STRUCTURE OF THE BEREA OIL SAND IN THE WOODSFIELD QUADRANGLE, BELMONT, MONROE, NOBLE, AND GUERNSEY COUNTIES, OHIO.

By D. Dale Condit.

INTRODUCTION.

The information set forth in this report is the result of four months of field work during the season of 1914, during which the writer was assisted by R. V. A. Mills and Frank Reeves. A detailed geologic investigation was made of the mineral resources of the Woodsfield quadrangle and of the Summerfield quadrangle, adjoining it on the west. In this report are given briefly the more important features pertaining to the geology of the oil and gas fields of the Woodsfield quadrangle. A similar report has been prepared for the Summerfield quadrangle. These preliminary papers are to be followed by a bulletin in which the geology of the oil and gas fields will be considered in greater detail and in which attention will also be given to coals and other mineral resources.

It is desired to express the thanks of the field party to the residents of the region for many courtesies, and to the oil drillers and operators for their cooperation. Special thanks are due to the officials of the Carter Oil Co. and the Pure Oil Co., to Mr. J. W. Hardwick, of the Ohio Fuel Supply Co., and to others who furnished maps and well records.

GEOGRAPHY.

The Woodsfield quadrangle is situated in southeastern Ohio and includes parts of Belmont, Monroe, Noble, and Guernsey counties. The location and extent of the area is represented in figure 13, which also shows other areas in southeastern Ohio and adjacent parts of Pennsylvania and West Virginia for which structural maps of the oil sands have been prepared. The Woodsfield quadrangle is adjoined on the north by the Flushing quadrangle, the structure of which is described in Bulletin 346 of the United States Geological Survey.

The principal towns in the area are Barnesville, in the northwest corner of the quadrangle, on the Baltimore & Ohio Railroad, and

Woodsfield, near the south edge of the quadrangle, on the Ohio River & Western Railroad, a narrow-gage line which follows a devious route from Bellaire, on Ohio River, westward to Zanesville. The population of Woodsfield, according to the census for 1910, was 2,502, and that of Barnesville 4,233. Smaller villages are Beallsville, Jerusalem, Ozark, and Lewisville, which are along the narrow-gage railroad, and Miltonsburg, Malaga, Somerton, and Temperanceville, which are 3 to 6 miles from any railroad. All but the southwest quarter of the quadrangle is underlain by the Pittsburgh coal in workable thickness, and the time is not remote when this coal will be the basis for an extensive mining industry. The only shipping mine now in operation is at Baileys Mills, on the Baltimore & Ohio Railroad, 3 miles southwest of Barnesville.

The highlands dividing eastward-flowing tributaries of Ohio River from westward-flowing branches of Tuscarawas River extend in a north-south direction across the western part of the quadrangle. Captina and Sunfish creeks, the principal streams, occupy deep, narrow valleys equal in bold ruggedness to any others in the State. The local relief from the valley floor of Sunfish Creek to neighboring hilltops ranges from 400 to 500 feet, and the maximum relief for the entire quadrangle is about 700 feet. The greatest altitude is 1,420 feet, on a hilltop 1½ miles northwest of Miltonsburg, and the least is found along the valley of Sunfish Creek, being only slightly more than 700 feet near the southeast corner of the area.

GEOLOGY.

STRATIGRAPHY.

The rocks at the surface in the Woodsfield quadrangle are of Pennsylvanian ("Coal Measures") and Permian age and include in ascending order the Conemaugh, Monongahela, and Washington formations as classified by geologists. The dip or slope of the beds is in general southeastward; therefore higher and higher strata are crossed when one travels in that direction. The direction and degree of the inclination of the strata have an important bearing on the location of oil pools, and these features are described under the heading "Structure" (pp. 243–247).

GENERAL SECTION.

The stratigraphy of eastern Ohio has been discussed in previous reports, and only a brief outline is needed here. The several formations represented, with their approximate thicknesses, are listed below. The classification given for the Mississippian rocks is the one introduced by Ohio geologists for these beds where they crop out in the central part of the State.

General section of formations in eastern Ohio.

	Feet.
Permian series:	
Washington formation ("Upper Barren")	400±
Pennsylvanian series ("Coal Measures"):	
Monongahela formation ("Upper Productive")	255–275
Conemaugh formation ("Lower Barren")	460–475
Allegheny formation ("Lower Productive")	250–265
Pottsville formation	155–170
Unconformity.	
Mississippian series:	
Maxville limestone (Big lime)	0–110
Unconformity.	
Logan formation (includes Keener sand)	600–700
Black Hand formation (includes Big Injun sand)	
Cuyahoga shale	
Sunbury shale	
Berea sandstone	
Bedford shale	

The Mississippian formations constitute the great oil-bearing rocks of southeastern Ohio and include the Berea, Big Injun, Keener, and Big lime sands, all of which are productive in the Woodsfield quadrangle. In outcrops some 80 miles to the west and northwest the same beds are quarried for building stone. Below the Berea is a great thickness of shale, the bottom of which has never been penetrated by the drill within the Woodsfield quadrangle. The Clinton sand, which yields much oil and gas in central and northeastern Ohio, if present in this region lies more than 4,000 feet below the Berea sand.

The Maxville limestone, known among oil drillers as the Big lime, varies considerably in thickness and is apparently missing in some parts of the Woodsfield quadrangle. This is to be expected, for the limestone is variable where seen in outcrop. It is overlain unconformably by sandstone, which forms an undulating contact and locally extends across the limestone, entirely replacing it.

The Pennsylvanian or "Coal Measures" rocks are made up largely of shale, clay, and sandstone, with numerous beds of coal and limestone. Several of the sandstones are oil bearing. The Pottsville and Allegheny formations and all but the upper third of the Conemaugh formation are below the surface throughout the quadrangle. The Allegheny is the great coal-bearing formation in the northern Appalachian coal basin. In Ohio, though only a little more than 250 feet thick, it includes a number of coal and clay beds of great economic importance. The Conemaugh is appropriately called the "Lower Barren," for it contains no coals of great value and also lacks important beds of limestone and clay. It consists for the most part of shale and reddish-brown clay, with lenses of sandstone. The Monongahela formation contains the Pittsburgh, Meigs Creek, and other valuable coal beds and important beds of limestone, together with sandy shale, clay, and nonpersistent beds of sandstone.

The Washington formation of the Permian series lacks valuable beds of coal and is characterized by nonpersistent sandstone members, with shale and clay commonly of reddish-brown color. The few coals and thin limestone beds of the formation are found near the base.

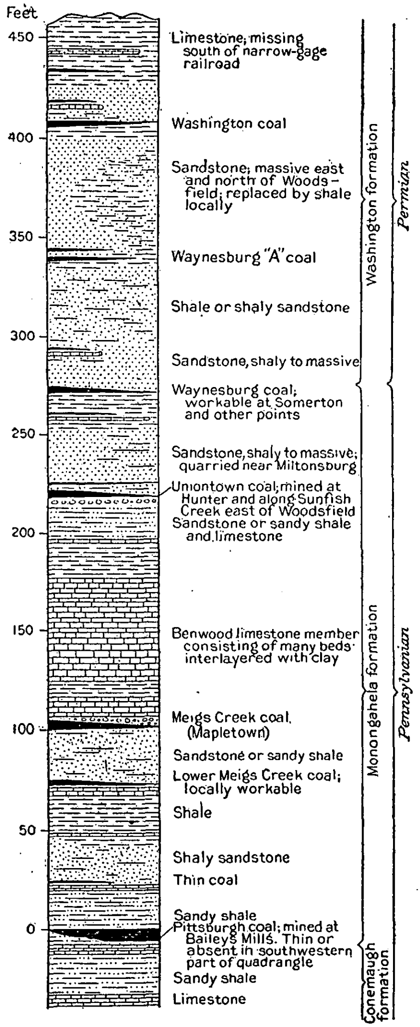

FIGURE 16.—Generalized section of rocks exposed in the Woodsfield quadrangle, Ohio.

ROCKS EXPOSED.

The thickness of the beds exposed within the Woodsfield quadrangle is about 800 feet. These beds are in part represented in figure 16. The exposures lowest in the geologic column are found along Leatherwood Creek, southwest of Barnesville, and the highest are in the ridges east of Woodsfield. The more important beds will be described in turn, beginning with the lowest.

The Pittsburgh coal crops out along the valleys west and southwest of Barnesville and also at Temperanceville. Farther east it is 100 feet or more below the surface throughout the quadrangle. It is recorded in nearly all oil wells and has also been tested by core drilling and is known to be present in workable thickness over the greater part of the area. The chief exception is the southwest corner, the limit of the workable coal being, roughly, a line drawn from Temperanceville to Miltonsburg, thence to Lewisville or possibly to Woodsfield. The rocks at the Pittsburgh horizon are exposed along the valleys of Seneca and Paynes forks south of Temperanceville, but the coal is too thin to be of value.

The Pittsburgh coal is correctly identified by oil men in drilling operations throughout the region, and its position with reference to higher strata is so well established by dozens of hillside measurements and by core-drill and oil-well records that it is chosen as the most convenient key bed for mapping the structure of quadrangles in this part of Ohio.

The Meigs Creek (Mapletown) coal lies 97 to 120 feet above the Pittsburgh bed. The larger interval is unusual and was found only in the region west of Barnesville. Another coal, the Lower Meigs Creek, is found in numerous places in the quadrangle 20 to 35 feet below the Meigs Creek proper. The two coals are commonly separated by massive sandstone. Typical exposures of the lower coal may be seen along Seneca Fork of Wills Creek, where it is mined for local use. The Meigs Creek coal lies near the valley floor of Captina Creek for miles eastward from Barnesville, and at the east edge of the quadrangle it is a few feet below the bed of the creek. In Adams Township the same coal is a few feet beneath the valley floor of Sunfish Creek and no outcrops were discovered.

From 100 to 120 feet above the Meigs Creek coal is the Uniontown coal, which is useful as a structural key on account of its extensive outcrop. Its value for this purpose is somewhat lessened, however, because the coal is in places divided into two beds separated by about 10 feet of shale. The Uniontown coal is mined along Sunfish Creek east of Woodsfield and also along Jakes Run and Bend Fork, tributaries of Captina Creek.

Three more beds that are noteworthy on account of their utility in structural mapping appear above the Uniontown coal, namely, the Waynesburg coal, at the top of the Monongahela formation, and the Waynesburg "A" and Washington coals, in the Washington formation. The first two are accompanied by thinner, less persistent beds, which necessitate careful study to avoid confusion. The Washington coal is an excellent key bed, being persistent with a thickness of 1 to 2 feet throughout the area, but it also is accompanied by other coal beds, one 10 feet higher and another 26 feet higher. The Washington coal is about 350 feet above the Pittsburgh in Goshen Township, in the northeast corner of the quadrangle. Toward the south the interval between the two coals gradually increases to about 400 feet at the Belmont-Monroe county line and to 420 feet at the south edge of the quadrangle.

About 40 feet above the Washington coal is a bed of limestone which was used as a guide in mapping in Belmont County. To the south, in Monroe County, this limestone is lacking, and in its place is greenish-gray brittle granular clay.

ROCKS PENETRATED BY THE DRILL.

Below the surface are about 2,000 feet of rocks which are fairly well known through evidence furnished by the drill. The Berea sand, the chief objective in the search for oil, lies 1,400 to 2,000 feet below the surface, and beneath it is an unknown thickness of shale practically devoid of oil sands, in southeastern Ohio. The general sequence of the oil sands, their names applied by oil men, and positions with reference to the Pittsburgh coal are represented in figure 17. The subjoined well records further illustrate the character of the rocks below the surface:

Log of well No. 90 on John Kemp farm, sec. 13, Goshen Township, Belmont County.

[Well nonproductive.]

	Thickness.	Depth.
	Feet.	*Feet.*
Coal (Waynesburg)	4	144-148
Coal (Meigs Creek)	3	297-300
Coal (Lower Meigs Creek)	3	325-328
Coal (Pittsburgh)	3	393-396
Second Cow Run sand	85	860-945
First salt sand	60	1,030-1,090
Sand	40	1,110-1,150
Second salt sand	45	1,205-1,250
Maxton sand	49	1,285-1,334
Big lime	51	1,334-1,385
Keener sand	37	1,385-1,422
Big Injun sand	173	1,422-1,595
Welsh stray sand	154	1,750-1,904
Berea sand	20	1,957-1,977
Total depth	......	2,006

Log of well No. 372 (No. 1 on Martha Mobley farm), sec. 31, Adams Township, Monroe County.

[Gas well.]

	Thickness.	Depth.
	Feet.	*Feet.*
Conductor	......	0- 9
Coal	3	167- 170
Coal (Pittsburgh)	4	504- 508
Red rock	100	600- 700
Lime	50	700- 750
Red rock	75	750- 825
Slate	45	825- 870
First Cow Run sand	20	870- 890
Second Cow Run sand	185	950-1,135
"Slate"	115	1,135-1,250
First salt sand (water at 1,280 feet)	60	1,250-1,310
Lime	10	1,310-1,320
Second salt sand (water, 1¼ barrels an hour, at 1,335 feet)	65	1,320-1,385
"Slate"	15	1,385-1,400
Maxton sand	50	1,400-1,450
"Slate"	30	1,450-1,480
Big lime	......	1,480
Keener sand (scum of oil at 1,586 feet; water rising 200 feet in 3 hours at 1,591 feet; water, 1 barrel an hour, at 1,615 feet)	33	1,582-1,615
"Slate"	10	1,615-1,625
Big Injun sand (little dark oil and gas at 1,665 feet)	175	1,625-1,800
"Slate" and lime	115	1,800-1,915
Welsh sand, limy	75	1,915
Berea sand (gas at 2,163 feet)	10	2,160-2,170
Total depth	......	2,179

Log of well No. 457, on Peter Ulrich farm, sec. 9, Malaga Township, Monroe County.

[Well nonproductive.]

	Thickness.	Depth.
	Feet.	*Feet.*
Coal (Waynesburg)		195
Coal (Meigs Creek)		335
Coal (Pittsburgh)		425
Cave		500
Cow Run sand		860
Salt sand	140	1,045-1,185
Maxton sand	100	1,250-1,350
Big lime (fine sand, poor, at 1,380 feet)	55	1,370-1,425
Keener sand (15 feet of white sand)	44	1,451-1,495
Big Injun sand	105	1,530-1,635
Shale break	10	1,635-1,645
Squaw sand	60	1,645-1,705
Berea, poor sand, top at		2,026

Many of the sandstone beds recorded in well logs are characterized by lack of persistence, and all are far from uniform in thickness, texture, and appearance from place to place. The uncertainty of the "Coal Measures" sandstones is evident when any prominent bed is followed for a short distance along its outcrop. Almost without exception it will be found to grade laterally into shale, and in many places the change is rather abrupt. On the other hand, two or more sandstone beds separated by shale "breaks" may locally combine into one thick bed of sandstone. A comparison of well records within the Woodsfield quadrangle shows that there is a lack of uniformity in the application of names to the several sands. For instance, the name Cow Run is applied to beds ranging from 340 to more than 500 feet below the Pittsburgh coal at different localities in the Woodsfield quadrangle, whereas the true position of the First Cow Run sand in Monroe County is 310 to 320 feet below the Pittsburgh coal.

OIL AND GAS SANDS.

General occurrence.—The search for oil and gas in the Woodsfield quadrangle has led to more extensive drilling than has been done in almost any other portion of southeastern Ohio. About 1,950 wells have been drilled, two-thirds of which are in the south half of the quadrangle. The area is in that favored portion of Ohio where the driller can hope to find oil in any one of a number of sands ranging in position from about 300 to 1,600 feet below the Pittsburgh coal. The most noteworthy productive sands, named in descending order, are the so-called Cow Run, Big lime, Keener, Big Injun, and Berea. The sequence of these sands and their relations to other beds are shown in the generalized section (fig. 17). The pools in which these various sands are productive are represented on Plates XXIV and XXV (in pocket). The Berea sand is an important source of oil and gas at three localities, designated on the maps the Barnesville, Temperanceville, and Woodsfield Berea grit pools, and in addition yields considerable gas in a recently discovered pool, the Schriver, southeast of Beallsville, along the east margin of the quadrangle. The Big Injun sand yields oil and gas at numerous points in the southwestern part of the area, the most productive pool being at Lewisville, with scattered wells to the northeast for several miles. The Keener sand probably ranks first as a source of oil in the area. It is productive at Malaga, Miltonsburg, Monroefield, and Lewisville and northeastward from Lewisville in an almost continuous belt for 6 miles. The Big lime sand is likewise of great importance, and its productive areas are coextensive with several of the Keener pools. In fact, there are many wells in which both sands are productive and the same wells may also derive oil from the Big Injun sand. Some of the more productive pools in the Big lime are at Newcastle and on Brushy Creek in Belmont County, and at Jerusalem, Ozark, Lewisville, and several intermediate points, in Monroe County. A still shallower sand called by oil men the Cow Run is productive in the vicinity of Beallsville. This sand is about 350 feet below the Pittsburgh coal, and its position suggests correlation with the Buell Run sand of Noble County rather than with the Second Cow Run sand.

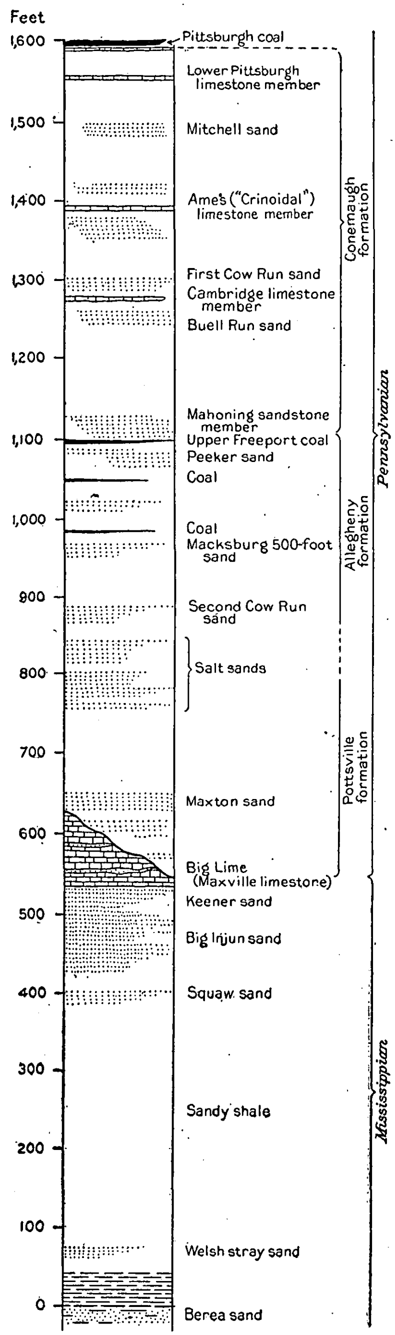

FIGURE 17.—Generalized section showing oil sands and accompanying beds in Woodsfield quadrangle, Ohio.

Names are applied by oil men to nearly every sand penetrated in drilling, and these are represented in figure 17, but the oil men are far from consistent in their use of several of the names applied in the section. Some of the terms in use are derived from localities in Washington County, Ohio; others are obtained from oil pools in West Virginia. As a result there is some confusion in the correlation of beds, and a single sand may be designated by several names in different localities. The skill of the drillers in correctly identifying beds, however, is remarkable when it is borne in mind that none of the sands maintain a uniform thickness over any considerable area, and not uncommonly several beds are combined into one great mass of sandstone. Elsewhere the sands are broken into a series of alternating beds of shale and sandstone, or are even entirely missing and only "shells" are recorded in their places.

Berea sand.—The Berea sand is one of the most important sources of oil and gas in southeastern Ohio and is the deepest oil sand that can be explored with a hope of profit in the Woodsfield quadrangle. It lies 1,550 to 1,660 feet below the Pittsburgh coal, the interval between it and beds near the surface varying considerably from place to place. For this reason a map showing accurately the lay of the Pittsburgh coal is not directly applicable to the Berea sand, and a correction for the variation in interval is required.

The thickness of the Berea is generally reported at 20 to 30 feet, but a few records show less than 10 feet. There is great variation in texture from place to place, and locally the sand is so fine textured and shaly that it is barely recognizable, and its position would not be detected were it not for the black shale which immediately overlies the Berea in Ohio. In the midst of the Berea are lenticular beds of coarser sand which serve as reservoirs for the oil and gas and hence are called the "pay sands." These are not persistent and vary in thickness. The color is generally white, and the grains of fairly uniform fineness, with no pebbles. The thickness of the "pay" sand in the several oil pools ranges from 4 to 15 feet, and in position it lies a few inches to more than 14 feet below the top of the Berea.

Big Injun sand.—The usual thickness of the Big Injun sand is about 100 feet, but at some places it is 175 feet or more and at others 50 feet or even less. In the southwestern portion of the Woodsfield quadrangle the Big Injun sand, where productive, is generally 40 to 60 feet thick. The sand is coarser textured than the Berea and contains pebble layers which are oil bearing and constitute the pay sands. Three or more of these may be found in a single well. The Big Injun is generally water bearing, and the life of the wells is commonly cut short by an inflow of salt water. Not infrequently the Big Injun sand is found separated into a number of beds interlayered with shale. There are great variations in thickness and shaly character in short distances. In fact, the Big Injun resembles sandstones of the "Coal Measures" in its diversity from place to place.

Keener sand.—The Keener sand is separated from the Big Injun by shale and is likewise overlain by shale, which separates it from the Big lime. The usual thickness of the Keener is about 25 to 35 feet, but in the vicinity of Woodsfield a few well records show as much as 60 feet. It is made up of alternating beds of coarse and fine grained sand varying in color from white to dark. The coarser beds yield great quantities of water, which is a menace to oil wells.

Several layers of sand in the Keener may be found oil bearing, and it is of interest to note that the oils from the different pay sands have not the same properties. In the pools east of Malaga the oils vary in viscosity, a portion being so thick that "steaming" is required in order to facilitate the flow through pipes, even in the summer months, whereas another oil from the Keener sand in the same vicinity flows readily without "steaming."

The initial production of many of the wells in the Keener sand has been 100 barrels a day and in a few is reported at more than 500 barrels. The life of the wells is as a rule shorter than that of wells in the Berea sand.

Big lime sand.—The Big lime, as its name implies, is made up largely of limestone in many beds alternating with sandy layers in which the oil and gas are collected. The thickness of the Big lime is reported to be 100 feet in a few places, but 30 to 60 feet is more common. In general the thickness diminishes toward the northwest, and in parts of the Summerfield quadrangle, adjoining the Woodsfield on the west, the Big lime is missing. It shows abrupt variations in thickness and character from place to place, as is illustrated by records of wells in the vicinity of Lewisville. On the Cooper farm, 3 miles northeast of the village, the Big lime is reported 100 feet thick with great quantities of salt water 31 feet below the top, whereas on the Buchanan farm, 1½ miles east of Lewisville, the Big lime is about 25 feet thick.

The pay sand is reported to consist of moderately coarse sand in layers 5 to 15 feet thick. A number of wells in the Big lime sand have had an initial production of 100 barrels a day, and 500 barrels is claimed for a few, but in most pools the best wells start at 25 barrels or less.

Other oil sands.—Above the Big lime are a number of oil-bearing sands which have been prospected rather extensively by the driller with moderately favorable results. The various sands have received names, which are shown in figure 17. The Maxton sand, closely overlying the Big lime, is productive at a few points east of Lewisville. Gas is found in the Salt sands, and oil in a sand reported to be the Cow Run. The production along the railroad northeast of Beallsville and also about 2 miles southeast of that village is credited to the

Cow Run sand, although its position, 350 feet below the Pittsburgh coal, suggests that it may possibly be equivalent to the Buell Run sand, which is productive in the region south of Summerfield, Noble County. The position of the First Cow Run sand where present in the Woodsfield quadrangle should be 280 to 310 feet below the Pittsburgh coal.

The oil from the Cow Run sand at Beallsville has a beautiful amber color. The best wells produced 20 to 25 barrels a day when first drilled, and a number after being pumped for more than 10 years still yield three to five barrels a day.

STRUCTURE.

The prevailing direction of slope or dip of the rocks in eastern Ohio is southeastward. The region forms the west side of a broad, shallow basin which constitutes the Appalachian coal field. The slopes of this basin are far from uniform and are traversed by numerous minor wrinkles which form anticlines and synclines. These are very insignificant when the basin is considered as a whole, but because of their influence in the accumulation of petroleum and natural gas accurate mapping of them is of importance to the oil operator.

PREPARATION OF STRUCTURAL MAP.

The methods of preparing structural maps of oil sands are outlined in the report on the Summerfield quadrangle (pp. 227–228). In preparing the contour map of the Berea sand which accompanies this report, elevations were determined on about 850 outcrops of several key beds and were then reduced to one datum, the Pittsburgh coal, by the addition or subtraction of the appropriate interval for each bed. With the elevation of the Pittsburgh coal thus determined throughout the area the position of the upper surface of the Berea sand at each point was calculated. Unfortunately, the undulations and flexures of the Berea sand do not exactly coincide with those of the Pittsburgh coal and other strata near the surface, and this necessitates a correction. The refinement with which this correction can be made depends upon the number of well records available. The Pittsburgh–Berea interval shows a total variation in the entire Woodsfield quadrangle of about 100 feet, being 1,550 feet in the northeastern part of the quadrangle and 1,650 feet in the southern part, east of Woodsfield. The change is not constant in any one direction and varies rather abruptly over small areas, and for this reason the correction can be applied with precision only in areas where many well records are available. In some portions of the quadrangle the wells are a mile or more apart, and it is probable that between these wells local variations in the interval exist for which no correction can be made. As the Berea sand lies considerably below sea level, 2,000 feet is added to each elevation of the key bed in order to avoid using the minus sign in numbering the contours of the oil sand. This is equivalent to assuming a datum plane 2,000 feet below sea level for the map of the oil sand. The contour map (Pl. XXIV) represents the lay or attitude of the upper surface of the Berea sand and shows all wells drilled up to the completion of the report. The locations of many coal test holes are also indicated. All wells drilled to the Berea are represented in red. Wells drilled to shallower sands are represented in black, the appropriate abbreviation being used for the sand where known.

SALIENT STRUCTURAL FEATURES.

The structural contour map shows the Berea sand to lie at 1,500 feet above the assumed datum plane, or 500 feet below sea level, in the northwest corner of the area and at 940 feet (1,060 feet below sea level) in the southeast corner, indicating a drop of 560 feet southeastward across the quadrangle. From the map it will be seen that the dip is fairly uniform in direction and degree, but there are places where the rocks lie nearly flat for a mile and abruptly drop 50 feet or more in the succeeding mile, thus producing terrace-like forms such as the one at Temperanceville. The general southeastward direction of dip is varied by minor flexures that extend across the faces of the terraces, producing down-folded embayments which alternate with promontory benches, typical illustrations of which appear along the Belmont-Monroe county line 3 miles southeast of Somerton.

Well-defined anticlinal folds are far from plentiful in this region, and there are in the quadrangle only two of any prominence. One lies west of Barnesville, extending in a southwesterly direction. Along its summit is a gas field and on the east slope an oil pool. On the northwest side is a shallow synclinal depression. An irregular anticlinal fold extends southward from Temperanceville and on its east flank the strata drop abruptly into a synclinal depression near the village of Somerton. One mile east of Somerton is a small anticlinal "nose" extending southward for several miles. The town of Woodsfield is situated in a shallow structural depression, east of which is a slightly higher terrace with a gentle southeastward slope, and on this is situated in the Woodsfield Berea grit oil pool. Extending southward from this locality beyond the area represented on the map is an anticlinal arch which may be coextensive with the Jackson Ridge oil pool.

RELATION OF STRUCTURE TO ACCUMULATION OF OIL AND GAS.

The occurrence of oil and gas pools along the crests and slopes of anticlines has been demonstrated at so many places during the 40 years since the introduction of the anticlinal theory that no one can fail to recognize the importance of these structures in oil accumulation. An excellent illustration is furnished in the Barnesville oil and gas field, in the northwestern part of the Woodsfield quadrangle, where the gas occupies the high portion of the anticlinal fold and is flanked by an oil-producing belt a little lower on the slope. The well logs for this field indicate a fairly open textured sand which permitted the circulation of water currents. It is conceivable that the oil particles were gathered from the steep slopes to the southeast and gradually—perhaps with some oscillatory motion—carried upward and united into the body of oil along the narrow terrace indicated by the contours, or they may have been brought from some other direction. The Berea oil sand is probably saturated with salt water throughout the area, and the oil and gas particles, while in circulation, are buoyed up by the water and tend to accumulate near the crests of arches. Thus the Barnesville pool furnishes an example of the simplest application of the anticlinal theory, where the oil sand is fairly open textured, saturated with salt water, and arched into an anticline. A study of other oil and gas pools indicates that this combination of ideal conditions is not usual and that elsewhere numerous modifying influences have been effective. In the first place, well-defined anticlines are far from plentiful in southeastern Ohio, and more commonly the arches are merely promontory-like "noses" such as that in the extreme southwest corner of Wayne Township.

Another modifying factor is variation in porosity. The Berea is not made up of a single sheet of open and even textured sand readily permeable by water but consists for the most part of hard, compact, fine-textured "lime" or "shells" with lenticular beds of "pay" sand only a few feet thick. Such is its character in the Summerfield gas field in the adjoining quadrangle to the west. Here the pay sand is compact and of variable thickness and the pool is bordered on the south by several dry holes in which "no sand" is reported by the drillers. The limited extent of the pay sand has prevented the migration of the gas up the slope to a location structurally more favorable, and it is retained on the flank of a shallow synclinal embayment. The quantity of salt water yielded by the wells in this field, though slight, is not believed by the writer to indicate partial saturation, but rather to show that the rock is so fine in texture that it holds the water even though it rises in the rock as the gas is exhausted.

From well records gathered in various parts of eastern Ohio it is evident that the Berea sand contains more or less salt water from a point near the outcrop down the dip to a position far below sea level. Where the rocks are comparatively pervious over considerable areas and the quantity of water is not sufficient to fill all pore spaces entirely it occupies the lower portion of the sand, and there is an upper limit of saturation existing as a nearly level water table of considerable extent. Conditions of this kind are found in the northern part of the Steubenville quadrangle, where the position of the water line is about 270 feet below sea level and rises gradually northward. This water table in the Berea sand is of local extent and probably has no relation to water tables in the same sand in other areas to the west and north. The partial saturation in this area does not signify that the quantity of salt water becomes less as the oil sand is followed up the dip. On the contrary, great quantities of salt water and also some oil are derived from the Berea all the way from the Woodsfield quadrangle northwest to Wooster and beyond, where the sand is only a little below the surface. It is even possible that the amount of water is progressively greater as the Berea is followed up the dip. This is to be expected in shallow areas, where contributions from ground-water circulation would probably be received.

In the same connection it should be emphasized that in the more porous strata water and oil seem to seek the lowest level that is readily accessible and to flow into the hole when a well is drilled. But it is believed by the writer that the failure of one or both to do so does not necessarily signify that the sand is dry. The texture of the sand may be found so fine as to enable it to hold its liquid content even when there is considerable gas pressure.

The water conditions in the Big Injun, Keener, and other shallower sands differ from those in the Berea. The sands are as a rule more open textured and give off quantities of water, which not infrequently rises to the surface in a well that is being drilled. Many oil wells are ruined by an inflow of salt water, but on the other hand wells have been drilled through all these sands without encountering either oil, gas, or water.

The Monroefield pool may be cited as an area where the Keener sand yields almost no salt water. Whether this signifies only slight saturation or is to be attributed to the close texture of the sand can not be stated until more detailed study has been given to the matter. It is worthy of note that in the Malaga and Cooper oil pools, some 70 feet down the dip, many Keener wells yield great quantities of salt water.

In several oil sands in the Woodsfield quadrangle the water in one oil pool situated on an anticlinal "nose," terrace, or other structural feature is commonly found to be a hydrostatic unit entirely independent of water conditions in another pool near by, even though the sands in the two pools lie at the same horizon. The same thing is also true of overlapping sand lentils separated by shale. In some places oil and much water are found in one stratum, and gas with little or no water in another stratum 40 feet lower. It does not seem strange, therefore, that in crossing down the dip in the Woodsfield quadrangle a succession of gas and oil is found to be repeated several times within a distance of a few miles. The localization of the oil into a number of small pools rather than into one large pool is in part explained by the gentle dip, which does not favor the migration of oil, and in part by the "spotted" condition of the sand.

SEARCH FOR NEW POOLS.

The study of the Berea and other oil sands in the Woodsfield and other quadrangles of southeastern Ohio forces the conclusion that the conditions of oil accumulation are controlled by so many intangible factors that in this region no one can with certainty predict the location of oil pools in advance of drilling. The structural map, even though made most carefully, may not accurately represent the surface of the Berea sand in a country that has been little drilled, owing to the varying distance of the Berea below beds that lie near the surface. Furthermore, it does not follow that oil or gas will be found in even the structurally most favorable location, for the reason that the accumulation into pools is controlled by many factors, such as the trend, extent, and texture of a lens of pay sand and its degree of saturation with salt water. It is noteworthy, however, that even in a sand such as the Berea the pools for the most part follow closely the strike of the rock or in other words extend parallel to the structural contours. The utility of the structural map in predicting the extension of pools after the first successful wild-cat well is drilled is thus at once evident. In addition it enables the driller to determine in which direction his next location should be made in order to find the oil sand at a higher point after a well showing oil and considerable salt water has been drilled.

The search for oil and gas in the Berea sand has been so thorough that dry holes are distributed at intervals of 1 to 2 miles in the areas between the several pools in this sand. In most of these holes the condition of the sand is reported unfavorable. It seems improbable that any undiscovered large pools remain in this quadrangle. Probably the most promising area in the quadrangle for prospecting is to the east and southeast of Temperanceville. Well 67 is a small oil producer in the Berea sand, and the area around it, especially to the southeast, is suggested as most favorable and the area to the south as almost equally promising. Mention should also be made of the terrace 1 mile south of Boston, where a show of oil is reported in well 131. Farther south, along the west margin of the quadrangle, the Berea sand is commonly reported "broken" and fine textured, but here and for several miles to the west it yields gas in wells of small volume but long life.

Both the Barnesville and Woodsfield Berea grit pools have been so defined by dry holes that there is little opportunity for important extensions. In the Barnesville pool wells drilled 20 years ago are still producing, their long life being attributed to the judicious spacing of the wells, most of which are 1,000 feet or more apart.

An attempt was made to develop an oil field along Captina Creek 1 mile east of the area represented on the map, at a locality known as Hogsink. Several small "pumpers" were drilled, but most of them have been abandoned. Southwest of this locality, toward Newcastle, Belmont County, a show of oil is reported in several Berea wells. Since the completion of this report a small oil well in the Berea sand has been drilled on the Evans farm, 1 mile east of Newcastle.

The only producing area deriving oil or gas from the Berea sand, aside from those already mentioned, is at and southeast of Beallsville, where a small gas field designated the Schriver pool has recently been discovered. Well 249 at Beallsville is a small producer and is separated from the pool to the southeast by several dry holes. The closed pressure of the wells in the gas field averages about 700 pounds and the initial yield of a number of the wells was about 3,000,000 cubic feet a day. At the east edge of this field, beyond the area represented on the map, the rocks form a gently southeastward-sloping, terraced embayment where oil may possibly be discovered.

The precise structural features of oil sands other than the Berea can not be gathered from an inspection of the map, because the Berea sand does not lie parallel to the Big Injun sand and other strata nearer the surface. It is evident, however, that in the extremely productive area that occupies so much of the southern half of the quadrangle the rocks have a comparatively uniform southeastward slope, with few terraces or cross flexures to vary the monotony. There is a suggestion of alignment of the productive areas along the strike of the rocks, as is illustrated by the wells in the Keener sand from Malaga southwestward past Miltonsburg to the Cooper pool, 1 mile southeast of Monroefield, and this alignment will doubtless be increasingly evident when the production is extended by future drilling. It seems highly probable that several of the gaps, especially the one along the east side of Miltonsburg, will in time be closed. There are, however, other pools whose longer dimensions extend at right angles to the strike of the rocks, suggesting that the shape of the pool is controlled by the trend of a lenticular pay sand. In many pools of seemingly abnormal shape and trend the production does not come from a single pay sand, but rather from two or more beds in the same formation, or possibly in different formations. The productive sand in each well is designated so far as possible on the map, but the oil in many wells is derived from two or even three sands. This is true of certain wells in the vicinity of Decker station, east of Lewisville.

With the above-stated facts in mind it may be said in conclusion that extensions are probable in many of the small pools and that the search should be continued along the strike of the rocks, or, in other words, parallel to the structural contours. A map representing the lay of the shallow sands is now in preparation and will be included in a future report, in which detailed attention will be given to the oil fields and also to coal and other mineral resources.

QUALITY OF THE OILS.

The oils of this region are shown by analyses to be of best Pennsylvania grade, ranging from 36° to 50° Baumé in gravity and from light amber to dark green in color. Asphalt and sulphur are lacking, and the percentage of paraffin ranges from 2.5 to more than 10. A number of analyses have been published by the United States Geological Survey.[1]

PUBLICATIONS.

A list of United States Geological Survey bulletins concerning oil and gas fields in eastern Ohio and adjacent parts of West Virginia and Pennsylvania is given on page 231.

[1] U. S. Geol. Survey Mineral Resources, 1913, pt. 2, pp. 1212-1217, 1914.