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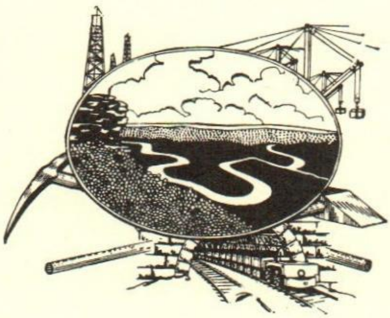
Geology and Oil Possibilities of the Northern Part of Overton County, Tenn., and of Adjoining Parts of Clay, Pickett and Fentress Counties.

By CHAS. BUTTS



NASHVILLE, TENNESSEE.

1919

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By CHAS. BUTTS.

Work done in co-operation with the United States Geological Survey.

INTRODUCTION

The well-known occurrence of oil at Spurrier and Riverton in Pickett and Fentress counties and on Spring Creek, three miles northeast of Algood in Overton County, afford grounds for belief that there are other oil pools in this general region. Accordingly, an examination has been made with the object of determining the geologic structure of the region—the existence or not of arches, domes, anticlines, etc., in the rock strata—because it is known from experience that accumulations of oil of commercial extent in the rocks are more likely to exist on and along the anticlines. Another reason for selecting this area for examination is the fact that it is covered by a fairly accurate topographic and geologic map, and is somewhat more accessible than other parts of the region. The structure was determined by stadia and vertical angle measurements of elevations, such determinations being supplemented by hand level and barometer measurements where convenience demanded. Generally such supplementary measurements did not exceed 100 feet, so that the general results are substantially accurate.

The field work was done by Charles Butts, of the United States Geological Survey; Rolf Schroeder, assistant geologist of the Tennessee Geological Survey, geologists, and by H. E. Hamilton, transit man of the Tennessee Geological Survey. The structure contour map was drawn and the report written by Mr. Butts.

Previous Work.—The area has been mapped topographically and geologically by the United States Geological Survey in the maps of the Standingstone quadrangle. The geologic maps and descriptions were published in the Standingstone Folio, which is out of print. The surface features are shown on the topographic map of the quadrangle, which can be obtained from the United States Geological Survey. The developed oil fields of the region have been described by M. J. Munn in Bulletin No. 2-E of the Tennessee Geological Survey in a paper entitled, "Preliminary Report upon the Oil and Gas Developments in Tennessee." This bulletin was published in 1911.

GEOGRAPHY

Location and Extent.—As shown by the key map, figure 1, the area covered by this report is located on the Highland Rim in the northeastern part of Middle Tennessee and comprises the northern one-third of the Standingstone quadrangle, the northern edge of which is about 8 miles south of the Kentucky-Tennessee State line. It is rectangular in shape, 28.2 miles long by 11.6 miles wide and contains approximately 327 square miles. The northern part of Overton County makes up the greater part of the area which includes also small parts of Jackson and Clay counties.

Surface Features.—Being near the western side of the Cumberland Plateau, the region has considerable relief due to outliers of the plateau rocks lying west of the edge of the plateau. Such high outliers are Gullett Mountain and Alpine Mountain, southeast of Livingston, Pilot Knob near Monroe, Skinner Mountain between Indian Creek and the east fork of Obey River, and the high ridges in the northeast corner of the area, north of Little Crab. The top of these high lands is about 1,800 feet above sea level. South of Livingston, between Livingston and Monroe, and northwest of Livingston to Ward are high, flat-topped ridges, mainly about 1,300 feet above sea level. These last-mentioned, high, flat areas are the result of the presence of a sandstone stratum which caps them and which has protected them from erosion to the common level of the region. The high knobs 2 miles north of Hilham and elsewhere are due to the same conditions. The rest of the area is much lower, lying mainly at about 1,000 feet above sea level and 300 to 800 feet below the high tracts just described and at the general level of the Highland Rim, which extends from north to south entirely across the State in a belt about 25 miles wide just west of the Cumberland plateau. The broadly rolling tract north of Monroe and Nettlecarrier and between Obey River and the high ridge country extending northwest of Livingston and a similar large area occupying the western and southwestern parts of the region mapped are parts of the Highland Rim. Into these tracts the streams have cut deep narrow valleys or gorges 100 to 300 feet below the general level of the Highland Rim. Roaring River, Mill Creek, Eagle Creek, and Obey River are the principal streams, and are bordered along much of their length by steep bluffs or by bare rock cliffs.

Vegetation.—The region, although originally heavily forested, is now largely cleared and cultivated. Some virgin timber still exists in the more inaccessible parts, such as the large ravines along the stream valleys and upon a few upland tracts. The steep slopes of the higher ridges and hills are usually forested, although the larger trees have been cut for lumber. Lumber and timbers for derricks, etc., can be had in the region.

Water.—The region is well supplied with water. Most of the larger streams are permanent, being fed by many springs that issue from certain horizons in the limestone of the region. Abundant water can always be had

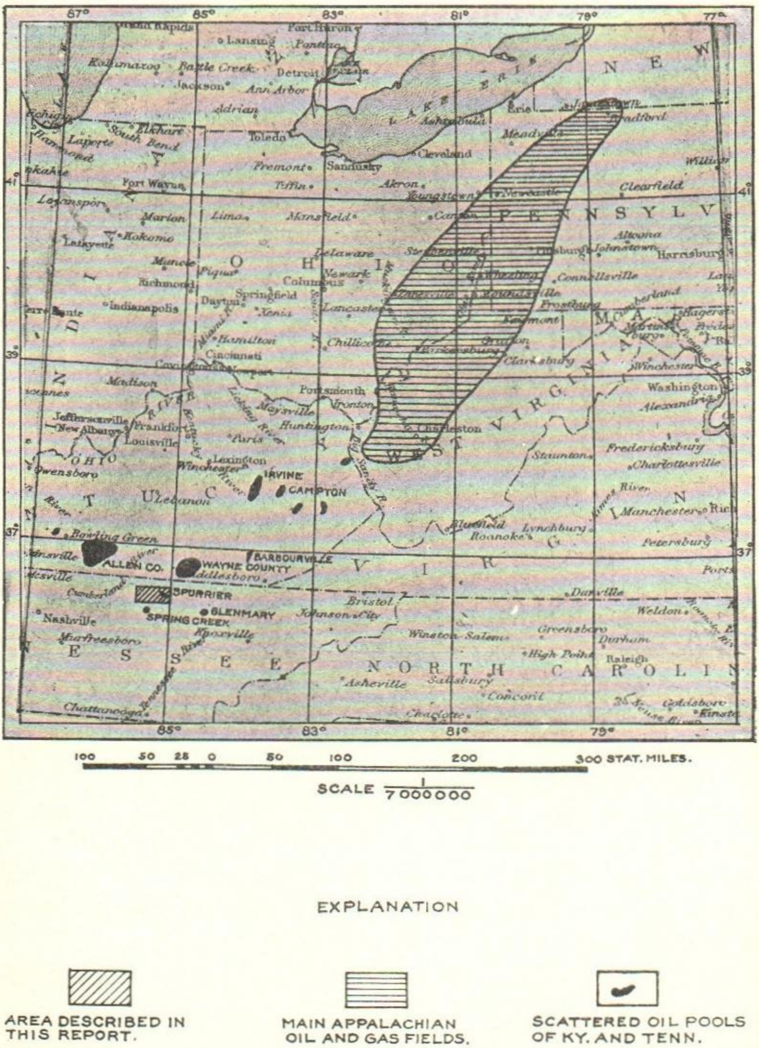

Fig. 1. Sketch map showing area described in this report and its relation to Main Appalachian oil field and scattered fields of Kentucky.

for drilling. The water, since it issues from limestone, is, of course, hard and would deposit calcium carbonate in boilers, but would probably not be injurious in other ways.

Culture.—The country is rather thickly populated and living conditions are satisfactory. Livingston, the county seat, is a good-sized town with a number of hotels sufficient to meet all ordinary demands of the traveling public. Monroe and Hilham are small country villages having good stores and accommodations for travelers. Good accommodations can also be had at Gunters, Riverton, Boatland, Nettlecarrier, Oakley, and Grey.

Roads are laid out at convenient intervals so as to traverse all parts of the region. At many places, where they cross outcrops of thick bedded limestone on steep slopes, the roads are very rough, and in other places they have mud holes that are almost impassable in wet weather. In dry weather they are passable enough, except on the steep rocky slopes where heavy hauling would be greatly hindered and expensive. The only railroad (Tennessee, Kentucky & Northern) ends at Livingston, the other terminus being at Algood on the Tennessee Central Railroad, 18 miles southwest of Livingston. All drilling machinery would have to be hauled from Livingston or Windle or, if its destination were some point on Mill Creek, or on Mitchell Creek, it might be more conveniently shipped by boat to the most accessible point on Cumberland River and hauled from there. In general, heavy hauling in winter should, if possible, be avoided.

GEOLOGY

Under the head of "Geology" falls the description of rock formations or strata, called stratigraphy, and the lay or attitude of the strata, whether horizontal, inclined or wavy, called geologic structure. Knowledge of the stratigraphy of a region is important in prospecting for oil because the oil is always found in some strata and not in others, and the driller should know the strata well enough to be able to determine when the oil-bearing ones have been reached and penetrated. Also since oil very commonly, if not in most cases, accumulates on or along uplifts or upbends in the strata (anticlines), it is important to know where the anticlines are, or, in other words, to know the geologic structure in order to locate wells where the chance of striking oil is greatest.

STRATIGRAPHY

The rocks outcropping at the surface of and underlying the region described are limestone, shale, and sandstone, the limestone predominating and the sandstone being proportionally a small part of the series. These rocks are divided from top to bottom into formations, each formation being composed of a different kind of rock or of rock having distinctive characteristics by which the formation can be recognized at points distant from one another. In fact, the strata or formations are like great sheets of rock relatively thin in proportion to their geographical extent, and spread out over large areas, in many cases covering several States. Such layered rocks are called stratified rocks, the stratification being the result of the manner of their origin. They were deposited as sediment in broad shallow seas of great size and necessarily took the form of relatively thin sheets deposited upon the bottom of such seas. Such rocks are also called aqueous or sedimentary rocks. The terms stratified, sedimentary, and aqueous distinguish the rocks formed in water from those formed by the agency of heat, or igneous rocks, such as granite or basalt, such rock not being as a rule in regular layers (stratified) but in great lenticular or irregular masses. Rocks are also classified according to their relative ages. It follows from the process of formations that any stratum is older than the one next on top and still older than the second one above, and so on, so that in a thick succession of strata, say 10,000 feet, the stratum at the bottom is very much older than the one at the top. Hence geologic time is subdivided into eras, periods, and epochs, just as human history is. The rocks corresponding to an epoch are called a formation, those corresponding to a period are called a system. A system may include and usually does include more than one formation. There is no name in general American geologic usage for the rocks corresponding to an era, which may include several systems.

The rocks that outcrop in the area under discussion range from Upper Ordovician limestone to rocks of lower Pottsville age in the Pennsylvanian or coal measures series. These rocks are divided into a number of formations. The sequence of formations is incomplete due to the absence of great thicknesses of rocks that exist in other regions. In New York and Pennsylvania, for example, there is, between the rocks corresponding to the Fort Payne formation and the rocks corresponding to the top of the Ordovician of Overton County, two entire systems, the Devonian and Silurian, say 12,000 feet thick, that are practically absent from Overton County. Such gaps are called unconformities. The Chattanooga ("Black") shale represents only a very small part of this interval. The succession, age classification, character, and thickness of the formations, and the position of the unconformities and oil horizons are shown in the generalized columnar section, p. 19.

DETAILED DESCRIPTION OF ROCKS

For the purpose of this description the rocks of Overton County may be divided into two groups, namely rocks not exposed at the surface and rocks outcropping. The description begins with the lowest and oldest and goes onward to the successively younger and higher formations. This is the order in which the strata originated—the historical order.

ROCKS NOT EXPOSED

The oldest and lowest rocks exposed in the area described, outcrop at water level on Roaring River and Mill Creek at the west margin of the area. Below these there is known to be at least 1,700 feet of limestone which was penetrated in a deep well at Livingston. Owing to a southwestward rise of the strata of the region a considerable part of these rocks from the top down outcrops in that direction so that the rocks can be examined at the surface. Of the limestone below the surface of Overton County, the deepest that thus rises to the surface in a southwestward direction is the limestone outcropping at Murfreesboro and vicinity in Rutherford County. This is the Murfreesboro limestone, the basal formation of the Stones River group. Above the Stones River group are rocks of Black River and Trenton ages, which outcrop to the northeast of Murfreesboro. These limestone formations vary somewhat in thickness of bedding, coarseness of grain, and color, but constitute essentially a continuous mass of limestone about 1,000 feet thick. In Sequatchie Valley, limestone of Beekmantown ("Calciferous") age about 1,000 feet thick, and below the latter limestone, cherty dolomite, perhaps 1,000 feet thick, are exposed below the Murfreesboro limestone. It is not improbable that the Chattanooga shale of this region is immediately underlain by at least 4,000 feet of continuous limestone and dolomite. The bottom of the Livingston well is probably in the limestone of Beekmantown age.

ROCKS EXPOSED

ORDOVICIAN SYSTEM

CINCINNATIAN SERIES

MAYSVILLE GROUP AND POSSIBLY RICHMOND GROUP AT TOP

The lower part of the limestone exposed below the Chattanooga shale on Mill Creek, Dry Fork of Mill Creek, and Roaring River is believed to be of the age of the Maysville group of the Cincinnati region, fossils collected 150 to 200 feet below the Chattanooga shale being of Maysville age. The lowest beds are exposed in the extreme western part of the area under discussion and are medium thick-bedded, dark bluish, and medium coarse-grained limestone. The layers often have rough surfaces, and are commonly separated by thin partings of blue, crumbling calcareous, clay shale. Thicker beds, predominantly of shale, but containing thin, irregular or somewhat nodular layers of limestone also exist here and there in the mass. The limestone is highly fossiliferous throughout, fossil bryozoans and brachiopods being most abundant. On Mill Creek, Mitchell Creek, and on Obey River north of Wirmingham and of the area described, the limestone immediately beneath the Chattanooga shale is thick-bedded, gray, and finely but distinctly crystalline. Under the bridge across Obey River on the Livingston-Byrdstown road, limestone of this character 20 feet thick is exposed. On Mill Creek this limestone is at least 5 feet thick and the Chattanooga shale is in contact with it at the top. At 40 feet below the Chattanooga on Mill Creek, however, the limestone is blue, more coarsely crystalline and full of fossils so that the gray limestone is less than 40 feet thick.

An interesting feature of this gray crystalline limestone is that it is full of small pores and has besides many irregular cavities of larger sizes—some as much as an inch in longer diameter. It seemingly is well adapted to be a reservoir for oil and will be further discussed in connection with that subject.

This gray limestone carries many specimens of a large *Platystrophia* like *P. ponderosa* of the Arnheim limestone of the northern Kentucky region at Louisville and Cincinnati. Other fossils occurring 40 feet below the Chattanooga shale, such as *Cyclonema fluctuosa* and *Pterinea demissa*, also occur in the Arnheim, so that it seems not improbable that the upper 40 feet at least of the limestone below the Chattanooga may be of Arnheim age. The Arnheim limestone is the basal formation of the Richmond group.

Neither the bottom of the Maysville nor the boundary between the latter and the Arnheim was determined. The limit of time under which the field work was done did not permit a sufficiently searching examination to determine such points, where, as in this case, the boundaries are very obscure. Whether the Eden group, underlying the Maysville group of northern Kentucky, is represented in the region, has not been determined.

UNCONFORMITY

The Silurian and Devonian systems are nearly absent from Overton County, as is also the upper and greater part of the Richmond group of northern Kentucky and southwestern Ohio commonly assigned to the Upper Ordovician series. Only the 20 feet of Chattanooga ("Black") shale is present in the place of the absent rocks and it is not certain that the Chattanooga belongs in that interval. As shown beyond, p. 12, its true place may be in the basal part of the Mississippian series of the Carboniferous system. Expressed in thickness of strata, there are absent from the geologic section in Overton County at least 12,000 feet of rocks that in New York, Pennsylvania, Maryland and West Virginia lie between the horizon of the limestone immediately below the Chattanooga shale of Overton County, Tennessee, and the bottom of the Burgoon sandstone (Big Injun oil sand) of Pennsylvania, which is supposed to be about the equivalent of the Fort Payne formation of Overton County. If the rocks of Overton County above the top of the limestone immediately below the Chattanooga shale were lifted up bodily 12,000 feet and the space filled up with strata of sandstone, shale, and limestone, the section would then be approximately what it is in the States named above. It is significant in connection with the subject of oil and gas in northern Middle Tennessee, that the oil-bearing sands of Pennsylvania, New York, eastern Ohio, and of the Irvine field of Kentucky fall into that part of the general geologic column of the eastern United States which is absent in Middle Tennessee and so no corresponding oil-bearing strata can be present in that part of the state.

DEVONIAN SYSTEM

Chattanooga shale

Immediately overlying the limestone just described under the head of Ordovician is 20 to 25 feet of very black, highly fissile, slaty shale known as the Chattanooga shale, from Chattanooga, Tenn., where it is practically the same in character and thickness as in Overton County. This is a very widespread formation and is remarkably constant in thickness and character. It extends from the Birmingham district, Alabama, where it feathers out, northeastward to Cumberland Gap, Ky.-Va.-Tenn., where it merges with a thicker body of black shale, the mass being 500 feet thick at Cumberland Gap and 1,100 feet at Big Stone Gap, Va. It extends westward across Tennessee and into Arkansas, Missouri, and Oklahoma, and northward into Illinois, Indiana, Kentucky, and Ohio, where it also merges into a thicker body of black shale known in Indiana and northern Kentucky as New Albany shale, from New Albany, Ind., and in Ohio as the Ohio shale, from its extensive development in that State.

In Kentucky, central Tennessee, Indiana, and Ohio this black shale contains oil which can be extracted by destructive distillation; the richest that has been tested yielding 10 gallons of oil to the ton, although richer shale may exist. It is supposed to be the source of the oil in the "Corniferous" limestone of the Irvine field, Ky., and of the Beaver "sand" of the Wayne County field, Ky. The oil is doubtless derived mostly from plant remains that were buried in the black sediment at the time of the deposition of the shale. Remains of plant spores rich in fatty matter are extremely abundant in some localities and in some layers; and microscopic plants such as algae probably are present as in some of the tertiary oil shale of Wyoming.

The shale contains a few species of animal fossils principally brachiopod shells of the genera *Lingula and Barrioseclla*. It also has in it many conodonts, a peculiar fossil of minute size, many forms of which have teeth on one side, like a comb. It is probable from the relative scarcity of animal remains that animal organisms contributed but little to the oil content of the shale.

The age of the Chattanooga of this region is a debated question, some geologists regarding it as Devonian and others regarding it as chiefly Carboniferous, but as the question has no economic bearing it will not be here discussed.

The Chattanooga shale, being so easily recognizable from its peculiarities, serves as a datum plane for determining and comparing geologic horizons throughout its extent. The oil-bearing strata of Trenton age of the Lima, Ohio, and Sunnybrook, Kentucky, fields; the probable Maysville oil horizon of Spurrier and Riverton; and the "Corniferous" oil rocks of the Irvine and Allen County fields, Kentucky, are all below the Chattanooga shale; while the Beaver oil rock of Wayne County, Ky., immediately overlies the Chattanooga or is a small distance above it. The oil horizons of Oneida, Scott County, and of Glen Mary in Morgan County are several hundred feet above the Chattanooga.

CARBONIFEROUS SYSTEM

MISSISSIPPIAN SERIES

New Providence shale

Throughout most of this region the New Providence shale of the Louisville region of Kentucky and Indiana is absent so that the Fort Payne formation lies upon the Chattanooga or is separated from it by 2 to 5 feet of green shale which may represent a small part of the New Providence shale. At two points on Roaring River, however, there were observed red and green shale with red and green limestone layers carrying the upper Burlington crinoid, *Macrocrinus verneuilliana*. One place is in a gully in a cleared field on the west of and a few rods from Roaring River about 1,000 feet northeast of the iron bridge at Crawfords Mill, and the other place is on Roaring River, one mile west of Browns Ford where the river is crossed by the highway south from Hilham. The red beds are fully exposed on the bluff 75 to 100 feet above the river. Here they are plainly a lenticular mass between the Chattanooga and the Fort Payne, the massive basal beds of the latter being very irregular and unconformable. The red shale and limestone here seem clearly to be a residual mass of New Providence left by erosion which was later covered by the Fort Payne sediments, the usual even base of the latter being consequently interrupted in covering up the hump of New Providence. Besides the crinoid named above, there is a coral very suggestive of *Cyathaxonia cynodon* of the New Providence shale in the vicinity of Louisville, Ky., and several other crinoids and several species of brachiopods.

The occurrence of these remnants of beds of Upper Burlington age makes it highly probable that the overlying Fort Payne is all of Keokuk age.

Fort Payne Formation

The Fort Payne was named from Fort Payne, Ala. At that place the strata designated are chert. In this region, however, the equivalent strata are so diverse in character both vertically and laterally within relatively short distances as to require designation as a formation.

The Fort Payne formation underlies much of the upland surface in the western part of the area and outcrops along the steep valley walls of Roaring River, Obey River, Mill Creek and its tributaries, Dry Fork of Mill Creek, Mitchell Creek, and Eagle Creek. Excellent sections are exposed on the Hilham-Celina road on the south bluff of Mill Creek, on the Livingston-Byrdstown road just north of Obey River, and on Obey River near Gunters store (see fig. 2). At Windle the formation, rising westward, emerges from below the Warsaw and the upper 20 feet or so—solid thick-bedded limestone—is exposed in the railroad cut just south of the station at that place. By far the best exposure of the limestone facies of the formation is at

Crawford's Mill, located at the point where the Hilham-Cookeville road crosses Roaring River. A view of the limestone at that place is shown in plate 1.

In the northern two-thirds of the area described, the Fort Payne is shale with a small aggregate thickness of limestone, while on Roaring River it is predominantly limestone and the shale is proportionally a small part. The varying lithologic character of the Fort Payne is illustrated by the sections of fig. 2.

The Fort Payne on Mill Creek and on the Dry Fork of Mill Creek is the same as on Mitchell Creek and the change to predominantly limestone takes place between Dry Fork and Roaring River, a distance of 6 miles.

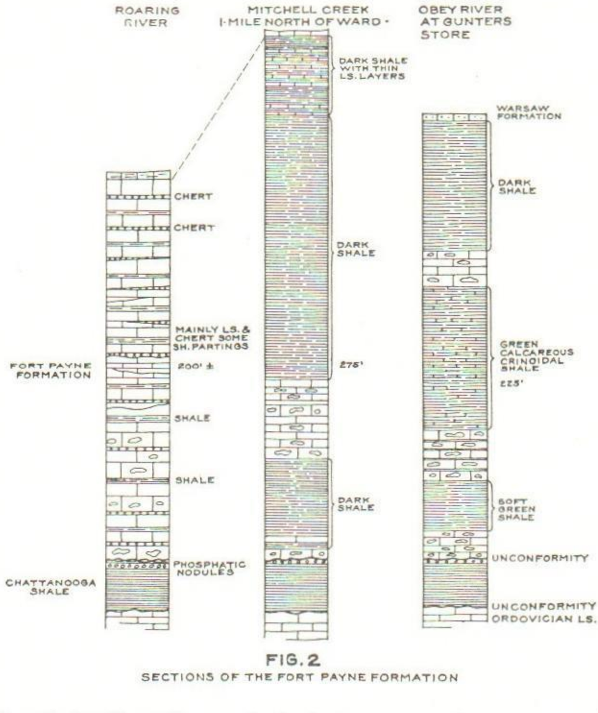

FIG. 2
SECTIONS OF THE FORT PAYNE FORMATION

The shale of the Fort Payne is dark or green, the green shale being of rather soft, fragile character, while the dark shale is fairly stiff and tough. The dark shale is siliceous rather than aluminous and breaks up into medium-sized chips with rough, irregular cleavage, differing greatly in that respect from the highly fissile shale of the Chattanooga which cleaves readily into thin, smooth-faced plates or flakes. The green shale is in the lower half of the formation and is well shown in the exposure on Obey River and in another on the Hilham-Celina road on the south side of Mill Creek valley, where it is 90 feet thick and follows immediately above the basal limestone of the formation shown in the Mitchell Creek and Obey River sections. On

PLATE 1

FORT PAYNE LIMESTONE.

Cliff on Roaring River at Crawfords Mill. At the crossing of the Hilham-Cookeville road, looking west.

About 100 feet exposed. The bottom of this exposure is about 40 feet above the Chattanooga ("Black") shale which outcrops in the bed of the river one-fourth mile below the cliff—to the left as viewed. The picture shows the thickening and thinning of some of the layers mentioned on page 14.

Mitchell Creek, however, at the place where the section, No. 2, fig. 2, was measured, and on Eagle Creek at the north margin of the area, the dark, stiff shale extends to the bottom of the formation and there is no green shale present. Here the shale is almost black at the bottom. Much of the limestone in the formation in the parts of the region where the shale predominates, as well as in those parts where limestone predominates, is highly crinoidal, crystalline, and blue, while a smaller part is somewhat earthy-textured and earthy-colored. The limestone is generally medium thick-bedded. Irregularity of bedding is a common feature, a layer here and there wedging nearly or quite out in a short distance. This gives a false appearance of dip in some cases, as in exposures in stream beds. Its general character is shown in the photograph, Plate 1, page 14. On weathering much chert is formed, whole layers turning to chert on their outcropping edges. It is worthy of special note that there is a persistent bed of limestone at the bottom of the formation in the position of the Beaver Creek oil "sand" of Wayne County, Ky. On Rich Branch of Mill Creek, 2 miles north-northwest of Hilham, this limestone is a solid mass 20 to 40 feet thick and full of large and small cavities, some of which are several feet in diameter. It is likewise thick and massive on Roaring River, 2 miles west of Crawford Mill, but apparently not cavernous. There is also a development of the same kind on Franklin Creek about 1 mile above its mouth. Franklin Creek flows for a mile through the northern margin of the area just east of Obey River. While the Fort Payne is prevailingly limestone along Roaring River, there is considerable shale existing as partings or as thin, interbedded layers, especially in the upper 50 to 75 feet. A bed of shale 5 feet or so thick and about 20 feet above the bottom is exposed in the gorge of Roaring River just below Crawford Mill.

The thickness of the Fort Payne varies from about 200 to about 275 feet, the greatest thickness being measured on Mitchell Creek. The thickness of 275 feet here may, however, be somewhat erroneous owing to possible dip between the points, about one-half mile apart, at which the elevation of the top and that of the bottom of the formation were determined. The deep well at Livingston started at the top of the Warsaw formation and encountered the Chattanooga ("Black") shale at the depth of 310 feet, giving 310 feet for the combined thickness of the Warsaw and Fort Payne. Deducting 100 feet, the usual thickness of the Warsaw, leaves the thickness of the Fort Payne 210 feet.

The Fort Payne is highly fossiliterous, crinoidal remains very greatly predominating. The upper 20 feet of limestone in the western part of the area is easily distinguished from the overlying Warsaw by the profusion of crinoidal stem plates and parts of columns. These are also notable for their large size, some being three-fourths of an inch or even one inch in diameter. None such occur in the Warsaw of the region. The occurrence of such fossils as *Spirifer logani*, *Spirifer montgomertensis*, and *Syringothyris textus* (?) in the bottom of the formation and of *Agaricocrinus americanus* in the top and in the lower part, clearly indicate the Keokuk age of the Fort Payne.

The Fort Payne makes up the larger part of the thickness of the Waverly formation of the Standingstone folio. The name Waverly, however, is not applicable in this region since the Fort Payne probably corresponds to only a small upper part of the typical Waverly of Ohio, namely to beds from the Black Hand to the top of the Logan formation, which in turn represent part of the Burgoon sandstone member of the Pocono formation of Pennsylvania. The Burgoon is the Big Injun oil sand of West Virginia. The Fort Payne is also equivalent to the Kenwood sandstone, the Rosewood shale and Holtsclaw sandstone of the Louisville region, Ky.,[1] and with the Keokuk limestone of Mississippi Valley.

Warsaw Formation

The name Warsaw is from the town of Warsaw, Ill., on Mississippi River. The Warsaw of Overton County was doubtfully included in the Waverly formation of the Standingstone folio. The formation outcrops over considerable areas along the valley walls of the upper parts of the tributaries to the main streams of the region, and on the ground of middle height between the deep valleys of the main streams and the base of the high hills such as Pilot Knob, Gullet Mountain and the plateaus northwest of Livingston. Good exposures are to be found along Copeland Creek and the railroad between Livingston and Windle, on the upper parts of Eagle Creek and its tributaries, along Flat Creek, and in the ravines of Dry Fork west of Hilham. Its top is well exposed in the western environs of Livingston as at the road crossing at the saw mill. The formation is persistent to the eastern part of the area and is well developed and exposed along Obey River and its tributaries. An excellent exposure has been made in grading the road approaches to the new bridge at Boatland. The top of the formation is marked in many localities by springs. The big spring, 1 mile west of Livingston, that at Garretts Mill on the south fork of Eagle Creek, 3 miles north-northeast of Livingston, and the big springs at Monroe are examples. The spring at Garretts Mill supplies the water power of the mill.

The Warsaw is a rather heterogeneous formation, being composed of about equal parts of limestone, shale, and calcareous sandstone. The lower one-third is usually made up of alternating beds of shale and limestone, the middle one-third of compact, thick-bedded, highly fossiliferous limestone, the fossils being largely fragmental. The upper one-third is mostly sandstone, some of the layers being highly calcareous or limy, and looking like limestone in the unweathered condition, but losing the limy matter by solution when weathered, so that only a loosely aggregated mass of quartz

[1]Butts, Charles, Geology of Jefferson County, Ky.: Kentucky Geol. Survey, Ser. 4, vol. 3, Pt. 2, 1915.

grains remain. In many localities, layers of sandstone at the very top are thin, 2 to 4 inches thick, ripple marked, and apparently never contained much calcium carbonate. They are purely clastic sandstone. In a few places, as east of Crab Creek on the Jamestown Road, shale occurs at the top immediately below the St. Louis limestone. Cross-bedding and fine cross lamination is very prevalent in the fragmental limestone and calcareous sandstone layers.

The thickness of the Warsaw varies but little from 100 feet throughout the area examined. The formation is thinnest in the vicinity of Riverton, on the east fork of Obey River. At the mouth of Poplar Cove Creek the thickness is 100 feet.

The Warsaw is highly fossiliferous but yields only a few good specimens owing to the generally broken-up condition of the fossils as well as to the fact that they are not commonly liberated from the matrix on decay but are etched away with the rock in which they are embedded. Such surely identifiable forms as *Tricoelocrinus woodmani* or a very closely related form, *Productus magnus*, *Spirifer subequalis*, which is common, *Spirifer tenuicostatus* (rare), *Spiriferella neglecta*, *Brachythyris subcardiformis*, and *Worthenopora spinosa* are sufficient evidence of the Warsaw age of the formation.

In the northern and eastern parts of the area the lower part of the Warsaw is not distinctly different in character and appearance from the Fort Payne and it is difficult to determine the boundary between them. In the western part, however, where the top of the Fort Payne is thick-bedded limestone crowded with large crinoidal remains, and elsewhere where the crinoidal remains persist, although the limestone has been almost wholly replaced by shale, the separation is easy. In all places, however, there are invariably two or more layers of calcareous rocks, weathering to look like coarse yellow sandstone, at the bottom of the Warsaw. An occasional layer of such rock occurs in the Fort Payne, indicating that the two formations were deposited under similar conditions. In fact, there is a general resemblance between the two formations near the contact.

The top of the Warsaw being sandstone in the midst of limestone, and being a very prolific water table, giving rise to springs and waterfalls, is everywhere easily identifiable and is thus a very important horizon for working out the structure of the region. It is one of the two horizons most relied upon in determining the structure, the other being the contact of the Gasper oolite and overlying Cypress sandstone.

St. Louis limestone

The St. Louis limestone comprises the rocks treated in the Standingstone folio as transitional from the Waverly (which included the Warsaw) to the Newman limestone. It is known in this region as the blue limestone in distinction from the overlying Fredonia and Gasper oolites which are called the gray limestone. It is named from St. Louis, Mo., which is built upon rocks of this formation. There is probably a stratigraphic gap or unconformity between the Warsaw and St. Louis.

In Overton County the St. Louis outcrops at the base of the high hills. It is not fully exposed anywhere in the area, but parts of it are exposed at several places. It is the limestone exposed at the railroad station in Livingston, the part of the formation exposed there being near the top, which is about 35 feet above the level of the railroad station. The bottom 40 feet are exposed just above the spring on the south side of the valley below the railroad track about three-fourths of a mile southwest of the station at Livingston and about the same thickness at the bottom is exposed at the big spring about one mile west of Livingston. One of the best exposures is at the head of the south branch of Eagle Creek, where nearly the entire thickness can be seen. The bottom 50 feet or so is exposed above the big spring at Garretts Mill, 3 miles north-northeast of Livingston.

The St. Louis is a medium thick-bedded, fine-grained, bluish or dark-colored limestone which, on weathering, yields much chert so that the surface underlain by the formation is thickly strewn with chunks of chert. The bottom 20 feet in places includes cross-bedded sandy layers and almost everywhere throughout the entire area examined is a bed of earthy limestone, 10 feet or so above the bottom, that weathers to green clay. Immediately above the clayey layer *Lithostrotion proliferum*, *Archeocidaris*, and *Melonites* appear, the last two being abundant and the first rare at this level. The first layers above the clay are full of small branching forms, probably fucoids. Such a succession is well-exposed on the road at the east base of the ridge one mile west of Monroe. The section here is as follows:

Section of basal part of the St. Louis limestone in road one mile west of Monroe.

St. Louis limestone:	
1. Limestone, blue, Lithostrotion proliferum and Archeocidaris	5
2. Limestone, greenish, argillaceous, weathers to clay	10
3. Limestone, blue	5
Warsaw limestone:	
4. Limestone, sandy and argillaceous with sandstone layers	5

This sequence with the fossils named is persistent, having been observed in every exposure of this part of the St. Louis limestone examined. More recent work in Barren County, Ky., has revealed the fact that the same succession, including the same fossils, exists except that the argillaceous limestone layer had not weathered to green clay at any point observed.

The clayey and sandy constituents of the basal St. Louis are derived from the underlying Warsaw formation. The cross-bedding in this part indicates rather shallow water, so that the waves and currents of the St. Louis sea worked up the disintegrated material at the top of the Warsaw and incorporated the same with the calcareous sediment deposited from the water. The Warsaw had probably been raised and eroded to a low land surface, covered with a thick mantle of decayed rock such as now covers the surface of dry land. It so remained for a long time before the beginning of St. Louis deposition, when the sea again gradually overflowed the area, and its early shallow waters performed the work on the basal St. Louis sediments just described. The mixture of sand, clay, and limestone in the basel St. Louis and its cross-bedding would naturally result from the conditions under which it was accumulated.

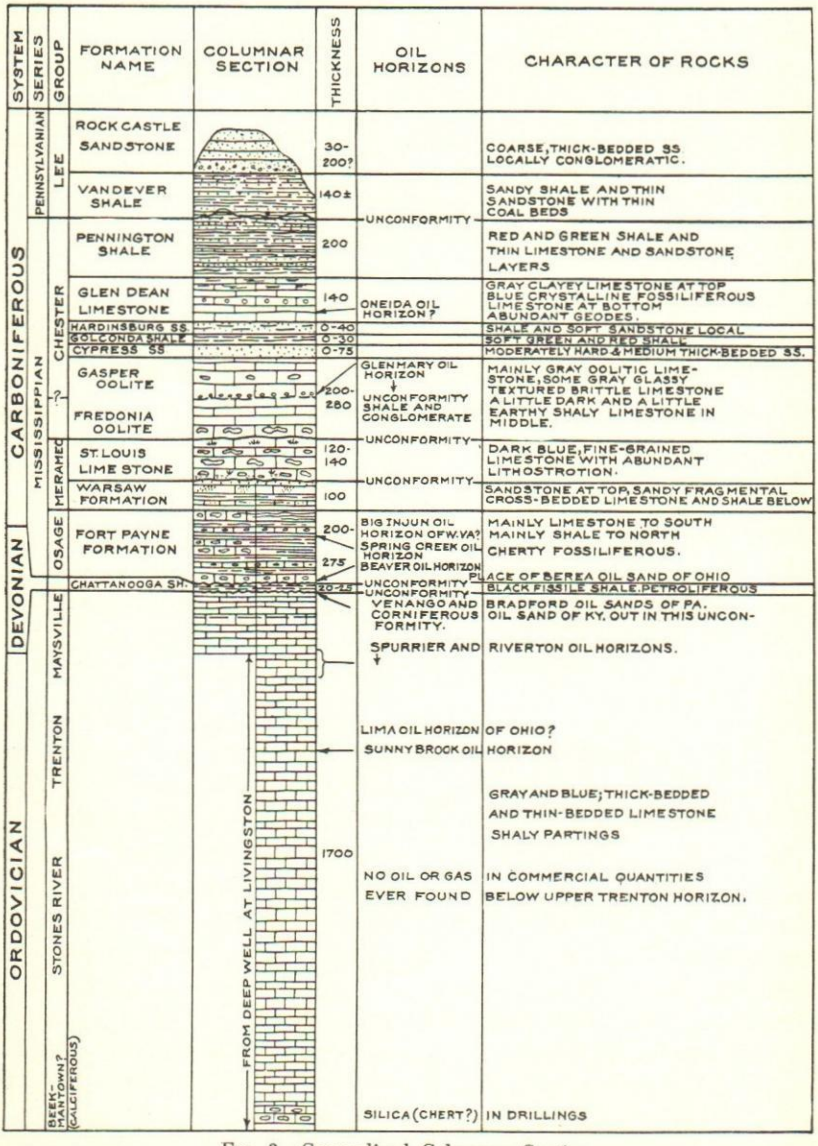

FIG. 3. Generalized Columnar Section

The St. Louis is 110 to 140 feet thick. In this region the St. Louis is notable for the profusion of the massive coral *Lithostrotion basaltiforme*, or, as it is better known, *L. canadense*. The silicified heads of these corals, up to one foot or more in diameter and smaller pieces are mingled in great numbers with the chert scattered over the areas on which the St. Louis outcrops. Beautiful specimens of the coral can be found in plenty in the streets of Livingston and in the fields in the immediate vicinity.

Lithostrotion proliferum is another form much less common in this region than *L. basaltiforme*, from which it differs in having cylindrical instead of polygonal coralites. These two species of coral probably are entirely diagnostic of the St. Louis limestone, never having been certainly found in any other formation. As stated, *L. proliferum* has been found in the course of this investigation as low in the St. Louis of this area as 20 feet above the top of the Warsaw. *L. basaltiforme* occurs on the slope south of Livingston to within 10 feet below the bottom of the Fredonia oolite. There can be no doubt whatever that the limestone under discussion is correctly identified as St. Louis.

Fredonia and Gasper oolites (gray limestone of common usage)

Overlying the St. Louis limestone and extending up to the bottom of the Cypress sandstone (Newman sandstone lentil of the Standingstone folio) is 200 to 280 feet of predominantly light gray oolitic limestone or oolite. This is the part of the Newman limestone of the Standingstone folio lying below the Newman sandstone lentil, which is the Cypress sandstone of this report.

This gray limestone includes two distinct formations that in western Kentucky and southern Illinois are separated by as much as 200 feet of limestone and sandstone. The absent formations are the Rosiclare sandstone, the Ohara limestone and the Bethel sandstone.[1]

The horizon of these absent rocks in the vicinity of Livingston is represented by 1 to 2 feet of shale, and overlying the shale a layer of limestone one foot thick, which contains limestone pebbles. The shale and pebbly limestone layers are exposed in the quarry for road metal on the hillside one-fourth mile southeast of Livingston, a few feet above the bottom of the quarry and about 100 feet above the top of the St. Louis limestone. The conglomerate or breccia is said by Mr. Nelson, State Geologist of Tennessee, to persist at this horizon as far south as Bon Air. The part of the gray oolite below the shale bed represents part or all of the Fredonia oolite member of the Ste. Genevieve limestone of western Kentucky and southern Illinois. For sake of brevity it will be called here the Fredonia oolite. The part of the gray oolite above the shale and conglomerate layers corresponds wholly or almost wholly to the Gasper oolite of Kentucky, which includes the "Bowling Green oolite" used for building stone. It is possible that a thin representative of the Ohara limestone is included in the basal part of the mass here assigned to the Gasper, but this is doubtful.

[1]See report on the Mississippian formations of western Kentucky, by Ulrich and Butts: Kentucky Geol. Survey, Frankfort, Ky., 1918.

As already stated, the gray oolitic limestone under discussion includes what elsewhere are two distinct formations. Furthermore, except possibly in a few places where the shaly conglomeratic layer is exposed, the Fredonia and Gasper in this region are for reasons given below inseparable by anyone but a paleontologist, so that they constitute a lithologic unit. To these rocks, including the absent members, Ulrich[1] applied the name "Monte Sana group," from Monte Sana near Huntsville, Ala., where the conditions are the same as in Overton County.

The Gasper and Fredonia formations are composed of limestone which is predominantly thick-bedded, light-gray, and oolitic. By "oolitic" is meant that the limestone contains many or is mostly made up of small spherical or spheroidal bodies about the size of fish eggs, which are plainly visible to the naked eye. A considerable proportion of the limestone is light blue or pearl gray and of glassy texture. As far as character of rock goes the Fredonia and Gasper are indistinguishable. They can only be distinguished by their fossils, the Fredonia containing forms that do not occur in the Gasper and vice versa.

These oolites are 240 to 280 feet thick in this region, the Fredonia making up the lower 100 to 130 feet, and the Gasper the upper 140 to 160 feet. There seems to be considerable variation in the relative thickness of the two formations within short distances.

Some of the more characteristic and dignostic fossils are the following:

List of fossils from the Fredonia oolite.

Crystelasma quinqueseptatum.
Lithostrotion harmodites. Locally very plentiful.
Mitchelinia princetonensis.
Mitchelinia subramosa.
Platycrinuus huntsvillae. Common to abundant from bottom to top of the Fredonia and absolutely diagnostic in this region.
Dielasma illinoisensis.
Girtyella indianensis.
Pugnoides ottumwa.

List of fossils from the Gasper oolite.

Clustered coral. Persistent near bottom of Gasper throughout region from Franklin County, Tenn., to Breckenridge County, Ky.

Agassizocrinus. Form occurring in the lower part of the Gasper.

Pentremites godoni. Pentremites planus? Pentremites pyrifonmis. Talarocrinus patei? Talarocrinus symmetricus. Girtyella indianensis?	Common but good specimens rare.

While fossils are abundant in many layers of both the Fredonia and Gasper, good identifiable specimens are rather rare because the limestone of these formations does not as a rule yield up its fossils on weathering.

[1]Ulrich, E. O., Revision of the Paleozoic systems, Bull. of the Geol. Soc. Am., vol. 22, pp. 281-680, 1911. Mississippian Series in western Kentucky: Kentucky Geol. Survey, 1918.

Many of these fossils are illustrated and described in a report entitled, "Descriptions and Correlation of the Mississippian Formations of Western Kentucky," by Charles Butts, and a report entitled, "The Formations of the Chester Series in Western Kentucky and their Correlates elsewhere," by E. O. Ulrich, published by the Kentucky Geological Survey in 1918.

Cypress sandstone

The Cypress sandstone is named from Cypress Creek, Union County, Ill. It is the only pure and persistent sandstone stratum in the Mississippian series of this region. It is the sandstone that caps the high knobs and flat-topped ridges of the area such as that just south and those to the east, northeast, north and northwest of Livingston. It also forms wide terraces or benches around some of the high knobs such as Gullett Mountain and Alpine Mountain. It is the same as the Newman sandstone lentil of the Standingstone folio. Moreover, since the sandstone has been proven in the last few years to be the same as the Cypress sandstone, which was so named in 1866, that name, being first applied and having priority over all others, has been adopted by geologists generally. The Cypress is, too, probably the same as the Hartselle sandstone of Alabama.

The Cypress of this regon is a grayish, medium coarse-grained, fairly firmly cemented, flaggy to thick-bedded sandstone. In places it yields good paving stones and chimney stones and has been quarried for those uses. It varies from 1 foot to 70 feet in thickness, 40 feet being its average thickness over most of this area. A thickness of 5 feet or less was observed on the west side of Pilot Knob near its northern end and a thickness of 10 feet at one place on the south side of Alpine Mountain. In the southeastern part of the area on both sides of East Fork of Obey River, the sandstone is, over considerable areas, reduced to a thickness of 6 inches or a foot and is perhaps locally wanting altogether. Cross-bedding and ripple markings are common features. Being a relatively thin sandstone interbedded in limestone and, except in one small area, the only such occurrence in the region, the Cypress is easily followed from place to place throughout this area and serves as an excellent datum for determining the lay or structure of the strata, which is the object of this investigation. For that purpose the bottom of the sandstone is used as a reference surface as described on page 28.

The contact of the Cypress with the underlying limestone is in nearly all places where it was observed absolutely sharp and clear cut and without any transitional material whatever. Only in the vicinity of Beard Mountain (Tower Hill), north of Livingston, was a thin layer of clay shale and some interbedded thin layers of sandstone and clay shale observed.

Golconda shale

Immediately overlying the Cypress sandstone throughout most of the area described is 20 to 30 feet of soft marly shale. The greater part of this shale is green, but it contains a layer of red shale 2 to 3 feet thick in the vicinity of Gullett Mountain, and about 1 foot of red shale just north of Allons which is 1 mile north of Beard Mountain.

It is believed that this shale is the thinned southeastern edge of the Golconda formation, named from Golconda, Ill., where the formation is 140 feet thick. It is therefore here designated as Golconda shale.

The best exhibition of the Golconda discovered is in the southeastern part of the area and in Fentress County, about half a mile east of the county line, on the west side of Big Indian Creek in the road leading west into Black Hollow. The shale is here greenish and gray and 40 feet thick. Another good display is at the road intersection at the east base of Gullett Mountain, about 3 miles southeast of Livingston. It is fairly well developed and exposed in the road just north of Allons. South of Alpine Mountain the Golconda has not been observed and it is absent at one point on the east end of Skinner Mountain, where the Cypress sandstone is also absent so that the Gasper and Glen Dean limestone are in contact. In all the Obey River country, even where the Cypress sandstone is absent or so thin as to be insignificant, there is a conspicuous shelf or bench several rods wide along the outcrop of the Golconda. These benches are in many places followed by roads or paths since they are nearly level along the hillside and free from stones. The highways of the country where they cross the outcrop of the Golconda are in wet weather usually marked by such deep mud as to be nearly impassable. A good example is on the summit of the ridge crossed by the Jamestown road between Livingston and Nettlecarrier. While not mentioned in the description nor shown on the map, this shale is clearly shown in the columnar section of the Standingstone folio just above the Cypress sandstone (Newman sandstone lentil).

Hardinsburg sandstone

Like the Golconda, the Hardingsburg sandstone is another of the western Kentucky and southern Illinois formations that is very thin or wanting in this region. It is named from Hardinsburg, the county seat of Breckinridge County, Ky.

The Hardinsburg sandstone is known in this area only in the vicinity of Beard Mountain and Allons. At the west base of Beard Mountain it appears to be only a few feet thick, as it is at the base of the knob, one-half mile west of Allons. In the road north of Allons it is 40 feet thick and composed of alternating layers of friable sandstone and of shale. Here it extends vertically from about the level of the village to the top of the hill to the north marked on the map as 1,420 feet in altitude. The Hardinsburg sandstone is an important formation of the Chester group from Breckinridge County, Ky., to Union County, Ill.

Glen Dean limestone

The Glen Dean limestone is named from the village of Glen Dean, Breckinridge County, Ky. In this region it outcrops on the slopes close above the Cypress sandstone and on such high knobs rising above the Cypress sandstone plateaus as Beard Mountain (Tower Hill) where it extends from the road level on the west side nearly to the top of the hill. It is well displayed on the sides of Beard Mountain and other similar knobs at the west base and for 1 1-2 miles along and above the road along the north base of Gullett Mountain, 3 miles southeast of Livingston. In general it is one of the best exposed formations in the region. It is the part of the Newman limestone of the Standingstone folio above the Cypress sandstone (Newman sandstone lentil).

The lower three-fourths of the thickness of the Glen Dean is blue, coarsely crystalline or highly fossiliferous and fragmental, medium thick-bedded, compact limestone; the upper one-fourth is thin-bedded, gray, apparently clayey and non-fossiliferous. Its character indicates clearly a gradual change to the conditions leading to the deposition of the shale and argillaceous, gray limestone layers of the overlying Pennington shale.

The Glen Dean is 140 to 150 feet thick and seems to hold this thickness very consistently.

As stated, this limestone is highly fossiliferous in its lower three-fourths. The bryozoan *Prismopora serrulata* is one of the most abundant fossils beginning at the bottom and extending upward 50 to 100 feet. In some layers it is exceedingly abundant. It can be distinguished from all other fossils by the triangular cross-section of the stems which can be seen on the surfaces of most any layer or slab containing the species. The sides of the triangle are about one-fourth inch long and concave, so that they meet in a sharp crest that is serrated or toothed like a saw along its edge. Another characteristic Glen Dean form is *Pentremites pyramidatus*, although identifiable specimens are rare in the region. Another form which is common in this region only in the Glen Dean is the genus Archimedes, a bryozoan which has a solid screw-shaped axis, fragments of which are common on the surfaces of the limestone layers. Such forms occur in the Pennington shale and very rarely in the Gasper oolite, but are not known in this region in any lower formations.

Another characteristic of the Glen Dean of this region is the great profusion of geodes or niggerheads as they are called. These are spherical bodies of silica up to 1 foot in diameter but more generally 2 to 4 inches. They are usually hollow and the walls of the cavity are covered with small pyramid pointed quartz crystals as clear as glass. The geodes everywhere strew the slopes underlain by the Glen Dean.

The Glen Dean extends northward at least to Sloans Valley in Pulaski County, Ky., and thence extends westward through western Kentucky and southern Illinois to Mississippi Valley and can be unmistakably identified throughout the entire region by its peculiar and highly characteristic assemblage of fossils. It is a most valuable datum plane for stratigraphic correlation.

Pennington shale

The Pennington shale is named from Pennington Gap, Va., between Big Stone Gap and Cumberland Gap. The Pennington is the uppermost of the Mississippian formations and in this region occupies the space between the Glen Dean limestone and the base of the Pennsylvanian (coal measures) shale and sandstone. In western Kentucky and southern Illinois the Glen Dean is overlain by the Tar Springs sandstone, 50 to 150 feet thick, but no such sandstone is present in this region, and it is unknown whether such may be represented by the basal part of the Pennington. If the Tar Springs sandstone is not so represented there is an unconformity between the Glen Dean and Pennington.

The Pennington outcrops on the steep middle slopes of the high hills such as Gullett, Alpine, and Skinner mountains and Pilot Knob, and the high spurs northeast of Spurrier and north of Little Crab in the northeast corner of the area under discussion.

The Pennington rocks are mainly shale, with limestone and sandstone making up a smaller proportion of the whole. The shale is mostly gray and probably calcareous, but there is a considerable amount of red shale in layers up to approximately 10 feet in thickness. The limestone contains much earthy matter which gives it a whitish or yellowish color on the weathered surfaces. Its layers are generally less than 10 feet thick and there are but few of them scattered through the mass of shale. In this region very little has been seen of the sandstone beds, their presence being indicated by sandstone debris on the surface which indicates shaly or laminated beds.

The Pennington is not a highly fossiliferous formation, although in some of the limestone beds, bryozoa and brachiopods, are fairly plentiful. In a general way the Pennington is correlated with the Buffalo Wallow[1] formation of Kentucky, and probably with the upper part of the red Mauch Chunk shale of Pennsylvania.

UNCONFORMITY

As shown in the table of formations, page 19, there is a great stratigraphic gap or unconformity between the Pennington formation and the immediately overlying lowest formation of the Pennsylvanian series of the region. There is absent here the Parkwood formation of Alabama, of Mississippian age, 2,000 feet thick, and the lower part of the lower Pottsville coal measures represented by the lowest coal beds of the anthracite fields of Pennsylvania, the Pocahontas coals of Virginia and West Virginia, and the lower two-thirds of the coal measures of the Cahaba coal field of Alabama, 6,000 feet thick. The aggregate thickness of rocks absent appears, therefore, to be about

[1]For description of the Buffalo Wallow formation see The Mississippian series in western Kentucky: Kentucky Geol. Survey, 1918.

8,000 feet. Even in Cumberland County, Tenn., there are rocks present including important coal beds, such as the Bon Air and Clifty coals, that thin out between Cumberland and northern Overton County, so that the coal measure rocks on the tops of the high hills here represent only the very highest rocks of Cumberland County.

PENNSYLVANIAN SERIES

The Pennsylvanian series or coal measures is represented in this area by a shaly formation below and a sandstone above. These occupy the tops only of the highest hills in the eastern half of the area, the top of Gullett Mountain bearing the westernmost outlier of Pennsylvanian. The sandstone is clearly the Rockcastle sandstone and it follows most probably that the underlying shale is the Vandever shale of Cumberland County.[1]

Vandever shale

The Pennington formation is succeeded unconformably by the Vandever shale, named from Vandever in Cumberland County. The Vandever is a sandy shale with thin sandstone beds, and locally includes one or more workable coal beds. It outcrops on the steep upper slopes of the high hills in the eastern part of the region extending nearly to the brow of the hills. Portions of the formations are well displayed on the south side of Gullett Mountain, where the sandstones and shales break up into thin, sandy, micaceous flakes or pieces a few inches square. Its thickness there was not accurately determined, owing to the fact that the contact between the Vandever and the underlying Pennington is not exposed, but it does not exceed 140 feet, for undoubted Pennington is exposed 140 feet below the Rockcastle sandstone. Probably the thickness is about 120 feet, the same as in northern Cumberland County.

Rockcastle sandstone

The Rockcastle sandstone is named from Rockcastle River in Kentucky. In this region it is the highest formation and has no rocks above it. Small areas exist on the top of Gullett, Alpine, and Skinner mountains and upon other of the highest summits of the eastern parts of the county.

In this region, as elsewhere, the Rockcastle varies in grain from coarse to medium and in bedding from thick to medium. Locally it is conglomeratic including a fair admixture of quartz pebbles, so far as seen generally less than one-half inch in diameter. Boulders of such conglomerate are scattered along the road at the north base of Gullett Mountain. East of the region here described the Rockcastle forms the surface rock of the Cumberland Plateau for a width of 10 miles. The thickness of the Rockcastle in the area is generally less than 100 feet, but may reach 200 feet in the extreme eastern part.

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[1]Butts, Charles, Structure of the southern part of Cumberland County in relation to the possible occurrence of oil and gas: Resources of Tennessee, vol. 6, No. 2, April, 1916.

STRUCTURE

Definition and method of representing structure.—By geologic structure is meant the lay or attitude of the strata whether flat, sloping, or wrinkled, etc. Stratified rocks from the manner of their origin were nearly or quite flat or horizontal at first. In some regions they still retain their original flatness, in others they have been gently disturbed, so that they are now more or less inclined, warped, or wrinkled; in still others they have been violently disturbed, so that they now stand in a vertical or highly inclined attitude or are even turned bottom side up. Overton County lies in a region of gentle disturbance and the strata deviate but little from horizontality. In general the strata slope or dip to the southeast as shown by the fact that the Chattanooga ("Black") shale, which is about 800 feet above sea level on the western margin of the area under discussion is 200 feet below sea level at Rugby, about 30 miles east of Livingston. While the strata have this general southeast slope or dip, they are also affected by minor bending and wrinkling so that they lie in low swells or depressions of varying shapes, sizes, and directions, or are locally squeezed into fairly sharp but low and narrow wrinkles called folds, which are fairly uniform in contour and direction.

The upward bending wrinkles or folds are called anticlines, the downward bending folds are called synclines. It is these wrinkles and swells that are of especial importance in connection with oil and gas, for, as stated in the introduction, it is a matter of experience in oil fields generally that oil and gas accumulate along such structures. The close association of oil deposits with anticlines has given rise to the anticlinal theory of oil and gas occurrence. In some oil fields, as in Oklahoma, it has been found that very low anticlines have in many cases an important influence on oil accumulation, so that it is a matter of great importance to have all such anticlines found and properly mapped for the benefit of oil operators.

After the geologist has located an anticline and determined its form and extent, it is necessary to represent it on a map for the use and benefit of the public. This is accomplished by the use of structure contours. The top or bottom of some stratum that can be identified at different points and followed throughout a region of greater or less extent is selected and the elevations above sea level of points upon that surface as accurately determined as possible. The location of each such point is platted upon a map and finally when as many points as practicable have been so determined and located, lines are drawn through a selected number of points having the same elevations. Thus a line may be drawn through all points having an elevation of 1,000 feet above sea level, another line through all points at 1,020 feet, another at points at 1,040 and so on. The surface of a stratum selected for this purpose is usually called the reference surface. The combined effect of these contour lines is to show the form and extent of all slopes of the reference surface, or, in other words, the geologic structure of the reference surface, and, since in a stratified series, the strata are substantially parallel, the structure of the reference surface stands for the structure of the body of the rocks as a whole. This last statement requires the following qualifications: Where a great unconformity exists below the reference surface the strata below the unconformity may not be parallel to those above the unconformity including the reference surface, so that the structure contouring does not hold below the unconformity; also even in a conformable series the anticlines and synclines tend to flatten out with depth, so that in the case of an anticline of moderate height at the surface, the structure might not be anticlinal 5,000 feet or even a much less distance below the surface.

DETAILED DESCRIPTION OF STRUCTURE

The structure of the country under description is represented by contours drawn upon the bottom of the Cypress sandstone at vertical intervals of 20 feet. The elevation of points on this surface was determined in two ways, viz., by direct stadia and vertical angle measurements upon the outcrop of the sandstone at convenient points and, where the sandstone is absent, by calculation from the elevation of points on the top of the Warsaw formation or of the Chattanooga shale by adding to the elevation of such points the thickness of the strata between the bottom of the Cypress sandstone and either one or the other of the two surfaces mentioned, as the case might be. The thickness between the Warsaw and Cypress varies with the locality from 330 to 380 feet, 380 feet being the more common thickness. In the Obey River region it is approximately 330 feet. The distance between the Chattanooga and the Cypress varies from 700 feet in most of the area to 755 feet on Mitchell Creek. The elevation of the top of the Warsaw, and, to some extent, of the top of the Chattanooga, as well as the bottom of the Cypress, were instrumentally determined. In the western parts of the area, however, the elevations of the Chattanooga are taken from the position of that formation as mapped in the Standingstone folio. The contouring of the small anticlines in the western part of the area is based in part upon the measurements of visible dips as shown by dip symbols on the map. While the form, extent, and probable height of these anticlines is believed to be represented with substantial accuracy, the contours as referred to the base of the Cypress sandstone may not be entirely correct. In general, however, the contours are probably accurate to within a contour interval of 20 feet.

The following detailed description of the anticlines and synclines proceeds in regular order from northwest to southeast.

Mill Creek Anticline

The Mill Creek anticline crosses the northwest corner of the region here described in a direction about north 60° east. The southeast slope of this anticline is plainly visible from the highway between the point where the

Hilham-Celina road crosses Mill Creek and the road intersection three-fourths of a mile to the northwest, and the dip to the northwest shows in the east bend or loop of the creek one-half mile to the west where the dip symbol is placed. The dip shows farther down the stream also on the south side of this loop. The extension of the anticline to the northeast and southwest is not known.

Dry Fork Anticline

A low anticline shows plainly on Dry Fork of Mill Creek just east of the county line. The dip is about 3° on each side of the axis, which seems to run nearly east and west.

Mitchell Creek Anticline

On Mitchell Creek on the northern margin of the area are three anticlines, the western one being most pronounced. Just north of the area the opposing dip of 5° affects a belt of several hundred feet on each side of the axis and the summit of the anticline is about 80 feet above the bottom of the adjacent synclines. On Carter Creek, a mile to the southwest of Mitchell Creek, the dip is lower, being about 3° on each side of the axis. On Mill Creek in line with the Mitchell Creek axis is a pronounced dip of 5° southwest, the strike being north 60° west. It seems probable that this is the southwest end of the southward extension of the Mitchell Creek anticline, which at this point pitches strongly southwestward, and it is so drawn on the map, although this interpretation has not been verified by field observation. Plate 2b shows the Ordovician limestone dipping southwest on Mill Creek as described above.

In the space about 2½ miles east of the main anticline on Mitchell Creek are two low anticlines striking slightly southeastward, separated by shallow synclines. On the east limb of the eastern one of these anticlines the rocks seem to dip toward Oakley 100 feet in the distance of a mile. To the east of this anticline, so far as data obtained tend to show, is a broad flat or terrace about 3 miles wide on which Oakley is situated.

Roaring River Anticline

In the southwestern corner of the area the Roaring River anticline extends 2 miles northeastward along Roaring River. At the most eastern point where it crosses the river the anticline is plainly exposed and has opposing dips to southeast and northwest of 4° and 5° respectively. Near the western margin of the area the anticline appears to widen out and the dips to decrease to 2°.

Flat Creek Anticline

Along the lower course of Flat Creek is the most pronounced anticline seen in the region. Just south of the road crossing Flat Creek one-half mile north of the mouth of Buffalo Branch the dip is 5° to the southeast; while on Buffalo Branch, a short distance above the mouth, the dip is 5° to the northwest. At the mill just above the crossing of the Hilham-Cookeville road the arch of the anticline is plainly exhibited in the bluff, and about 2,000 feet down stream from the crossing, the arch is exposed in the bluff as shown in the photograph, Plate 2-A.

The Flat Creek anticline shows very plainly in the bluffs of Roaring River, beginning immediately west of the road crossing at Browns Ford, the opposing dips being 4° and 5°.

Crawford Mill Anticline

At Crawfords Mill is another low anticline running in a northeast-southwest direction. Here, also, the arch is exposed in the bluff just north of the mill, and the dip on the southeast limb shows in the bluff south of the mill. Possibly the Crawford Mill arch extends northeastward to Livingston, where it disappears in an "anticlinal nose." The country between Copeland and Flat creeks was not surveyed, so the supposed structure was not verified and the doubt is indicated by the question marks along the line representing the axis.

Flat Creek Monocline

On Flat Creek, about one-fourth mile northwest of Crawfords Mill, is a sharp monoclinal dip to the northeast of about 5°. The strike of this flexure is about north 60° west. It appears to be about 500 feet wide.

Excepting these fairly well-defined anticlines, the structure of the western half of the area appears to be a gentle eastward slope crossed by broad anticlinal and synclinal warpings with a general trend transverse to the main strike of the strata. The best-defined and determined of these have been named. Others more or less doubtful as to their existence or extent are indicated by unnamed axes.

Garretts Mill Syncline

On the upper forks of Eagle Creek is a broad structural depression, in which is located Garretts mill, where issues the big spring that furnishes water power for the mill. From this depression a broad, shallow, but well-defined syncline runs westward, its axis lying along Tompkins Cove and rising to the west. Two other narrow synclines extending northward between the eastern anticlines on Mitchell Creek are probably connected with the Garretts mill syncline. Still another apparently connected broad syncline extends southwestward toward Garrett.

Monroe Anticline

The Monroe anticline extends in a general southward direction from Monroe to the east end of Gullett Mountain. The northern half of this structure is essentially a flat-topped triangular "dome," while the south half is a relatively narrow linear fold extending southward from the "dome." The dip from the Monroe axis is low toward the west and south, but fairly steep to the east.

Gullett Mountain Syncline

About two miles south of Livingston is a well defined and relatively deep syncline, in the eastern end of which is situated Gullett Mountain, capped

A—LIMESTONE ON MILL CREEK.

Limestone just below the Chattanooga ("Black") Shale on Mill Creek, two miles west of Grey. Chattanooga shale just about the top of the exposed limestone. Looking nearly north, strike north 60° west; dip 5° southwest.

B—ANTICLINAL ARCH ON FLAT CREEK.

Arch of anticline on Flat Creek 2,000 feet below crossing of Hilham-Cookeville road. Looking north, strike about north 55° east; dip to southwest (right) 14° to northwest (left) 10°.

The crest of this arch is about 40 feet higher than the base on the right, not shown in the picture. Rocks in the lower part of the Fort Payne formation.

with coal measure shale, sandstones, and conglomerate, the presence of which is probably due to the existence of the syncline. From the bluff just south of Livingston to the axis of this syncline at the east base of Gullett Mountain the Cypress sandstone dips nearly 80 feet. From the axis southward the sandstone rises in one mile about an equal amount to the axis of the Copeland anticline. The southwest end of this syncline was not worked out in detail, but determinations on the top of the Warsaw formation on Gilberts Creek and for two miles to the south clearly indicate a syncline in the position marked.

Copeland Anticline

Between Collins and Copeland coves is an anticline well established by observations at the east end. The dip is fairly uniform, both to the north and south, at the rate of about 60 feet to the mile.

Alpine Mountain Syncline

Like Gullett Mountain, Alpine Mountain marks the presence of a syncline the axis of which begins on the north opposite the middle of the Monroe anticline and pitches southward. On the south side of the area mapped the syncline broadens so as to hold nearly the full extent of Alpine Mountain.

To the northeast of Monroe there seems to be a shallow syncline extending northwestward to Eagle Creek. In general, however, the strata in this region are nearly flat, as shown by a line of levels on the top of the Warsaw formation from Garretts mill to the north edge of the area. At least there is for several miles a variation, except near the north margin of the area, of less than 20 feet. The contours between Eagle Creek and Wirmingham are not based on any engineering data, but are suggested by the structure of the surrounding region.

Spurrier Syncline

The Spurrier syncline extends from south of Pilot Knob to about a mile north of Spurrier. It has the usual northeast-southwest trend of the better defined linear structures of the Appalachian region generally. It is a narrow shallow trough in its southwestern half, but broadens and deepens in the northeastern half, reaching its greatest depth west of Spurrier. It is a matter of interest that the Lacy and Padgett oil wells are situated in the northeast limb of this syncline--a not unusual structural relation of both oil and gas in oil fields in general.

West Fork Anticline

The West Fork anticline is a broadly curving structure extending nearly across the area mapped. It is narrow in the middle north of Nettlecarrier, but broadens at each end. The amount of dip toward the Spurrier and Alpine Mountain synclines is about 40 feet, while the total eastward dip to the axis of the Rockhouse syncline is 80 to 100 feet. The rate of east dip is about 75 feet to the mile between West Fork and Nettlecarrier, but only about one-half as much southeast of Nettlecarrier.

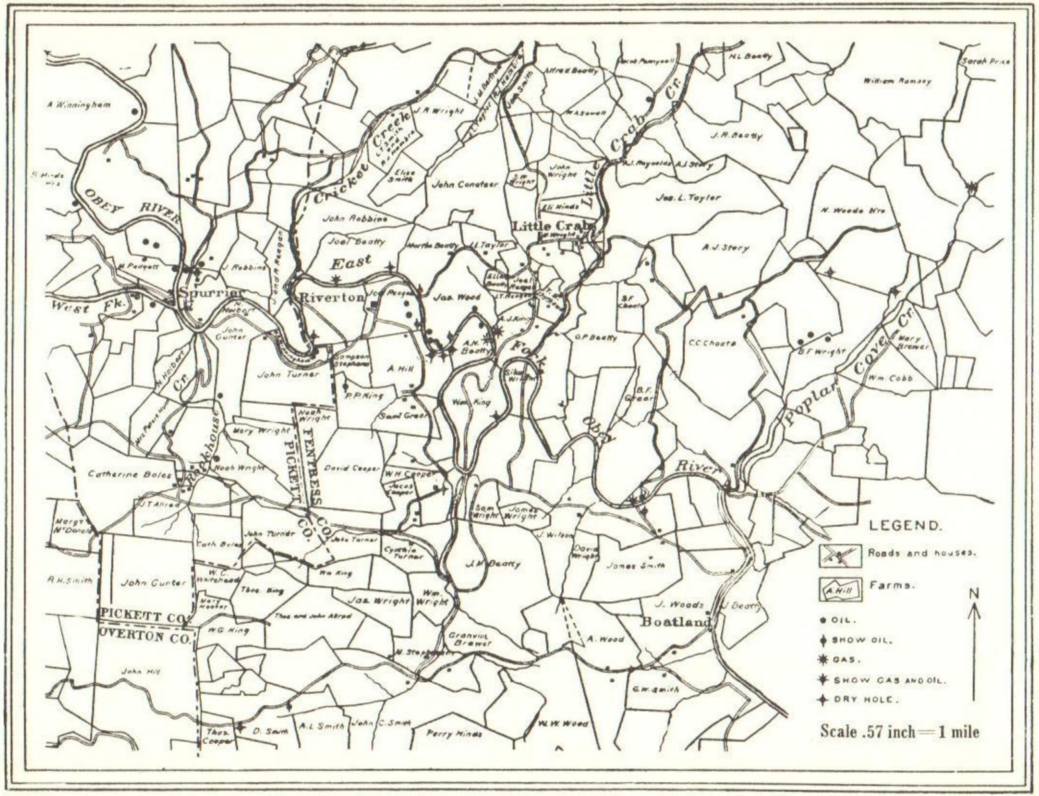

Fig. 4—Farm line map of Spurrier-Riverton oil and gas district, Pickett and Fentress counties, Tennessee.

Rockhouse Branch Syncline

The Rockhouse Branch syncline is a rather deep curving trough, the axis of which rises to the narrow northeast end at the head of Rockhouse Branch. Southeastward into Fentress County this syncline seems to merge into the broad southeast structural slope extending beyond East Fork of Obey River.

Franklin Creek Anticline

On Franklin Creek, which flows through the north margin of the area for a mile east of Obey River, the rocks dip eastward about 5° just north of the eastern point where the creek crosses the edge of the area. A low east dip continues along the north margin of the area for at least three miles and, part of the distance, the Cypress sandstone can be seen gently dipping eastward. All the observations indicate an anticline with axis rising to the northwest, in which direction and north of this area the anticline may attain its maximum development.

Riverton Anticline

The existence of the Riverton anticline is assumed from the outcrop of the Chattanooga shale at the river just northeast of Riverton. The shale dips northwest about 20° and is exposed for only a few yards. The southeast limb of the anticline is not exposed, but the anticline must be a very narrow and relatively sharp fold. It does not affect the rocks on the north side of the river 200 feet or so from the exposure of the Chattanooga on the south side. It is possible that the shale is brought up to outcrop by a fault, but no evidence of a fault could be obtained.

Crab Creek Syncline

The Crab Creek syncline is a well defined trough narrowing to a sharp point at the southwest end and expanding to a broad depression on Little Crab Creek, three miles above its mouth.

Little Crab Creek Anticline

The Little Crab Creek anticline is composed of two long, narrow structural ridges running about north 50° east connected at the southwest end by a broad oval dome. It might be better to regard the structure as made up of two anticlines and a connecting dome, but so far as data obtained reveal it, the structure is continuous and so considered as one. The degree of dip is about equal on both legs of the anticline and on all limbs, being about 75 feet to a mile. The large wells on the Woods farm, including the noted Bobs Bar well, are located squarely across the north leg of this U-shaped fold and the Cobb wells on Poplar Cove Creek appear to be on the northeast end of the south leg.

The remarkable general parallelism of the curving structures of the eastern half of the area, especially as manifested in the West Fork and Little Crab Creek anticlines, is worthy of note.

Goose Neck Anticline

The Goose Neck anticline is an oval dome the summit of which lies just southeast of the loop in the river known as the Goose Neck. This structure is apparent in the walls of Indian Creek gorge and was detected a short distance to the west of Indian Creek.

Indian Creek Syncline

The Indian Creek syncline is a narrow and shallow trough parallel to and a short distance northwest of the south leg of the Little Crab anticline. The low south dip toward the axis of this syncline can be seen in the ledges exposed on the walls of Indian Creek.

Boatland Syncline

A very distinct syncline extends east and west at Boatland. The dip, both north and south and over 40 feet in amount, is very plainly revealed in the river bluff on the west. The syncline does not appear to extend far either to the west or east.

Glen Obey Anticline

The Glen Obey anticline is immediately south of the Boatland syncline, to which it is a parallel structure of about equal magnitude. The arch is exposed in the river about one mile southeast of Boatland. A well, reported dry, is located about one-half a mile south of the axis of this anticline.

Southeast corner of the area

The structure of the southeast corner of the area was not thoroughly worked out. Levels were run on the Cypress sandstone as far south as the mouth of Bills Creek and the elevation and form of the contours to that point accurately determined. No cross structure was detected and it seems probable that there is a fairly uniform east dip as shown. The doubt is expressed by the broken lines.

ACTUAL AND POSSIBLE SOURCES OF OIL

In the preceding description of the strata, page 11, it is shown that, excepting beds of about the same age as the "Trenton" oil rock of Ohio, neither the principal oil-bearing strata of the United States nor any rocks of equivalent age and stratigraphic position are present in this part of Tennessee, great stratigraphic gaps or unconformities existing at those places in the geologic column where they would lie if present. Also there are only two sandstone formations in this region, the Cypress and Rockcastle, and neither is, owing to its topographic relations, likely to be oil-bearing. The possible reservoirs of oil in this region are, therefore, limited to limestone or dolomite. Oil has actually been found in two of the limestone formations of this region, namely, the Ordovician limestone in the Spurrier and Riverton field, and the Fort Payne limestone in the Spring Creek field, about ten miles south of Livingston. About all the available data concerning the occurrence of oil in these fields has been collected by Munn[1] and published

[1]Munn, M. J., Preliminary report on the oil and gas developments in Tennessee, Tenn. Geol. Survey Bull. 2, 1911.

by the Tennessee Geological Survey. His descriptions, supplemented by comments and additional matter by Compton, are reprinted here.

Spurrier and Riverton Oil District

"For data relative to the oil and gas developments in the vicinity of Spurrier and Riverton the writer is largely indebted to Mr. J. H. Compton of Riverton, than whom no one was more intimately connected with the development of these fields."

"From the early settlement of the country many oil and gas springs have been known to exist along the east and west forks of Obey River and their tributaries in Overton, Fentress and Pickett counties. In 1892 Mr. Bruno Gernt of Allardt and others, known together as the "Miss J. W. Stone syndicate," leased land in the vicinity of Spurrier, Pickett County, and drilled a well for oil. This well was located on the J. L. Lacey farm, about one mile northwest of Spurrier, on the banks of Obey River. It started in the Fort Payne formation, and about 61 feet above the Chattanooga shale. At a depth of 268 feet this well flowed oil temporarily until the supply was shut off by fresh water. It was later drilled deeper and more oil encountered at depths of 297 and 357 feet. This well is said to have reached a depth of 1,000 feet, flowing for a short time at the rate of 800 barrels per day and later pumping at the rate of 25 barrels per hour. Great trouble was experienced, however, in preventing invasions of fresh water into the well. The following record of this well has been given:

Record of Lacey No. 1 Well, Spurrier, Tenn.

	Thickness Feet	From Feet	To Feet
Shales, etc.	64	0	64
Chattanooga shale	28	64	92
Limestone and shale	268	92	360
Limestone, siliceous (brown)	373	360	733
Shale, blue, soft	150	733	883
Limestone and shale alternating	117	883	1,000

"Salt water was also encountered in this well at 370 and 500 feet, but it is said to have been easily exhausted by pumping."[1]

"Following this discovery of oil more than a dozen wells were drilled in Spurrier within the next few years. Lacey well No. 2 reached the Chattanooga shale at 82 feet and got 'shows' of oil at depths of 211, 216, 220 and 256 feet and salt water at 360 feet. A well on the James Boles property on West Fork, a short distance from its mouth, found oil at a depth of 425 feet, which is 337 feet below the top of the black Chattanooga shale. Well No. 2 on this farm at Spurrier furnished only a "show" of oil. Another well on the C. Bilbrey property near the mouth of West Fork also had a 'show' of oil and gas at a depth of 425 feet. The Geo. Robbins well No. 1 found an amber colored oil of excellent quality at a depth of 242 feet. In the J. A. Reagan well No. 2 the amber oil with gas was encountered in what is said to be a 'regular oil sand' 20 feet or more in thickness. Well No. 1 on the Reagan farm was a dry hole. The Marion Padgett well No. 1 found oil at 265, 294 and 354 feet. This oil was accompanied by water which quickly shut off the supply. When a 3-inch pump was put into the well and the water exhausted it is said to have flowed at the rate of 50 bar-

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[1]The following additional information about the Lacey well was given the writer, Mr. Butts, by Mr. Compton in a letter dated April 1, 1919:

"The oil was found in the Lacey well at 268, 297 and 357 feet. The well flowed temporarily, from the 268 feet horizon, and when the gas pressure was relieved, fresh water appeared and shut off the oil. The casing was then pulled and set deeper in order to shut off the water that had appeared at 268 feet. With the casing reset, drilling was resumed and more oil encountered at 297 feet and this oil, too, was succeeded by fresh water. Again the casing was pulled, the hole reamed and the casing again set deeper. The third strike was had at 357 feet and the last level remained undisturbed by water until the then owners of the lease, in about 1905, "shot" the sand in which the last oil was found and blew the casing from the hole. The casing was put back but, for some reason, would not exclude the water thereafter. For that reason the hole was abandoned. The two upper horizons I regard as 'crevice' oil."

rels per day, but when pumping ceased the water again shut off the supply of oil.[1] The above mentioned wells are located to the east and south of those on the Lacey farm.

"A well drilled about one mile west of the Lacey No. 1 on the S. Hind farm found the Chattanooga shale at a depth of 80 feet, where it was 29 feet thick. In this well a good 'show' of oil was found at 180 feet. About one and a quarter miles north of the Hind well on the A. Winningham farm a well was drilled which found traces of oil and considerable gas and salt water at the following depths: salt water, 210; gas and trace of oil, 328, 334, 364 and 384 feet."

"In 1896 a well was located at a shoal known as Bob's Bar, on the east fork of Obey River, three miles east of Spurrier in what has come to be called the Riverton field. Oil was encountered in this well at a depth of 275 feet in such quantities that it is said to have flowed for fourteen hours in a solid 6-inch stream from 5 to 20 feet above the casing, after which it caught fire and burned, consuming derrick, tools, tank, etc., and continued burning until the well ceased to flow. When put to pumping the well is said, on authority of its owner, Mr. John H. Compton, of Riverton, to have started off at the rate of 600 barrels per day, but to have soon settled to 22 barrels daily. The following record of the Bob's Bar well has been kindly furnished by Mr. J. H. Compton:

Record of Bob's Bar Well, Riverton, Tenn.

	Thickness Feet	From Feet	To Feet
Alluvium	10	0	10
Dark calcareous shale and shaly limestone	70	10	80
Chattanooga shale (black)	28	80	108
Limestone, varying in texture color, and hardness, to bottom of well at	....	....	275

"The oil-bearing zone in this limestone was subsequently shown to be about 100 feet thick. The well was eventually drilled to a depth of about 1,000 feet, the particulars of which are given below."

"Previous to the drilling of Bob's Bar well there were no facilities for transporting the oil from this region. The fine showing made by this well induced the Cumberland Pipe Line Company to build two 20,000-barrel steel tanks on the Lacey farm and to lay a pipe line from them to this well on the condition that it would be pumped by its owners until a full test of its capacity might be made. In 1905 and 1906, when about 18,000 barrels had been produced from it, the indications of a steady production were so good that the Cumberland Pipe Line Company laid a 2-inch pipe line to the field from its nearest branch in southern Kentucky. Supplied with a market for the oil, drilling operations were resumed and a number of wells put down in the vicinity of Bob's Bar. Of these, Wood No. 2, located about 400 feet away, reached the 'pay' sand at about the depth of the Bob's Bar well. When this well 'came in' the Bob's Bar ceased to furnish oil and began to furnish large quantities of fresh water. After a number of wells had been drilled in this field and great trouble experienced in preventing the wells from becoming flooded with fresh water, Mr. J. H. Compton, the present owner of the field, devised a means of exhausting the supply of fresh water by raising the casing in the wells to a point just below the source of supply. When this was done over the entire field and the water in the oil horizon pumped off, the wells began producing their normal supply of oil. Woods No. 5 greatly reduced the capacity of the Bob's Bar well, but when the latter was drilled deeper it exhausted the oil from Woods

[1]The following account of the behavior of the Padget well by Mr. Compton will be of interest to oil producers:

"The facts are these: After running the three-inch pump, night and day at the fastest possible rate for fifteen days, the well suddenly began flowing oil through both ways of the casing-head, through two 2-inch openings, under great pressure and sending two solid streams of oil fully 60 feet from the casing-head. The pumper, in alarm lest the well should catch fire, put out the fire under his boiler after stopping his pump. The well made this display for about 15 minutes and then quit as suddenly as it had begun. Understand that pumping had been carried on at this well for many weeks prior thereto but that the pumper, always having a color of oil with the water, ran the machinery for the last two weeks with the energy of despair because he was short of money. He started his pump to going again, after the oil had shut off, but never gained on the water sufficiently to lower it past the crevice that fed the oil to the well. Being without money and credit and wood being difficult to get in cold and rainy weather, he quit. While the well was flowing it was putting out oil at the rate of not less than 500 barrels daily—probably more. The Padgett well, I have since proven, has a sensitive connection with the Lacey wells, Nos. 1 and 2."—Letter to Butts cited above.

No. 5. Later, when the Woods No. 5 was drilled deeper, the supply of oil again came entirely from that well. The supply of oil thus shifting from one well to the other until the entire thickness of the oil-bearing limestone (about 100 feet) was penetrated by both.

The following additional information and discussion of the water problem by Mr. Compton is of interest:

"Drilled in 1896, the Bob's Bar well was not pumped until after I purchased the property in August, 1898. It was in 1902 and not 1895, when about 18,000 barrels had been accumulated in the storage tanks near Spurrier, that I induced the Cumberland Pipeline Company to lay a two-inch (not four-inch) line to this field from Sunnybrook, Wayne County, Ky. Munn's exposition of the water problem falls short of illustrating, in a manner that would be comprehended by the laity, how the water (fresh water) problem could be obviated entirely, or remedied when it had occurred. How to prevent this, and how to remedy it, I must confess that I have heretofore guarded somewhat as a "trade" secret; but, in the interest of the field, and for the guidance of future operators, I have decided to give you an exact exposition of the process so that you, in your forthcoming Bulletin, may, if you deem it important, include it in your report. This thing had rendered nugatory the splendid find upon the Lacey and Padgett farms. It had cut short the production at Sunnybrook, Wayne County, Ky. It had shut off a flowing well on the Choate farm in Poplar Cove and it had thrown consternation into my camp here and, generally, had hurt the showing for this whole section so that it became a current phrase: 'Yes,. you may get a 250-barrel oil well, in Tennessee, for about 24 hours, and then you will have a perfectly beautiful water well.' This phenomenon, you will please understand, attaches wholly to 'crevice' horizons."

"Where oil has found lodgment, under pressure, in fractured or creviced strata, or stratum, there must necessarily be, above such oil, some strata or stratum, that is sufficiently impervious to prevent the upwards escape of the gas and oil: In this particular region, in the great majority of cases, the Chattanooga shale may be relied upon as being one stratum that will afford sufficient density to confine the oil and gas. In other observed instances the Ordovician limestone, to no fixed depth, will be impervious, and right here is where the trouble occurs.

"The gas and oil, in the creviced, or fractured, horizons, is found in the Ordovician lime in the Bob's Bar pool, at from 20 to 192 feet below the bottom of the Chattanooga shale. Gas was found in Woods No. 5 at 20 feet below the bottom of the Chattanooga shale; in Woods No. 2 at 65 feet below the bottom of the Chattanooga shale, and at 78 feet below the bottom of the same shale in Woods No. 1 (The Bob's Bar).

"When Woods No. 1, the discovery well, was drilled the big hole was carried past the gas at 150 feet and past the gas at 190 feet and set at 222 feet. The fundamental error was in carrying the casing past the gas at either point where it had shown. Why? Because the presence of the gas, at any point indicated that the drill had then passed through the lowest impervious rock that confined the gas under pressure and assuming that the gas had a connection with the oil that was found at from 267 to 275 feet in the same well you can readily see that the driller had created a passage for the water that would come into the well from above the Chattanooga shale. This water would pass down the channel thus made, between the casing and the wall of the hole, to the gas crevice and there it would be held until the gas pressure, as the well flowed, or was pumped, was reduced to such an extent that the gas pressure, in resistance, became less than the pressure of the column of water. The first was, therefore, variable, while the second was constant. The Bob's Bar well was fed by a crevice, after it got down to its settled production, but the body of oil that fed it was still under pressure That pressure was sufficient to hold back the water even after 36,000 barrels of oil had been tanked from the first well in addition to the oil that had run to waste. However, when well No. 2 was drilled, the casing in that well having been carried to 220 feet and past the gas at 145 and past the gas at 180 feet, thus creating a second channel for the passage of the water, and getting in oil flow at 225 feet in the second well and which had hit the main body of the oil and thus let off all gas resistance against the downward influx of water. So, the water then poured in, got beneath the oil and lifted that oil above the crevice that had theretofore fed the Bob's Bar well, at 267 to 275 feet, and lifted the oil past the crevice that fed No. 2 Woods, at 225 feet, and our oil production was gone. We could lower the water with the pumps and get a fine color of oil right along, but if we stopped the pumping machinery, for any reason, then the wells would fill to the level of the water in the river."

"When the first gas is encountered, coming from a creviced or fractured situation, the operator has the proof that he has passed through his impervious stratum or strata He should stop the drill immediately and set his casing and fill around it to a height of a couple of feet with drillings from the hole. The weight of the water plus the weight of the material, will hold them in place where they will settle and compact He can then safely proceed with his drilling."

"Where he has carried the casing below gas and subsequently strikes oil, followed by water, the remedy is to pull his casing, place a packer on the bottom of the bottom joint and then set that packer in the impervious rock above the point where the first gas was encountered in the hole."

"So proceeding, I left the Bob's Bar well plugged, above the first gas at 150 feet. That is the way the well ended as a producer. Then I set the casing on a packer, above 150 feet, in No. 2, pumped off the water and brought that well back on to oil doing 150 barrels daily where, before so proceeding, I could get only water and a color of oil." —J. H. Compton letter cited.

The following additional descriptions are taken from Munn's reports already mentioned:

"The Riverton field consists of about seventeen wells, closely grouped along the river in the vicinity of Bob's Bar. Here the Joel Reagan wells, Nos. 2, 3 and 4, furnshed a few barrels of amber oil from what is considered by Mr. Compton to be a sandstone ranging from 8 to 10 feet in thickness and at a depth of 625 feet. These wells are all located in the valley of east fork of Obey River west of Bob's Bar well. On the north side of the river opposite Joel Reagan's No. 2 a deep well was drilled on the Martha Beatty farm, which found a 'show' of oil in a sandstone 80 feet thick at a depth of 1,700 feet. No other oil or gas horizons were reported in this well. The James Wood wells, Nos. 2, 3 and 5, produced crevice oil from the same oil horizon as the Bob's Bar (Woods No. 1). No. 4 on this farm was dry. On the bluff south of the river the A. Hill well No. 3 found 28 feet of Chattanooga shale at 305 feet and a show of green oil with gas at 638 feet. Well No. 4 on this farm found 30 feet of Chattanooga shale at 305 feet, gas at a number of places between 400 and 500 feet and also at 560 feet, and a peculiar shale, known as the Pencil Cave, at 870 feet, with a little gas below, the total depth of the well being about 900 feet. East of the Bob's Bar well two wells were drilled on the A. Beatty farm. No. 1 on this farm showed oil at 270 feet and at 600 feet the heaviest flow of gas in the field was encountered. The No. 2 on this farm was a small oil well.[1] Across the river from Beatty No. 1 the well on the A. J King farm was drilled to a depth of 1,100 feet and is reported to have encountered gas in small quantities at no less than 22 horizons. The above named wells in the Riverton field have furnished all the oil."

"The exact amount of oil produced from the Spurrier-Riverton district is not known The total amount piped from Tennessee by the Cumberland Pipe Line Company, as stated by that company, amounted to 58,776.34 barrels. Of this, 41,462.56 barrels came from the James Woods farm at Riverton, and 50.81 barrels from the Joel Reagan farm in the same field. It is believed that a considerable portion of the remaining 17,262.97 barrels came from the Spurrier field. Of the 41,462.56 barrels produced from the James Woods farm, the Bob's Bar or James Woods No. 1 well is said to have furnished about 36,000 barrels, besides the large amount lost before the well was gotten under control."[2]

[1]"No. 2 is a remarkable small oil well. Drilled in about 1902, and good for 3 barrels daily, it is still as good and, seemingly, better than in the beginning. It was operated daily until the pipe line was taken out in September, 1906. The oil comes from a horizon 500 feet below the top of the Chattanooga shale. It has a gravity of 42°, Baume. Shows 36 per cent gasoline of superior voltatility at low temperatures. The oil occurs in a highly silicious limestone member 12 feet thick."—J. H. Compton, letter cited.

[2]All of the oil piped from the Spurrier-Riverton district came from my wells, near Riverton. That which is credited to Spurrier had been run through the pipeline and stored at Spurrier, after coming from my wells. The credit of 50.81 barrels as coming from the amber oil wells on the Joel Reagan farm, is erroneous. One 250-barrel tank received the amber oil from three wells on the Joel Reagan farm and this tank was filled several times before the pipeline was cut loose from the lease. The three wells afforded around eight and one-half barrels daily, the oil coming from a horizon about 452 feet below the bottom of the Chattanooga shale. This oil occurs on the south side of a fold with an approximate east and west axis.—J. H. Compton, letter cited.

"*Test Wells in the Vicinity of Spurrier and Riverton Fields.*—Of the test wells drilled in search of other pools in this vicinity one on the W. H. Cooper farm, about two miles south of Riverton, found good 'shows' of oil at 540 and 900 feet. About three miles southeast of Bob's Bar on East Fork at a place where oil seeps from the river bluff, three wells were put down, all of which had good 'shows' of oil, but not in paying quantities. One of these wells, the David Beatty No. 1, furnished light amber oil similar in quality to that of the Riverton field. In another the gas pressure was sufficient, it is said, to blow the tools from the well several times during drilling."

"A small oil pool was found on Poplar Cove Creek, about five miles east of Riverton. Here the C. C. Choate well No. 1, drilled by the Obey River Oil Company reached the Chattanooga shale at 245 feet, the shale being 30 feet thick. At a depth of 730 feet a dark, heavy oil was encountered in this well, which is said to have flowed for seven hours, after which the supply was shut off by an invasion of fresh water. By the use of large pumps this water was temporarily kept in check; during this time the well produced from 30 to 40 barrels per day of heavy black asphaltic oil. A pipe line was laid from Spurrier to this field and oil taken from it about one year. In well No. 2 on this farm oil is said to have been found at a shallower depth than in No. 1, the maximum daily production being about 30 barrels, which lasted only for a short time."

"Cobb's well No. 1 on an adjoining farm furnished a 'show' of dark heavy oil, and after being abandoned for five years this well still stands full of oil. About one mile north of the Cobb's and Choates' wells, test wells were put down on the farm belonging to the heirs of N. Wood and on the L. B. Chism farm. These were drilled to a depth of about 700 feet without finding either oil or gas."

"Between the Spurrier and Riverton fields a number of tests were made in an endeavor to connect the two productive areas. Three of these wells were on the Joel Beatty farm. No. 1 was dry at 700 feet; No. 2 had 'shows' of oil and gas at about 600 feet, probably from the so-called 'amber sand'; No. 3 penetrated the Chattanooga shale at 60 to 90 feet and obtained gas at 140 and 358 feet. A test well on the R. A. Winningham farm is reported to have produced 1½ barrels of amber oil per day, the oil sand being from 340 to 351 feet in depth. Well No. 2 on this farm produced about ½ barrel of amber oil per day at 360 feet, the 'sand' being about 10 feet thick. A test well on the P. P. King farm southeast of the Winningham wells found the Chattanooga shale at 305 to 335 feet and a 'show' of oil at 540 feet, the total depth being about 693 feet. Two miles north of the Winningham wells, a deep test well was drilled on the John Robbins farm which is said to have penetrated to the 80-foot sandstone mentioned in the Martha Beatty well. In the Robbins well this sand is said to have furnished a 'show' of oil. This sandstone was also reached in a deep test on the J. P. Reynolds farm about three miles northeast of Riverton at a depth of 1,781 feet, where it is said to be between 70 and 80 feet thick. In this well the Chattanooga shale was found at a depth of 243 feet and shows of oil at 210 and 310 feet."

"Southwest of Riverton on Rock House Creek two test wells were drilled. One of these on the John Gunter farm found the Chattanooga shale at 82 feet, gas at 144, 150, 190, 270, 336, 358, and 620 feet, with a 'show' of oil at 345 feet. Sulphur water was encountered at 685 feet, which rose about 1,200 feet in this well. Total depth of the well 1,689 feet. The other well on the Noah Wright farm found the Chattanooga shale at a depth of 131 feet. In it amber oil which filled the hole was found at 435 feet and is said to still drip from the well mouth. The following statement concerning the analysis of a sample of oil from this well is taken from an article by Mr. E. J. Schmitz, published in the Engineering and Mining Journal, March 7, 1896, p. 728:"

"The sample of crude petroleum, Noah Wright well, Rock House Creek. Pickett County, Tenn., received January 31, contains no rhigolene or gasolene. It commences to boil at 90° C. and yielded:

Naptha	3.8%	Specific gravity comb 0.703 (Naptha and Benzoin)
Benzoin	1.8%	
Kerosene to 204° C.	15.2%	Specific gravity comb 0.750
Kerosene to 260° C.	14.8%	Specific gravity comb 0.801
Kerosene to 306° C.	12.8%	Specific gravity comb 0.830
Heavy parafine oil	51.6%	Specific gravity comb 0.859

The latter on standing overnight had already partly crystallized (parafine). The oil yields to treatment with oil of vitriol. Original specific gravity 0.625."

"About six miles southeast of Riverton two wells were drilled on the Duncan Smith farm. In well No. 1 the Chattanooga shale occurred at 307 to 400 feet and amber oil was found at 819 feet. The well produced about ½ barrel per day from a 6-foot sand. Gas was also found at a number of places in this well. Well No. 2 on the Smith farm was a dry hole."

"*Abandonment of the Fields.*—When the greatest trouble was being experienced in the Spurrier and Riverton fields from flooding of wells by fresh water and at a time when the production of the field was reduced to a few barrels per day, a tax was laid by Pickett County on the pipe line of this district. Up to this time the pipe line had not proven to be a paying investment, and this fact, together with the falling off in production of the district; the failure of test wells at various points to find oil in paying quantities, and the additional expense of what was thought by the Cumberland Pipe Line Company to be an unjust tax, led to the taking up of the pipe line in 1906 from Spurrier to the Sunnybrook field in southern Kentucky. Thus deprived of a market for the oil, development work in this region came to a standstill and the producing wells fell into disuse."

The principal data contained in Mr. Munn's description are tabulated on the following page for ready reference.

Table of Oil Wells and Oil Horizons in the Spring Creek and Spurrier-Riverton Oil Fields

Name of Well		Date	Product	Depth Total	Depths to Oil	Above Black Shale	Below Bottom of Black Shale	Formation	Initial Daily Production and Remarks.
Spring Creek field—									
Newman	No. 1	1866	Oil	126	19, 26, 52	153, 146, 120		Fort Payne	
Jackson			Oil	530	100	72		"	
Douglass			Oil	172	22	150		"	
Hosier	No. 1	do	Oil		52½, 70	119½, 102		"	30 bbls. at 52½, 110 at 70.
Hosier	No. 2		Oil		55½	116½		"	25 bbls.
Hosier	No. 3		Oil					"	160 bbls.
Five other wells		1870							No oil in paying quantities.
Spurrier-Riverton field—									
Lacey	No. 1	1892	Oil	1,000	268, 297, 357		179, 208, 258	Ordovician limestone	800 bbls. for a short time.
Lacey	No. 2		Shows		211, 216, 220, 256		101, 106, 110, 146	" "	
James Boles	No. 1		Oil		425		309	" "	
James Boles	No. 2		Show					" "	
C. Bilbrey			Show		425			" "	
Geo. Robbins			Oil		242			" "	
Marion Padgett	No. 1		Oil		265, 294, 354			" "	50 bbls.
S. Hind			Show		180		71	" "	
A. Winningham			Shows						
			Oil-Gas		328, 334, 364, 384			" "	
James Wood No. 1 (Bob's Bar)		1896	Oil	1,000	275		167, 267	" "	600 bbls.
James Wood	Nos. 2, 3, 5		Oil		275		167, 267	" "	
James Wood	No. 4		Dry					" "	
Joel Reagan	Nos. 1, 2, 3		Oil		625		452	" "	Small.
Martha Beatty			Show		1,700			" "	
A. Hill	No. 3		Show		638			" "	
A. Hill	No. 4		Gas	900	400 to 500, 560		65, 165, 225	" "	Pencil cave at 870.
A. Beatty	No. 1		Oil-Gas		270 Oil, 600 Gas			" "	Show oil, much gas.
A. Beatty	No. 2		Oil				472	" "	3 bbls.
A. J. King			Gas	1,100				" "	Gas at 22 horizon.
Scattered test wells—									
W. H. Cooper			Shows		540, 900			" "	
Joe Beatty	No. 1		Dry	700				" "	
Joe Beatty	No. 2		Show		600			" "	
Joe Beatty	No. 3		Gas		140, 358		60, 268	" "	
R. A. Winningham	No. 1		Oil		340 to 351			" "	1½ bbls.
R. A. Winningham	No. 2		Oil		360			" "	½ bbl.
P. P. King			Oil Show	693	540		205	" "	
J. P. Reynolds			Oil Show	1,860?	210, 310	33	37	" "	
John Gunter			Oil Show	1,689	345		235	" "	
John Gunter			Gas		144 to 620		32 to 508	" "	
Noah Wright			Oil		435			" "	Small
Duncan Smith	No. 1		Oil		819		419	" "	½ bbl.
Duncan Smith	No. 2		Dry					" "	
Poplar Cove Creek—									
C. C. Choate	No. 1		Oil		730		455	" "	30 to 40 bbls.
C. C. Choate	No. 2		Oil					" "	30 bbls.
Cobb	No. 1		Oii Show					" "	
Eagle Creek—									
Several wells		1866 1867	Oil		50-300		20 to 270, most less than 100	" "	

Oil has been proven then to exist in two localities in this general region and at two different geological horizons. These horizons are 116 to 150 feet above the black shale and 70 to 500 feet below the black shale, the main horizon below the black shale being 167 to 267 feet below. The proven oil-bearing area in the Spring Creek field is small, that of the Spurrier-Riverton field is of large extent, reaching from the Choate wells on Poplar Cove Creek in a northwestern direction to the mouth of Eagle Creek and having a breadth of about two miles either shows of oil in scattered wells or paying wells have been found throughout this territory.

The physical condition of the oil-bearing portions of the limestone by virtue of which it becomes a reservoir for oil is an interesting and important subject. It is assumed by Mr. Munn, Mr. Compton, and presumably by others that the rock is "creviced," by which is probably meant the existence of many vertical crevices or fissures intersecting each other and giving free communication throughout the oil reservoir. Such crevicing is probably postulated upon the behavior of the wells in draining one another, depending upon which well is deepest, the deepest well receiving all the oil, as related in the case of two wells in the Spring Creek field, page 33, and the wells on the Woods farm in the Riverton field, page 35. It seems to the writer, however, that no such assumption is demanded by the facts of the case. Other conditions, as a very open, porous, or cavernous rock or a series of thin, uneven layers of limestone with relatively wide and partially open spaces between would permit free flowage of oil. In such strata after the initial high pressure was relieved by flowing and the movements of the oil regulated by gravity, a well sunk to a lower level would establish a gradient in its direction and draw the oil away from the shallower well. The writer is, therefore, rather opposed to the crevice theory and believes it much more probable that the oil occurs in pores or cavities or in open spaces between the layers of the limestone. In favor of the belief in porous beds may be cited the fact that on Obey River at the bridge on the Livingston-Byrdstown road there is 20 feet of coarse-grained, brownish, porous, and cavernous rock next under the black shale. Owing to the great unconformity described on page 11, this bed may dip southeast at a greater rate than the black shale. This seems all the more probable when the fact that in the head of Sequatchie Valley to the south in Cumberland County at least 200 feet of unfossiliferous thin limestones and shales come in between the highest fossiliferous beds and the black shale. The fossiliferous beds in Sequatchie Valley bear the same large Platystrophias that the porous bed immediately below the black shale on Obey River bears and is possibly at the same geologic horizon. Another probable feature of the oil-bearing rocks that would favor accumulation along the bedding is the notably irregular surfaces of the thin limestone layers common in the upper Ordovician rocks. Thick strata are usually made up of thin layers having protuberances and depressions, both on the upper and under surfaces, so that no two layers fit closely together. The spaces are usually filled with calcareous mud which consolidates to a crumbling shale, and probably shrinks considerably in the process. It can be readily seen how empty spaces could arise in this manner for the occupancy and free movement of oil. Against the crevice theory also are the facts that no such creviced limestone appears in outcrop and that the rocks of the region have not been subjected to great deforming forces such as would fracture them extensively. Much could have been learned by a geologist as to the actual nature and conditions of the oil rock if he could have been on the ground at the time of drilling and had the opportunity of examining an extensive series of drillings. As it is, there are at present no data for a satisfactory determination of the matters under discussion.

The occurrence of oil in porous layers or between layers would apparently have one important consequence, namely, the accumulation in paying quantities should be more probably influenced by structure than it would if it occurs in crevices. In order that oil accumulation in creviced or fractured rocks could be influenced by structure it would be necessary that geographically extensive fracturing should exist in a particular stratum or series of layers of relatively small thickness overlain and underlain by unfractured and impervious layers. It is very improbable that fracturing could be confined to any 10 feet or 20 feet of thickness of rock over a large tract without the overlying and underlying layers partaking in such fracturing. If the oil actually is accumulated in fractured portions of the limestone other than particular layers under the conditions just described, and structure has little or no influence on its accumulation, the determination of the structure—the location of anticlines and synclines—may be of little or no assistance in locating oil pools. The only means of guidance to the prospector in that case would be oil seeps or springs such as existed on Obey River in the Spurrier-Riverton district and which probably led to the drilling there.

One important conclusion is clearly suggested by the developments up to date and that is that the rich oil pools are of very small extent. The main development at Riverton, from the Joel Reagan wells on the northwest to the A. Beatty well on the southeast, and including the Bob's Bar and other wells on the Woods farm, is limited to a radius of about one-half mile. The pools tapped by the Padgett No. 1 with 50 barrels per day reported and by Lacey No. 1 reported 800 barrels per day were limited to the one well in each pool. Of course, it is not conclusively demonstrated that these rich pools are thus limited, for not enough drilling has been done in all directions in the immediate vicinity of each to show that they have no linear extensions, more or less irregular perhaps, in some direction.

RELATION TO STRUCTURE OF KNOWN OIL POOLS AND TEST WELLS

For obvious reasons it is very important to know what actual tests and developments have been made concerning the relation to geologic structure of oil in the commercial oil pools of this region. In the Spurrier-Riverton district, the main and practically the only commercial development are, viz: those on the Woods and Joel Reagan farms upon pools located in conformity with the anticlinal theory, as may be seen by an examination of the map. The pool northwest of Spurrier tapped by the Lacey and Padgett wells seems, however, to be rather closely connected with a broad synclinal depression, although the productive wells are not located in the bottom of the sag in the strata. In this connection, though, it must be understood that the structure here has not been determined in sufficient detail to establish beyond doubt that these wells are located in a syncline. While the structure is truly represented, in general there may be and probably are undetermined irregularities in the structure and there is a possibility that the wells are located upon a low anticlinal spur or dome lying within or projecting into the syncline. The Choate and Cobb wells on Poplar Cove Creek seem to be located on the northeast extremity of a long narrow anticline and the wells on the David Beatty farm, No. 7, are located upon the north flank of the same anticline. On the other hand, the dry hole between Boatland and Glen Obey seems to be favorably located on the south flank of a rather pronounced anticlinal nose. Likewise the dry wells south of the productive wells on the Woods farm are favorably located. These wells, however, were not drilled until after the oil in that pool had been largely exhausted by the Woods wells. The well at Livingston seems to have been favorably located upon an anticlinal nose. However, according to actual experience, it was located too far back from the steep slope bounding the nose.

On the whole it seems sure that the known facts indicate with reasonable certainty that the anticlinal theory holds true in this field and that exploration should be guided by the structure.

Another fact of importance seems to be revealed; that is, that the oil-bearing rocks are open and that the oil moves freely so that a single well would drain a large territory. The original Bob's Bar well would doubtless have produced all the oil that was produced by the four productive wells on the Woods farm, and the expense of drilling three wells and the expense of combating the incursions of water that seems to have resulted from some of the latter drilled wells, could have been avoided with a resulting great increase of profit.

Oil in paying quantities is reported to have been produced from shallow wells at Butler's Landing and vicinity at the mouth of Mill Creek, and other paying wells in Clay County are reported. All this oil issues from the Ordovician limestone, probably not more than 400 feet below the Chattanooga shale. From all the facts now known the belief is amply justified that oil is rather generally disseminated throughout the early Mississippian and Upper Ordovician limestones of this general region. In a few cases sufficient local concentration to yield paying wells has been demonstrated. It is hardly credible that the one place in the Fort Payne and the three rich spots in the Spurrier-Riverton fields are the only such in the region. Other small rich pools almost certainly exist. The probability of finding such seems greatest along the anticlines shown on the map, but in case it should not be found that structure affects accumulation in this region as it does in most others, the location of the rich pools will be a matter of chance or of close and systematic exploration by the drill. A well on every ten acres, say, might be an adequate test. If a 500-foot well could be sunk for $2,000 on the average and one well in ten or even one in twenty should prove a gusher like the Bob's Bar or Newman No. 1, and the other nine or nineteen small or even dry, the business, at present prices of oil, would be highly profitable. By careful observations by which all the peculiarities of the field could be discovered and by scientific management in drilling and handling the wells afterward, especially as to the water control and possibly in shooting the small wells and those yielding only shows of oil, the profits could be increased or at least profit could be secured where less efficient management would result only in loss.

The demonstrated conditions justify further venture on the part of those who can afford to lose money in case of failure. Others had best keep out of the game.