impregnated with salt, to the extent of

¹ Palmer, Chase, Quality of the underground waters in the Blue Grass region, Ky.: U. S. Geol. Survey Water-Supply Paper 233, p. 206, 1909.

² Owen, D. D., Kentucky Geol. Survey Third Rept., for 1856-57, p. 140, 1857.

³ Owen, D. D., Kentucky Geol. Survey Fourth Rept., for 1858-59, p. 23, 1861.

600 to 700 grains in a wine gallon—mixed, however, with a variety of other salts and mineral substances.”

The composition of oil-field waters is of importance in petroleum geology because it promises aid in understanding the origin, the accumulation, and perhaps the quality of the oil. Oil-field waters are salty; so is ocean water; many of the strata of oil fields were laid down in the ocean, and the suggestion thus arises that the oil-field water is, so to speak, fossil sea water, or as Lane¹ has called it, connate water—water of the ancient ocean in which the strata were formed. If so, there has been little or no free circulation of water in the rocks containing the salt water and oil in all the long periods of geologic time, and the oil was formed not far from its present position. On the other hand, accurate chemical analyses show that the oil-field waters differ more or less from present ocean water and presumably from the ocean water of the distant past, being, for one thing, more concentrated. Whether these differences have probably been produced underground so that the oil-field water is somewhat modified fossil sea water or whether the oil-field water has had a different source is a matter of discussion. If it came from a source far within the earth, perhaps the oil also came from great depths. The available evidence seems to indicate that neither the water nor the oil had a deep-seated source.

It is often suggested that salt water exerts some kind of a pickling effect on the remains of organisms that become buried in the sediments which now constitute the strata of rock, and that the product in thousands or millions of years, under the conditions existing in nature's underground laboratory, is petroleum and gas. This hypothesis seems rather doubtful, but the salts dissolved in the water, particularly those containing chlorine, may affect the quality of the oil if they do not control its development.

SUGGESTIONS FOR PROSPECTING.

The facts that the Irvine anticline seems to extend eastward for several miles beyond the proved oil territory and that the field has not been delimited on the east by dry holes² make the territory between Estill Furnace and East Fork of South Fork of Red River and south of the fault zone very promising. It seems probable that the field will be extended eastward without interruption for several miles.³

¹ Lane, A. C., *Mine waters: Lake Superior Min. Inst. Proc.*, vol. 13, pp. 64, 125, 1908.

² In March, 1917, this statement was still true.

³ Since this paragraph was written (Nov. 10, 1916) several tests far east of the field as it existed at that time have, according to news journals, proved successful, and the field has had no appreciable growth in any other direction.

The next most promising territory appears to be the Locust Branch anticline, the exact form of which has not been determined, and the third is the anticline on the north side of the Irvine fault zone. The attractiveness of this third anticline is enhanced by the tradition that a gas and oil well was drilled on it over half a century ago. The best part of it seems to be that lying a few miles a little north of west of "The Furnace." To be sure, several unsuccessful tests have been made in apparently favorable situations in this area, but that does not prove that in other favorable situations oil and gas may not be found.

On account of the fact that the oil-bearing rock lies comparatively near the surface, the structural relations of the oil pools near its outcrop may be somewhat different from those where it is far underground. If, as the writer is inclined to believe, most of the reported deep, dry sands are only apparently dry, oil pools may be more likely to occur on anticlines in them than in shallow sands, which really are partly or altogether dry.

The structure map (Pl. XIV, in pocket) shows certain minor untested structural features that may contain oil. One of these is 2 to 3 miles northwest of High Rock. Another is near the head of Laurel Rock. These suggestions are made with a large element of doubt because of the reconnaissance nature of the survey and the fact that the features are small, whereas in other regions many pools do not conform to even the larger structural features.

SURFACE INDICATIONS OF OIL AND GAS AROUND IRVINE.

In order to reduce the cost of searching for new pools it is highly important to learn what indications of petroleum existed at the surface in each field before petroleum was discovered. In the vicinity of Irvine the most significant features observable at the surface seem to have been the anticline, gas and salt water in water wells, carbonaceous rock, and the free bitumen found in a few places. As the anticline occurs in a region where the rocks are suitable for the formation of oil and its accumulation into pools it may be said to have been by far the most promising feature, and had it been discovered and mapped, and had the map been used, prospecting could have been carried on with a much better knowledge of the chances of finding oil. The development of the field would also have been more rapid and less costly if the facts concerning the structure had been fully known and used; but, on the other hand, most pools do not conform closely to the structure, and hence sooner or later, whether or not geologic data are used, the unpromising spots will be tested.

Gas and salt water are said to have been found in some water wells—for example, those referred to on page 141, and such occur-

rences appear to be much more common in oil fields than elsewhere. They seem to indicate a lack of free circulation of ground water—a condition favorable to the retention of oil and gas in reservoirs. Inasmuch as many rocks were formed in the sea, they must have contained salt water at first, and if they are very porous or have cracks so that the water in the ground can circulate freely through them, the salt water and any oil or gas they may contain may be washed out. For this reason it seems probable that in regions where sand is unusually abundant oil and gas pools are much less likely to be found than where clay, shale, and other impervious rocks are relatively common.

Although no tar seepages or asphaltic rocks are known around Irvine, some of the rocks give forth a bituminous odor when freshly broken, especially the Ohio shale and the underlying limestone or dolomite, which constitutes the oil "sand" of the Irvine and other fields. Oil is said to have issued in a quarry at the base of the Ohio shale near Irvine, several gallons having been obtained.

CAPACITY AND LIFE OF WELLS AND AMOUNT OF OIL STILL IN THE "SAND."

The estimation of how much more oil can be extracted from the Irvine field is a difficult problem, one reason being that little enlightening information is available from which to construct life and production curves of the wells in this field, because they have not been worked to their full possibilities, and another reason being that the pore space of the oil-bearing limestone is extremely irregular. In some places the limestone is compact; elsewhere it has an abundance of not only small pores but also cavities of various sizes. Some of these cavities may be closed, so that if they give up their oil at all it will be at so slow a rate that wells which might be supplied from them will be abandoned before the oil gets out.

PRODUCTION OF OIL.

The production of oil in the Irvine field is indicated in the accompanying diagrams (figs. 24-28) made up from data published in the Oil and Gas Journal and the Wayne County (Ky.) Outlook. The diagrams show that the number of wells and daily production of the field have grown rapidly; that the percentage of successful wells has been rather high since the development of the field got fairly started, and that the average initial production, though showing much variation, seems to show no general trend as the field is extended eastward.

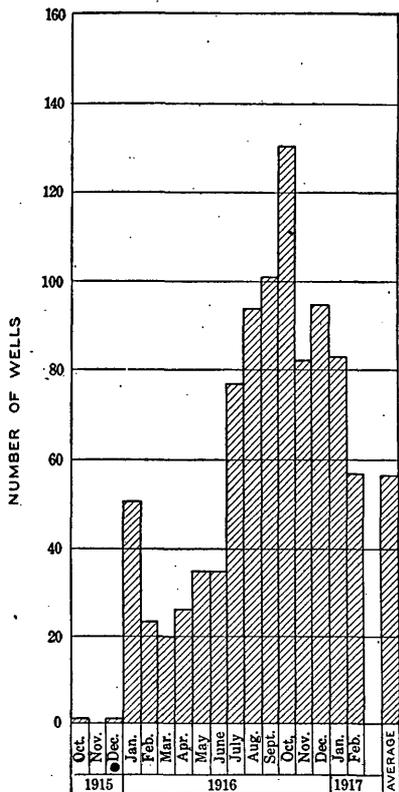


FIGURE 24.—Diagram showing number of wells drilled in and near the Irvine oil field, Ky., from October, 1915, to February, 1917.

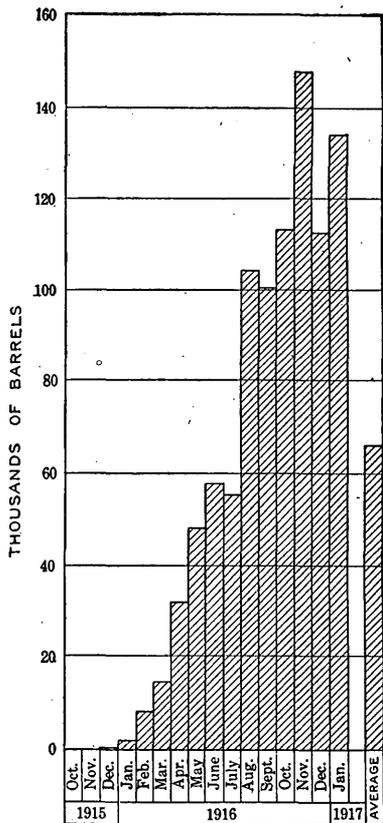


FIGURE 25.—Diagram showing production of Irvine oil field, Ky., from December, 1915, to January, 1917.

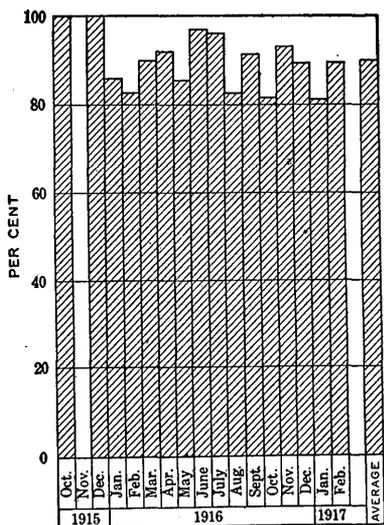


FIGURE 26.—Diagram showing percentage of successful wells in Irvine oil field, Ky., from October, 1915, to February, 1917.

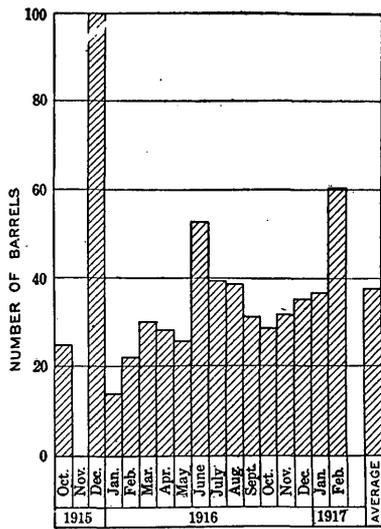


FIGURE 27.—Diagram showing average percentage of initial production of successful wells in Irvine oil field, Ky., from October, 1915, to February, 1917.

The statistics represented by the diagrams, with some later figures which have appeared since the diagrams were prepared, are given in the table on page 184.

The pore space of the oil "sand" is evidently extremely variable within short distances, though perhaps that of considerable bodies of the rock is fairly uniform. A specimen from an outcrop absorbed, after being dried, 25 per cent by volume of water. This percentage is probably much above the average for the oil-bearing rock, for, although the sample was selected as being approximately representative of the visible or outcropping portion of the oil rock, it probably differs from the buried portion on account of exposure to the weather, one effect of which is the gradual leaching out of the small admixture of lime carbonate in the rock.

It is evident that on account of the variations in effective or communicating pore space and the numerous small cavities, accurate estimates as to pore space can not be made from the few small fragments of the oil rock that have thus far been obtained from wells. When the shooting of wells becomes more general it will no doubt be possible to get many chunks of the rock an inch or more in diameter, from which fairly reliable determinations of pore space can be made, and from these the total quantity of oil in the rock can be estimated. Perhaps when the field is supposed to be exhausted it can be shown from the total amount of pore space in the "pay" throughout the field and the total amount of oil and gas produced that actually much oil remains in the rock as a lining of pores at that time containing water.

In any case the total pore space of the "pay" in the present productive area is apparently five to ten times as great as the total quantity of oil so far marketed, and it seems probable that the pool will be found to have an extent 30 or 40 per cent greater than the present proved area.

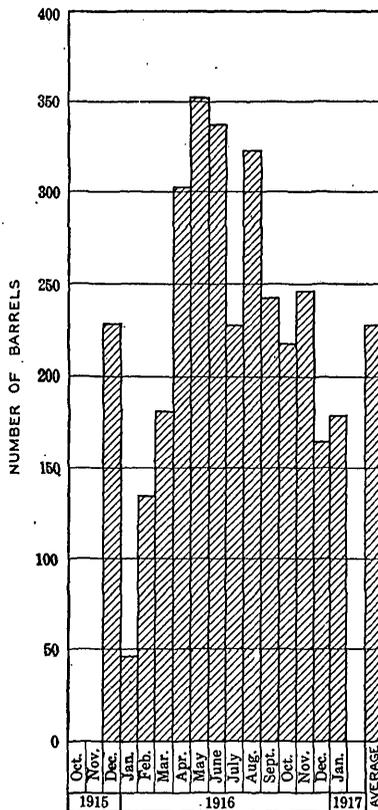


FIGURE 28.—Diagram showing production in Irvine oil field, Ky., for each month from December, 1915, to January, 1917, divided by total number of productive wells previously drilled.

The initial pumping capacity of wells in the Irvine field seems to run generally between 10 and 70 barrels a day. Very few of the wells have flowed naturally. Because the marketing facilities are inadequate the production has been much below the full capacity of the wells. Practically all the oil marketed is said to be shipped through a 4-inch pipe line. Partly for the same reason few wells have been shot. It seems unlikely, however, that shooting would greatly increase the capacity of the average well and very improbable that the ultimate yield of the wells could thus be greatly increased, for the oil-bearing rock has comparatively large pores and fracturing is not greatly needed. However, many of the wells will no doubt be shot as soon as their capacity drops or shipping facilities are increased to the point where the oil obtained by a temporary increase of capacity could all be marketed.

Well data for Irvine, Ravenna, and Station Camp fields, Ky.

Month.	Number of wells completed.	Percentage of productive wells.	Average initial production of productive wells (barrels a day).	Total production (barrels).	Production for the month divided by total number of productive wells to date.
1915.					
October.....	1	100.0	25.0
November.....					
December.....	1	100.0	100.0	456.00	228.00
1916.					
January.....	51	86.3	14.2	2,120.14	46.09
February.....	23	82.6	22.1	8,725.00	134.23
March.....	20	90.0	30.1	15,000.00	180.72
April.....	26	92.3	28.4	32,343.71	302.28
May.....	35	85.7	25.8	48,250.60	352.19
June.....	35	97.1	55.2	57,845.56	338.29
July.....	77	96.1	39.2	55,721.03	227.43
August.....	94	82.9	38.4	104,189.02	322.57
September.....	101	91.1	31.4	100,567.84	242.33
October.....	131	81.7	28.3	113,137.29	216.74
November.....	82	93.9	31.8	147,670.39	246.53
December.....	95	89.5	34.5	112,554.70	164.55
1917.					
January.....	83	81.9	36.4	133,953.24	178.13
February.....	57	89.5	60.4	107,341.13	118.87
March.....	72	81.9	55.6	145,000±	150.72
April.....	68	83.8	49.1	130,000±	127.57
Average.....	55	89.2	39.2	77,345.63	210.43

CHARACTER OF THE OIL.

The Irvine oil is dark green by reflected light; by transmitted light it is of so dark a brown as to seem opaque except where the thickness of the sample is only an eighth or a quarter of an inch. Its specific gravity is said to range from 30° to 36° Baumé, and its gasoline content is said to be so high that the oil sometimes bubbles in the tanks.

A sample of oil was collected from the Bud Rawlins farm, 2 miles northeast of Irvine, and sent to the Bureau of Mines for analysis. The returns are of especial interest because this farm lies next to the fault and also less than 2 miles from several exposures of the oil-bearing rock. The sample was collected from a freshly filled tank, and the oil came from wells Nos. 1 to 11, inclusive, except well No. 4.

Analysis of crude oil from Irvine field, Ky.

[Specific gravity at 15° C., 0.872=30.5° B. Distillation in Bureau of Mines Hempel flask. Barometer, 747 millimeters.]

Temperature (°C.).	Frac- tions (per cent by vol- ume).	Total distilled (per cent by vol- ume).	Specific gravity.
Up to 125	3.4	3.4	0.739
125-150	4.0	7.4	.773
150-175	4.9	12.3	.794
175-200	3.7	16.0	.811
200-225	4.2	20.2	.823
225-250	4.8	25.0	.831
250-275	5.7	30.7	.844
275-300	8.7	39.4	.847

ORIGIN OF THE OIL.

The source and mode of formation of petroleum are not yet known with certainty, though fairly convincing evidence has been brought forth concerning the oil of certain fields. The most prevalent opinion among oil geologists is that it is of organic origin and that most of it at least has been derived from the remains of plants rather than of animals. However, the arguments for animal origin, as, for example, the fact that oil is in many places associated with mollusk shells, have appealed to many.

To the writer it seems very probable that most petroleum is of plant origin. The two principal reasons are, first, that carbonaceous remains of plants are far more abundant than those of animals in all rocks, and, second, that the hydrocarbon-bearing portions of animals decompose far more readily and quickly than such parts of plants.

By far the greater part (probably over 99 per cent) of the carbonaceous material in the earth's crust that can be classified with certainty is of plant origin, and, except for water, plants consist principally of the elements that go to make up petroleum and natural gas, namely, carbon, hydrogen, and oxygen. The soft parts of animals also consist mainly of the same elements with more or less nitrogen, but they decompose or oxidize much more readily,

and hence are much more likely to be lost in the air and surface water before being buried so deep that decomposition or oxidation ceases. The writer has had the opportunity of observing many lime, sand, and other formations in process of development, and has seen many places where plant material was being incorporated with sediment, including the great mud deposits at the mouth of Mississippi River and certain rivers in northern Europe; the lime deposits around Florida and Yucatan, the Great Salt Lake, and elsewhere; sand deposits at various places along the Atlantic coast, the Great Lakes, the smaller lakes and streams; and more or less sandy, limy, and clayey deposits in glacial and other lakes. He has seen only a few places where the soft parts of animals have been or are being buried, and at most of these places it is presumable that decomposition continues to completion. Most oils contain a little nitrogen, which is a much more abundant and characteristic constituent of animal matter than of plant matter, but the amount in petroleum is generally a small fraction of 1 per cent. Many plants contain some nitrogen, and it appears possible that some of the nitrogen in petroleum may have come from air buried with the organic mud, the oxygen having been used up in other combinations.

The fact that globules of petroleum have been observed in cavities associated with shells of sea animals does not seem significant, because petroleum is almost exclusively found in cavities or in the larger openings and pores of rocks, and it is much more reasonable to assume that the oil came from elsewhere and stopped where it found a cavity, than that a part of the flesh of a Paleozoic sea mollusk was converted into petroleum, and that the other products of the change were carried away, although presumably less easily transported, while the petroleum was left for ages precisely where it was formed, particularly as, though fossils are abundant, occurrences of globules of oil in them are rare and are confined to those which happen to have cavities.

In the Irvine field a very large quantity of carbonaceous material is included in the Ohio black shale, which contains abundant remains of plants, particularly spore cases of ferns, which may be seen on almost any slab of the shale. They form rather conspicuous black or dark-brown spots ranging from one-sixteenth to one-fourth inch in diameter, and are commonly surrounded by resinous masses, which are beyond a doubt derived from plant matter and yet are very similar in composition to petroleum.

The facts that this shale immediately overlies the oil-bearing rock, though generally the very carbonaceous portion is separated from the oil rock by a few feet of light-colored clay shale; that it is by far the most carbonaceous bed in the region; and that a petroleum heavier

than that in the oil "sand" can be distilled from it make it seem extremely probable, if not almost certain, that this shale has been the source of the oil now being produced in the field. The writer knows of no oil field where the circumstantial evidence as to the source of oil is stronger than in the Irvine field. The spore cases themselves, which are beyond doubt of plant origin, have undergone a gradual slight rearrangement of their molecules that brings their composition close to that of petroleum, as is indicated when they are distilled in a closed tube. If they or in fact any portion of the shale is put in a glass tube a few inches long and closed except for a small opening at one end, and if the shale is shaken down to the opposite end and this end heated over a hot flame, gas will issue from the opening at the other end and may be ignited, while a conspicuous ring of oil distilled from the shale will form on the inside of the tube.

The conditions that determine whether oil or gas, which are composed of practically the same elements, and what variety of either will be formed when the shale is subjected to pressure for ages are not yet fully understood, but David White,¹ who has given much attention to this subject, believes that gas is more likely to predominate over oil where the pressure is greatest.

MODE OF ACCUMULATION OF THE OIL.

The next problem is to trace the oil from its original position of wide dissemination in the shale to the oil "sand" and to portions of the oil "sand" where the structure is favorable for the accumulation and retention of pools. The Ohio shale, like most other geologic formations, was laid down in water of one kind or another, and its original thickness, when it was saturated with water, was much greater than its present thickness. When great deposits of mud, particularly carbonaceous mud, are buried beneath hundreds of thousands of feet of later deposits and allowed to lie thus buried for thousands or millions of years, compacting must obviously take place. To judge by determinations of pore space made by the writer, the average carbonaceous mud that is not yet buried has 8 to 10 times as much pore space as the present Ohio shale. In the compacting process all the fluids contained in the mud which later became the Ohio shale were forced out by the most available route, whether that was down, up, or sidewise. This process has recently been discussed by Johnson.² In borings which the writer has made in recent carbonaceous materials no oil has been found, even in portions that have been considerably compacted. He is hence inclined to believe

¹ White, David, Some relations in origin between coal and petroleum: Washington Acad. Sci. Jour., vol. 5, pp. 189-212, 1915.

² Johnson, R. H., The rôle and fate of the connate water in oil and gas sands: Am. Inst. Min. Eng. Bull. 98, pp. 221-226, 1915.

that the formation of petroleum does not begin until after the main compacting has been accomplished. If any were formed before, it might be carried out in whatever direction the original water was forced out.

After most of the compacting had been accomplished the fluids contained in the Ohio shale and the overlying and underlying formations must have been shifted about a little from time to time by any further compacting that took place, by crustal movements of the earth, by changes in internal temperature, by tidal stresses, by changes in air pressure, and probably by an extremely slow direct or indirect downward migration, such as the writer suspects is common to all water under lands that attain any considerable altitude above the sea. In this way the oil and gas formed in the Ohio shale were very likely shifted somewhat, though the facts concerning their evident close confinement and the existence of salt water near the surface indicate that the migration of none of the fluids has been extensive.

According to the writer's views, the migration and separation of the oil, gas, and water are effected as follows:

The water, oil, and gas in all rocks are constantly under the influence of intermolecular attractions, which are effective through only minute distances, but which within those distances are very great, much exceeding that between the earth and a molecule. Such forces differ from substance to substance, and their general effect in a sand is to push the oil and gas into the larger pores or cavities, or at least to retain it in such places after it has arrived. Apparently the heat activity of the molecules would not profoundly modify the result. The largest pores available to the oil of the Irvine field are in the "Corniferous" limestone. As the amount of oil was insufficient to fill all the cavities in the limestone throughout its extent, the continuance of all the processes that tend to shift about fluids within the earth might very reasonably have caused the oil and gas to respond to the force of gravity, which is stronger for water than for oil, and to migrate to the places where the sand lay highest, leaving water in the lower places. As Munn¹ has pointed out, it seems impossible that in the nearly flat-lying beds of most oil fields the migration to the top of an anticline or other favorable structural feature could be accomplished by gravity alone, while all fluids were quiescent, but if the fluids were moved any considerable distance the oil and gas might during their migration accommodate themselves to gravity and get to the tops of the anticlines, and if all fluids were subject to an oscillatory motion, even if so slight as to amount to the diameter of only a few pores, the oil and gas would perhaps still migrate to the tops of the anticlines.

¹ Munn, M. J., *The anticlinal and hydraulic theories of oil and gas accumulation*: Econ. Geology, vol. 4, pp. 509-539, 1909.

SHALE OIL.

It is interesting, both for the scientific purpose of a better understanding of the origin of petroleum and for the practical purpose of knowing what opportunity exists of making artificial petroleum from the Ohio shale, to know the nature and proportions of hydrocarbons which may be extracted from it. Shales from which oil may be obtained are not at all uncommon in the United States and other countries, and in some places, particularly in Scotland, the manufacture of petroleum from shale has been carried on for many years. It is said that many plants built for the extraction of oil from the Ohio shale were in operation in Kentucky and Ohio 50 or 60 years ago. Some of the petroleum in the shale may be dissolved out with ether or some other liquid in which petroleum dissolves readily, and some requires distillation; in other words, some seems to exist as petroleum in the shale, but a larger part is a chemical product of the distillation of other hydrocarbons.

A sample of the Ohio black shale from Irvine was submitted to the Bureau of Mines for destructive distillation. The test indicated that the shale would yield 7 gallons of oil and 8 gallons of water to the ton.

Samples of black shale from numerous places in Kentucky, Tennessee, Pennsylvania, Ohio, Indiana, and other States have been tested, and the results are discussed by Ashley,¹ who remarks: "According to these figures, the Devonian black shale can be expected to yield not over 10 or 12 gallons of oil, 2,000 cubic feet of gas (as a by-product), and one-third of a pound of ammonia to the ton."

The chemical composition of the shale is shown by the following analysis, by Robert Peter, of more or less weathered material collected by Owen:²

Devonian black slate, sifted out of soil from Thomas Carson's farm, near Irvine, Estill County, Ky.

[Composition, dried at 212° F.]

Alumina and oxides of iron and manganese-----	6.860
Carbonate of lime-----	.244
Magnesia-----	.433
Phosphoric acid-----	.310
Sulphuric acid-----	.132
Potash-----	1.101
Soda-----	.340
Sand and insoluble silicates-----	82.280
Bituminous matters, water and loss-----	8.300
	100.000

¹ Ashley, G. H., Oil resources of black shales of the eastern United States: U. S. Geol. Survey Bull. 641, p. 320, 1917.

² Owen, D. D., A summary of the chemical analyses of ores, rocks, soils, clays, marls, iron furnace products, mineral waters, etc., of Kentucky: Kentucky Geol. Survey Fourth Rept., for 1858-59, p. 145, 1861.

The soft aluminous shales are very generally rich in potash, and where they are easily decomposable they yield a rich soil, subject, however, to be wet, heavy, or swampy, because of the considerable amount of clay present and imperfect natural drainage. When well drained, these lands may be made quite productive.

Two samples of the black shale were submitted to C. E. Van Orstrand with the request that the porosity and specific gravity be determined before and after extraction of carbon dioxide, combined water, and organic material by acid and ignition. He made the following report:

The porosity of sample No. 1 was found to be 7.6 per cent; that of No. 2 to be 7.4 per cent.

After grinding the samples until they passed through the 100-mesh sieve they were washed in petroleum ether. The sample which gave 7.6 per cent porosity was washed 12 times; the other one was washed 18 times. A washing consisted of covering the sample with petroleum ether, letting it boil for about 15 minutes, and then decanting off the petroleum ether. Petroleum ether was again poured over the sample and then poured off. The above process was then repeated. The final porosity of each sample was found to be 8 per cent.

The separated grains of the shale passed through the 300-mesh sieve.

A 3-gram sample of the shale was passed through a 100-mesh sieve, and then boiled for 20 minutes in concentrated hydrochloric acid. The porosity determined from the powder thus treated is 8 per cent, the same as was obtained by boiling in petroleum ether. Another 3-gram sample was passed through the 100-mesh sieve and heated 20 minutes in a Bunsen flame. The porosity determined from this final product is 19.6 per cent. The specific gravity of the powder thus treated is 2.59, and a solid cubic foot of it would weigh 161.69 pounds. A cubic foot of the shale with the 19.6 per cent of pore space emptied in the way outlined would weigh 130 pounds.

This and previous tests were made by A. F. Melcher.

The shale as it lies in the earth with water and other substances in the pores probably weighs 140 to 145 pounds to the cubic foot.

NOTES ON DEVELOPMENT.

Although this report is designed primarily to be purely geologic in nature, the geology of the field is so closely related to problems of the recovery of petroleum that a few brief notes on these problems are worthy of record in this place.

As the oil "sand" lies not far below the valley bottoms, drilling is comparatively inexpensive. It is reported that the discovery well cost less than \$50. The average cost of wells is, however, several hundred dollars, for most of them are deeper than the discovery well, and some have cost more than \$2,000. Most of the drilling is done with machines, but derricks have been erected here and there. The general appearance of the field differs markedly from those where the oil lies at great depth, for there is no forest of derricks, but instead inconspicuous pumping jacks scattered over the more or less wooded mountain sides.

As the country is rough, it is commonly difficult to haul drilling machinery to a well site, and generally temporary roads have to be built. For a similar reason it is difficult to get a supply of water to wells at relatively high altitudes.

Many of the first wells are said to have been drilled too deep and to have penetrated a salt-water zone, which seems to underlie the oil "sand" throughout a large part of the field. Some of the early wells were also shot too heavily, several wells having apparently been ruined in this way.

It is also difficult and expensive to bring fuel to the oil wells, and many of them have, curiously enough, been drilled with gasoline costing 15 or 20 times as much as the market price of the gasoline-bearing oil, for which they were being drilled.

The connecting pores of the oil-bearing rock are relatively large throughout its extent, and the oil is under more or less pressure from gas. Hence the oil flows into the wells rapidly, and there is little need for close drilling. However, the rock varies somewhat in porosity, and hence there seems to be a possibility that small portions of the pool may be surrounded by advancing water and their oil prevented from reaching a well.

The method of advance of this water is a geologic problem of great economic importance. As the oil is taken out, air, gas, or water must flow into the pores to take its place, and the question immediately arises, How complete is the replacement? If the walls of the pores retain a coating of oil, the oil recovered may be much less than the original amount in the ground, for most of the pores are probably not over 0.002 inch in diameter and a thin coating on their walls would be a large part of their original content. It may be that the replacement is more complete with slow extraction, so that the percentage of recovery would be higher if the oil were taken out at a slower rate. The pores are extremely irregular in diameter, more so than the grains composing the sand, and it may be that some of the smallest pores retain their oil.

Few of the wells have been shot, and few flow. Partly on account of insufficient marketing facilities, there has been no effort to force wells to their full capacity. As these facilities grow better and the demand for oil increases and as the production of individual wells declines no doubt many of them will be shot and thus rejuvenated.

It is said that much more oil would have been produced if it could have been readily marketed. The outlet has been a single 4-inch pipe line, and this has been taxed to its utmost capacity, being at times subjected to a pressure, it is reported, as high as 1,100 pounds to the square inch. However, an additional pipe line is said to be in process of installation.

